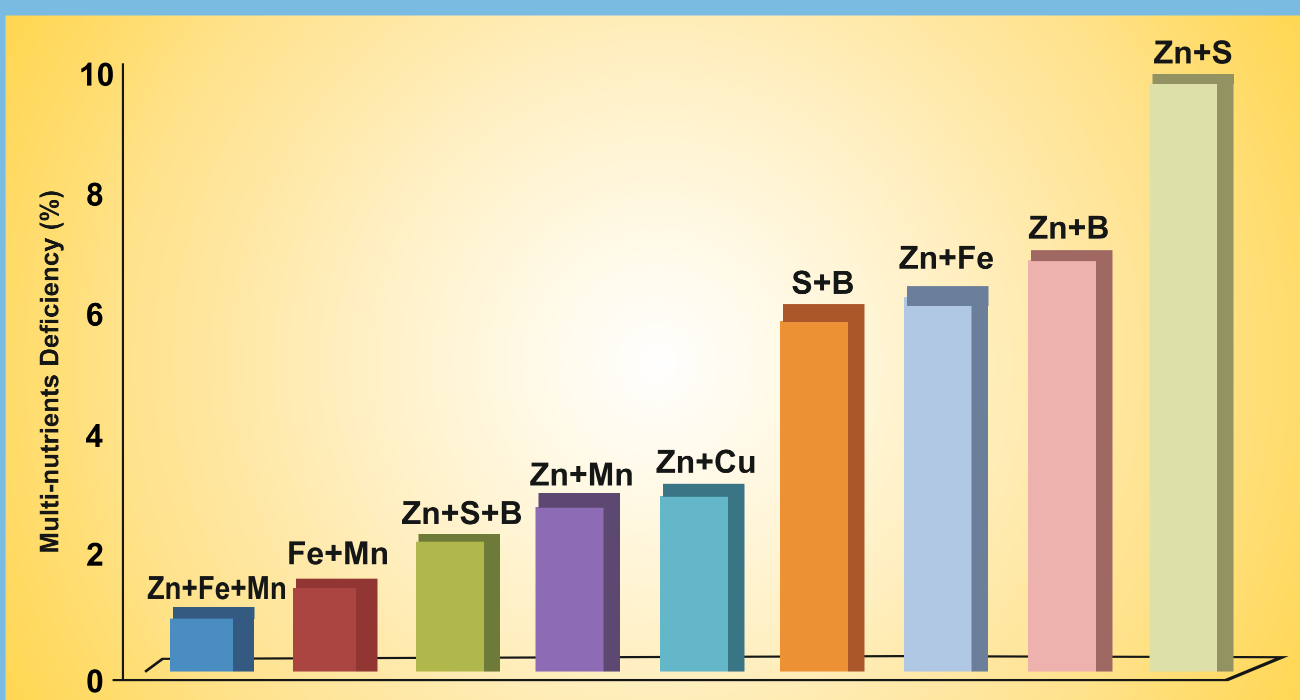
AICRP (MSPE)

Progress Report : 2011-13

Progress Report : 2011-13

MICRO- AND SECONDARY - NUTRIENTS AND POLLUTANT ELEMENTS RESEARCH IN INDIA



Arvind K. Shukla
Pankaj K. Tiwari

AICRP on Micro- and Secondary - Nutrients and Pollutant Elements in Soils and Plants

भाकृअनुप
ICAR

INDIAN INSTITUTE OF SOIL SCIENCE
Nabibagh, Berasia Road, Bhopal - 462 038

Micro- and Secondary - Nutrients and Pollutant Elements Research in India

Arvind K. Shukla
Project Coordinator (MSPE)

Pankaj K. Tiwari
Scientist

Progress Report
2011- 13

All India Coordinated Research Project on Micro- and Secondary-Nutrients and Pollutant Elements in Soils and Plants

INDIAN INSTITUTE OF SOIL SCIENCE
Nabibagh, Berasia Road, Bhopal – 462 038, India

Editors: **Dr. Arvind K. Shukla**
Project Coordinator (MSPE)
Pankaj K. Tiwari
Scientist

Year of Publication **: 2014**

Published by: **Dr. Arvind K. Shukla**
Project Coordinator (MSPE)
Indian Institute of Soil Science
Nabibagh, Berasia Road,
Bhopal – 462 038

Correct citation:

Shukla, A. K. and Tiwari, P. K. (2014). Micro- and Secondary Nutrients and Pollutant Elements Research in India. Coordinator Report - AICRP on Micro- and Secondary Nutrients and Pollutant Elements in Soils and Plants, IISS, Bhopal. pp. 1-…

Technical support: **Mr. Shahab Siddiqui**
Senior Technical Officer
PCM Unit, IISS Bhopal

Pooja Singh
Research Associate
PCM Unit, IISS Bhopal

Cover Page: Graph on cover page shows emerging trend of multiple micro- and secondary nutrients deficiency in Indian soils.

Printed by: Bhandari Printing Press
E3/12, Arera Colony, Bhopal, Ph. 0755-2463769

For Official Use Only

Progress Report

Micro- and Secondary- Nutrients and Pollutant Elements Research in India

(2011- 2013)

IMPORTANT MESSAGE

- The results presented in the manuscript symbolize the joint contribution of the sixteen centres and of Project Coordinator Cell of the All India Coordinated Scheme of Micro- and Secondary- Nutrients and Pollutant Elements in Soils and Plants.
- This manuscript is compiled at the National Headquarter of the All India Coordinated Scheme of Micro- and Secondary- Nutrients and Pollutant Elements in Soils and Plants at Indian Institute of Soil Science, Nabibagh, Berasia Road, Bhopal and is published by:

Arvind K. Shukla
Project Coordinator (MSPE)

- The use of some trade names in this report is no way means endorsement of these products by the All India Coordinated Research Project of Micro and Secondary Nutrients and Pollutant Elements in Soils and Plants.

Arvind K. Shukla
Project Coordinator (MSPE)

CONTENT

Particulars	Page No.
Preface	**v**
Executive Summary	**vii**
ςϱϖϱΎΓϱ	**x**
Introduction	**xiii**
Chapter I	**1**
Basic Research	
Chapter II	**24**
Delineation of Micro- and Secondary Nutrients Deficient Areas	
Chapter III	**41**
Response of Crops to Micro- and Secondary Nutrients Application	
Chapter IV	**51**
Amelioration of Micro- and Secondary Nutrients Deficiencies and their Use Efficiency	
Chapter V	**74**
Micronutrients Biofortification	
Chapter VI	**93**
Heavy Metal Pollution and Remediation	
Details of Manpower	**143**
List of Publications	**146**

PREFACE

It has now been well established that micronutrients play major role in enhancing agricultural production, crop quality and efficiency of macronutrients. For example, absence of one atom of Zn could impair the biochemical advantages arising from the presence of 3000-3500 atoms of N, 800-850 atoms of K, 200-250 atoms of P and 100-120 atoms of Sulphur. Good plant health and quality of produce are indicators of nutrient sufficiency index in soil, which in turn renders better human and animal health. Accelerated depletion of micronutrients from soil reserve due to enhanced food production accentuated the micronutrients deficiencies which brought sharp reduction in productivity, crop quality as well as animal and human health. Such importance of micronutrients in agriculture necessitates strengthening the coordinated programmes by developing best micronutrient management options for different farming systems to recognize the increasing public scrutiny of nutritional security and environmental quality along with enhanced productivity and input use efficiency.

This coordinated research report of 'Micro- and Secondary- Nutrients and Pollutant Elements Research in India' is brought at the time when role of micronutrient is extending from soil-plant system to soil-plant-animal/human continuum. Ensuring nutritional security is now major issue after achieving self sufficiency in food production in the country. Since plants get micronutrients from the soil, animals fed on fodder and humans fed on plant and animal food hence the deficiencies of micronutrients is not only affecting soil plant system but also affecting animal/human health. On another hand multiple micronutrient deficiencies are emerging in many soils and crops due to intensification of cropping. This is evident from the extensive research done under our project and elsewhere in the country.

Due to enhanced pace of industrialization the by-product of industry are dumped with several heavy metal including Fe, Zn, Mn and pollutants like As, Al, Cd, Pb and Cr etc. moreover, the urban wastes waters, sewage and industrial effluents used for irrigation in the vicinity of big cities has resulted in accumulation in high amounts of undesirable heavy metals and pollutants in soil which enter into the plants, animals and human chain. There is always need to develop suitable protocols for use of industrial effluent and sewage water for reducing load of heavy metal and pollutants before their use in field.

In view of above, the report summarizes the important contributions made by the team of scientists at various co-operative centres in developing technologies for efficient diagnosis of nutritional disorders, delineation of deficient areas and nutrient indexing for forecasting emerging micronutrient deficiencies, crop response, developing strategies for enhancing nutrient use efficiency and monitoring heavy metal contamination to soil-plants system.

I am extremely thankful to the scientists working under the Project at different SAUs centres for their whole hearted support, co-operation and valuable contributions and dedication in carrying out research programme more sincerely and effectively. The colour photographs included in this report showing deficiency symptoms of micro and secondary nutrients and heavy metal toxicities supplied by various scientists working under the project are duly acknowledged.

I express my gratitude to Dr. S, Ayyappan, Secretary, DARE, Govt. of India and Director General, Indian Council of Agricultural Research for his kind support and keen interest. My sincere thanks are due to Dr. A. K Sikka, Deputy Director General (NRM) for his noble guidance, generous support, painstaking efforts and encouragement all the time in planning and implementation of the research programme. Thanks are due to Dr. S. K. Chaudhari, Assistant Director General (SWM), ICAR, New Delhi for his consistent encouragements. All the time support from ICAR authorities made us outstanding among the ICAR-AICRPs. I am highly thankful to Dr. A. Subba Rao, Director, IISS, Bhopal for his critic comments and sound observation and suggestions for improving the report. Thanks are also due to Dr. Muneshwar Singh, PC (LTFE), Dr. D.L.N. Rao, NC (Biofertilizer) and Dr. Pradip Dey, PC (STCR), IISS, Bhopal for their valuable suggestion and encouragement. I am thankful to Dr. Ranbir Singh, Dinesh Kumar Verma and Mr. Jai Singh for their cooperation and valuable help in the project work. I sincerely thank Mr. Venny Joy and Mr. Harish Kumar for their valuable co-operation, dedication and keen interest in the activities of this project. I wish that the information provided in this report will be helpful in managing micro- and secondary nutrient problems and heavy metals toxicities in soil-plant system for enhancing crop production and better animal / human health, and environment.

Arvind K. Shukla
Project Coordinator (MSPE)

EXECUTIVE SUMMARY

Basic research on role and importance of micro- and secondary nutrients in plant metabolism, delineation of micro and secondary nutrients deficient areas, conducting different Front Line Demonstrations on farmers' field, development of amelioration techniques, developing strategies for enhancing nutrient use efficiencies, working out critical limits in soils and plants, identification of micronutrient efficient cultivars and agronomic biofortification strategies and monitoring extent of heavy metal pollution in soil-plant systems are the major areas of research under the project. The brief description of the works carried out during the period under report is furnished below.

- Physiological as well as biochemical changes including metabolism of different crops as influenced by low and excess supply of micronutrient and pollutant elements has been studied. The Cu deficiency symptoms were marked in mustard, especially in var. Nidhi-1 and BIO-902 as compared to Pusa Bold and Neha. The total biomass yield of mustard cultivars decreased 13 to 16% at 73 days and 29 to 41% at 96 days under deficient as well as excess Cu supply. The specific activity of catalase increased at both low and excess Cu supply in Cv. Nidhi-1 as compared BIO-902 and Pusa Bold while specific activity of peroxidase decreased. The cysteine and proline contents however, decreased in Cv. BIO-902 and Nidhi-1. On the basis of these parameters, varieties Pusa Bold and Neha appeared to be tolerant to Cu stress while BIO-902 was susceptible to Cu deficiency and Nidhi-1 to Cu excess.

- In black gram, total chlorophyll content also decreased both at low (3.0 µM B) and excess B (60 µM B) supply. However, the concentration of both chlorophyll a and b decreased at all B levels with excess P (2.25 mM) supply. The activity of Catalase decreased at low and excess B supply, while specific activity of Peroxidase and polyphenol oxidase was markedly increased irrespective of B levels.

- Increase in Mo supply from low (0.002 µM) to adequate (0.2 µM), significantly enhanced the nitrogen use efficiency in cowpea by increasing dry matter, seed yield, 100 seed weight, Mo concentration, nitrate reductase activity and seed protein content. In cowpea, B applied either through roots (30µM) or spray (300 µM) could mitigate the visible effects of low B partially and recovered the growth and yield to some extent.

- The biomass of maize decreased at both low and excess zinc supply (0.01 and 100 µM Zn) but reduction was pronounced at low Zn supply while little effect was seen under excess Zn supply. Zinc stress also affected the uptake and translocation of nutrients; for example, Fe and P uptake decreased in low and excess Zn supply, whereas Mn uptake decreased under low Zn and increased with excess Zn. Zinc uptake increased with an increase in Zn supply in different plant part of maize.

- Critical concentration of Zn in different crop plants established the severe deficiency, threshold of deficiency, sufficiency, threshold of toxicity and threshold of severe toxicity concentration of Zinc to various crops. The toxic level of Cd in shoots of fenugreek at grand growth stage was established as 7.97 $\mu g\ g^{-1}$ dry matter.

- At Ludhiana, response to B application was observed in only 20 percent of the soils containing more than 0.51 mg HWS-B Kg^{-1} while critical level of B in green toria at 45 days, was found to be 29.2 mg kg^{-1}. The critical levels of Cu extracted by DTPA, AB-DTPA, AB-EDTA, DTPA+HCl, 0.1N HCl, Mehlich-1 and Mehlich-3 to produce 90% of the maximum yield as estimated by Mitscherlich model, irrespective of the growth stage was found to be 0.21, 0.61, 0.67, 0.40, 0.27, 0.37 and 0.75 mg kg^{-1} soil, respectively. The corresponding values of soil Cu measured by Cate and Nelson (1965) were 0.24, 0.63, 0.61, 0.50, 0.27, 0.35 and 0.57 mg kg^{-1} soil, respectively. The critical value of Cu in dry matter at 30 and 60 days, grain and straw at maturity to produce 90% of the maximum yield as measured by Cate and Nelson procedure was observed to be 16.50, 11.50, 4.20 and 3.00 µg g^{-1}, respectively. Available sulphur in medium black soils of Dewas district was extracted with 0.15% $CaCl_2$ and Morgan's extractants registered a significant correlation (r=0.848** and r=0.810**) with Bray's per cent yield of linseed.

- After introduction of GPS- based sampling in the project, 70,759 soil samples with GPS point-wise data have been collected from 174 districts of the 13 states of the country. Of 63,243 soil samples from12 states of country, analyzed for available Sulphur 27.8% samples were found in deficient categories. Overall, 39.9% of samples collected across the country were deficient in available Zn which varied among states with a minimum of 8.5% in West Bengal to as high as 62.2% in Tamil Nadu. The Fe deficiency in India stayed close to 13% but in some of the states like Maharashtra (22.8%), Gujarat (23.6%), Haryana (21.6%) and Andhra Pradesh (17.3%) its deficiency is increasing rapidly. On average, manganese deficiency in the country was 6.0% but in Punjab (26.8%) and Haryana (6.1%) its deficiency is coming in a big way. The overall Cu deficiency (4.3%) is close to the Mn but its extent is high in Tamil Nadu and Uttar Pradesh.

- Crop response trials were conducted by the different centers of the project to assess the effect of micro and secondary nutrient application on crop yield. Significant response to multinutrient application was recorded in several crops at Akola, Ludhiana, Hisar and Palampur, Jabalpur, Pusa, Hyderabad, Pantnagar, Anand, although percent response varied significantly with crops and nutrients. Besides Zn being the most crucial nutrient for crops, increased responses were recorded when it was applied along with S, Boron and molybdenum.

- Several amelioration techniques were standardized for mitigation of micro and secondary nutrient deficiencies in soil-plant system for enhanced crop production. At Bhavanisagar in Tamil Nadu, IPNS technology involving combined application of FYM at 12.5 t ha^{-1} with $ZnSO_4$ at 37.5 kg ha^{-1} to the main crop (*kharif)* alone had performed better in increasing the cumulative rice productivity of rice-rice cropping system in a zinc deficient soil. In Odisha the highest yield of 4.53 t ha^{-1} was obtained when Zn was applied @ 2.5 kg ha^{-1} with FYM to rice. At Pantnagar, foliar spray of 2 kg Zn ha^{-1} at 30 and 60 days after planting increased the grain yield of basmati rice by 8.8 percent over the no Zn control. In other experiment at Jabalpur, 0.5% salt spray of Zn EDTA, $ZnSO_4$ and $Zn_3(PO_4)_2$ were also used to ameliorate the Zn deficiency in crops.

- In a field experiment on *Inceptisol* of Bhubaneshwar application of B @ 1 kg h^{a-1} gave significant and highest grain yield (5.04 t h^{a-1}) of rice which was 39 percent higher than control. At three locations in Maharashtra, the highest grain yield of soybean was observed with application of zinc @ 5 kg h^{a-1} which was significantly superior over all the treatments followed by application of boron @ 1 kg h^{a-1}. In iron toxic soil, application of K @ 40 kg ha^{-1} and Zn @ 5.0 kg ha^{-1} along with recommended dose of fertilizer gave highest grain yield of rice which was increased by about 19 percent over control.

- In chilli, application of 50% recommended dose of Zn and B incubated with organic for a month was more useful as it resulted in highest Zn and B use efficiency of 3.96 and 15.6% as compared to 100% soil application of zinc and boron (1.88 and 9.2%, respectively) without any detrimental effect on yields. Application of potassium and sulphur, in general, increased the seed and straw yield of raya (RH-30) at all levels of their application.

- Application of different concentration of micronutrients helped in increasing the green fodder yield of jowar significantly, the highest green fodder yield of 21.67 t h^{a-1} was recorded due to combined application of micronutrients of 0.50% Cu, Zn, Fe, Mn+ 0.050% B .

- Biofortification strategies were used for grain enrichment of edible portions with micronutrients in different crops *viz.* wheat and pigeon pea (Kanpur), maize and wheat (Palampur) and rice and wheat (Pantnagar) for Zn and Mn enrichment study in wheat and rice at Ludhiana. Similarly, at Hyderabad (rice and maize), Bhopal (pigeon pea and wheat), Jabalpur (rice and wheat), Coimbatore (maize), Jorhat (rice), Bhubaneswar (rice), Kalyani (rice) and Ranchi (rice) also Zn enrichment studies were performed. At Pusa, Bihar (rice, wheat and maize) and at Anand (chickpea and pigeon pea studies were performed for Fe enrichment. Using yield efficiency index and uptake efficiency the genetically efficient cultivars, which can thrive well under micronutrient deficient conditions, were identified the genetically inefficient cultivar were to nutrient application and thus considered agronomic ally efficient. Among the strategies, by and large soil+ foliar applications proved to be the best tool for enrichment of grains with micronutrients.

- The intensity of visible symptoms of toxicity of these elements in maize was in the order: Cr > Cd > Co > Ni > Pb. However, at 56 DAS the depression in biomass as compared to control was Cr > Co > Cd > Ni > Pb. In maize plants, a major fraction of almost all heavy metals (Cd, Co, Ni and Pb), except Cr were and accumulated in roots and little was translocated variably to the upper plant parts. The accumulation of the elements in roots was as follows: Co (82%) > Pb (65%) >Cd (57%) > Ni (41%) > Cr (17%).

- The soils in the peri-urban areas of Nagpur and Aurangabad districts of Maharashtra continuously irrigated with sewage water showed higher average available sulphur (29.8 mg kg^{-1}) as compared to well water irrigated soil (17.4 mg kg^{-1}). Average DTPA-extractable micronutrients and heavy metals were also found higher in the soils irrigated with sewage effluent. The mean DTPA-Zn, Fe, Mn, Cu, Co, Cd, Pb and Cr were found to be 3.12, 21.46, 26.43, 3.67, 0.769, 0.144, 1.85 and 0.595 mg kg^{-1}, respectively, while in well water irrigated areas it was found to be 0.63, 9.91, 15.50, 1.81, 0.050, 0.026, 0.32 and 0.238 mg kg^{-1}, respectively.

- The threshold toxic limits of Ni in buckwheat for 10 percent reduction in relative yields were 25.4, 29.0 and 11.5 mg Ni kg^{-1} dry matter for soil which received 0, 2.23 and 4.46 g FYM kg^{-1} soil, respectively while threshold toxic limit for Cd in buckwheat were 6.0, 21.0 and 15.25 mg Cd kg^{-1} dry matter grown in soil which received 0, 2.23 and 4.46 g FYM kg^{-1} soil, respectively.

ςϱϖϱ'YΓϱ

सूक्ष्म एवं द्वितीयक पोषक तत्वों पर अखिल भारतीय शोध परियोजना के अन्तर्गत सूक्ष्म एवं द्वितीयक पोषक तत्वों की पौधों की दैहिकी पर पड़ने वाले प्रभाव एवं महत्व पर मौलिक शोध कार्य, इन तत्वों की कमी वाले क्षेत्रों का आलेखन, किसानों के खेतों पर अग्रिम पंक्ति प्रदर्शन, इन तत्वों की कमी वाले क्षेत्रों में मृदा में सुधार की तकनीकों का विकास किया गया। इसके अलावा विभिन्न फसलों के लिए मृदा तथा पौधों में सूक्ष्म एवं द्वितीयक पोषक तत्वों की कमी के क्रांतिक स्तर का निर्धारण, सस्य विधियों द्वारा बायोफोर्टीफिकेशन एवं मृदा–पादप तंत्र में भारी तत्वों के प्रदूषण पर निगरानी रखना इस परियोजना के मुख्य शोध कार्य हैं। इस अवधि में परियोजना के अन्तर्गत किये गये कार्यों का संक्षिप्त विवरण निम्न है।

❖ विभिन्न फसलों पर सूक्ष्म एवं प्रदूषक तत्वों की कमी व अधिक उपलब्धता का पादप कार्यिकी पर पड़ने वाले प्रभावों जैसे जैव रासायनिक परिवर्तन और उपापचय की क्रियाओं का विश्लेषण किया गया। सरसों की फसल में ताँबे की कमी एवं अधिकता का प्रभाव देखा गया जिसमें यह पाया गया कि सरसों की पूसा बोल्ड एवं नेहा किस्मों की तुलना में बायो–92 किस्म में ताँबा की कमी का प्रभाव अधिक पड़ता है।, अधिक व कम ताँबा उपलब्धता स्तर पर क्रमशः सरसों की 73 दिन की अवस्था में कुल जैव भार उत्पादन में 13–16% की कमी देखी गई जबकि 96 दिन की अवस्था में यह कमी बढ़कर 29–41% हो गई। पूसा बोल्ड एवं बायो–92 की तुलना में निधि–1 प्रजाति में केटेलेज एन्जाइम की गतिविधि ताँबा उपलब्धता के दोनों स्तर पर अधिक पाई गई जबकि ऑक्सीडेज की गतिविधि कम हुई। हालाँकि क्रिस्टीन एवं प्रोलीन की मात्रा बायो–92 एवं निधि–1 में कम देखी गई। इन मानकों के आधार पर यह पाया गया कि पूसा वोल्ड एवं नेहा किस्म ताँबा की कमी के प्रति अधिक सहनशील है जबकि बायो–92 ताँबे की कमी एवं निधि–1 ताँबे की अधिकता के प्रति संवेदनशील हैं।

❖ उड़द की फसल में अधिक व कम बोरॉन उपलब्धता से हरित लवक की मात्रा से कमी देखी गई एवं क्लोरोफिल a व b, दोनों का सान्द्रण बोरॉन के सभी स्तरों पर कम पाया गया। केटेलेज की गतिविधि में भी कम व अधिक बोरॉन के स्तर पर कमी देखी गई जबकि बोरॉन के बढ़ते स्तर के साथ ऑक्सीडेज की विशेष गतिविधि एवं पॉली फिनोल ऑक्सीडेज की गतिविधि में भी उल्लेखनीय वृद्धि देखी गई।

❖ मॉलिब्डेनम की उपलब्धता में निम्न (0.002 μm) से सामान्य (0.2 μm) स्तर तक वृद्धि से लोबिया की फसल में नत्रजन उपयोग क्षमता, शुष्क भार, बीज उपज व 100 दानों के वजन में सार्थक वृद्धि देखी गई। मॉलिब्डेनम सान्द्रण, नाइट्रेट रिडेक्टेज की गतिविधि, बीज में प्रोटीन की मात्रा में भी वृद्धि देखी गई। प्रयोग के दौरान यह भी पाया गया कि लोबिया की फसल में मॉलिब्डेनम की कमी को जड़ों द्वारा (30 μm) या पर्णीय छिड़काव (300 μm) के द्वारा इसके उपयोग से दूर किया जा सकता है।

❖ जिंक की उपलब्धता स्तर में कमी (0.01 μm) एवं अधिकता (100 μm) होने पर वृद्धि के समानान्तर मक्का के जैव भार में भी कमी देखी गई। हालाँकि जिंक में कमी वाले स्तर पर वृद्धि एवं जैव भार पर अधिक प्रभाव पड़ा। जबकि अधिकता वाले स्तर पर इसका प्रभाव कम देखा गया। जिंक की कमी का प्रभाव तत्वों के अवशोषण एवं उत्संवेदन पर भी देखा गया। उदाहरण स्वरूप जिंक के निम्न स्तर पर लोहा एवं फास्फोरस के अवशोषण में कमी देखी गई जबकि जिंक के स्तर में वृद्धि के साथ मक्का के पौधे के विभिन्न भागों में अधिक अवशोषित हुई।

- विभिन्न फसलों के लिये जिंक का क्रांतिक स्तर, कमी की अधिकतम सीमा, पर्याप्त मात्रा एवं विषाक्तता सीमा का निर्धारण किया गया। मेथी मे कैडमियम की विषाक्तता स्तर का भी निर्धारण किया गया एवं वृद्धि अवस्था पर विषाक्त मात्रा 7.97μg प्रति ग्राम शुष्क भार निर्धारित की गई।

- लुधियाना की 20% मृदाओं में बोरॉन का स्तर 0.51 mg HWS-B kg^{-1} मृदा से कम था उनमें बोरॉन डालने पर फसलों की प्रतिक्रिया देखी गई। हरी तोरिया फसल में 45 दिन की अवस्था पर पौधों मे 29.2 mg kg^{-1} बोरॉन का क्रांतिक स्तर निर्धारित किया गया। ताँबा का क्रांतिक स्तर का निर्धारण करने के लिए मृदा में DTPA, AB-DTPA, AB-EDTA, DTPA+ HCl; 0.1NHCl, मेहलिच–1 तथा मेहलिच–3 द्वारा अवशोषित ताँबा की मात्रा देखी गई जिसमें अधिकतम उपज की 90% उत्पाद का आकलन Mitscherlich मॉडल में वृद्धि अवस्थाओं पर क्रमशः 0.21, 0.61, 0.67, 0.47, 0.27, 0.37 एवं 0.75 mg kg^{-1} मृदा में देखा गया। इन आँकड़ो को केट एवं नेल्सन (1965) के अनुरूप 0.24, 0.63, 0.61, 0.50, 0.27, 0.35 एवं 0.57 mg kg^{-1} मृदा extractants के क्रमानुसार निर्धारित की गई। मध्य प्रदेश के देवास जिले की मध्यम काली मृदाओं में 0.15% $CaCl_2$ व मॉर्गन extractants एवं अलसी के Bray's percent yield के साथ सार्थक सहसंबन्ध ($R=0.85^{**}$ एवं $R=0.811^{**}$) पाया गया।

- भौगोलिक स्थिति आधारित (G.P.S. based) मृदा नमूना एकत्रीकरण आरम्भ होने के बाद से इस परियोजना के अन्तर्गत 13 राज्यों के 174 जिलों से 70,759 मृदा नमूने एकत्रित किये गये। 12 राज्यों के 167 जिलों से एकत्र किये गये लगभग 63 हजार मृदा नमूनों की जाँच के बाद 27.8% मृदा नमूनों में गंधक की कमी पाई गई। जबकि 70,751 नमूनों में लगभग 39.9% नमूनों में जिंक की कमी देखी गई जिनमें सबसे कम 8.5% नमूनों मे जिंक की कमी पश्चिम बंगााल में व सबसे अधिक कमी 62.2% तमिलनाडू में दर्ज की गई। भारत मे लौह तत्व की कमी 13% के लगभग पाई गई है जबकि कुछ राज्यों जैसे महाराष्ट्र (22.8%), गुजरात (23.6%), हरियाणा (21.6%) तथा आन्ध्र प्रदेश (17.3%) मे लौह तत्व की कमी तेजी से बढ़ी है। पंजाब में (26.8%) और हरियाणा में (6.1%) अधिकतम मैंग्नीज की कमी देखी गई है। इस दौरान यह भी देखा गया कि देश में ताँवे की औसत कमी (4.3%) मैंग्नीज के समान ही है एवं इसकी सबसे अधिक कमी तमिलनाडू एवं उत्तर प्रदेश मे ही पाई गई है।

- सूक्ष्म एवं द्वितीयक पोषक तत्वों की फसलों पर प्रतिक्रिया प्रदर्शन हेतु परियोजना के विभिन्न केन्द्रों द्वारा किसानों के खेतों पर विभिन्न अग्रिम पंक्ति प्रदर्शन लगाये गये। विभिन्न फसलों पर अकोला, लुधियाना और हिसार में किये गऐ बहुपोषक तत्वीय प्रयोग से सार्थक उपज वृद्धि देखी गई। साथ ही पालमपुर, जबलपुर, पूसा, हैदराबाद, पंतनगर और आनंद में भी यह देखा गया कि विभिन्न फसलों में जिंक के पोषण से सार्थक उपज वृद्धि हुई। इन स्थानों पर जब जिंक का प्रयोग गंधक, बोरॉन व मोलिब्डेनम के साथ किया गया तब और भी सार्थक उपज वृद्धि देखी गई।

- मृदा में सूक्ष्म एवं द्वितीयक पोषक तत्वों की कमी के निवारण हेतु विभिन्न तकनीकों का विकास किया गया जिसमें मृदा–पादप तंत्र में सुधार व उपज वृद्धि तकनीक शामिल है। तमिलनाडू के भवानी सागर में एकीकृत पादप पोषक तत्व पूर्ति तंत्र (IPNS) में गोबर की खाद (12.5 टन गोबर की खाद) के साथ जिंक सल्फेट (37.5 कि.ग्रा. प्रति. है.) का मुख्य फसल (खरीफ) में प्रयोग से धान–धान फसल चक्र में सार्थक उपज वृद्धि देखी गई। इसी प्रकार ओडिसा के भुवनेश्वर में गोबर की खाद के साथ जिंक का प्रयोग करने से धान की अधिकतम उपज देखी गई। पंतनगर में बासमती धान मे पौध रोपाई के 30 व 60 दिन बाद 2 कि.ग्रा. जिंक प्रति है. की दर से पर्णीय छिड़काव करने से 8.8% उपज वृद्धि देखी गई। जबलपुर में 0.5% Zn-EDTA या $ZnSO_4$ या $Zn_3(PO_4)_2$ का पर्णीय छिड़काव फसलों में जिंक की कमी के निवारण में सहायक सिद्ध हुआ।

- भुवनेश्वर की इन्सेप्टीसोल मृदा में किये गये एक परीक्षण में 1.0 कि.ग्रा. प्रति. है. बोरॉन प्रयोग से धान में अधिकतम उपज वृद्धि (5.04 टन प्रति. है.) देखी गई यह उपज वृद्धि नियमित उपज की उपेक्षा 39% अधिक थी। महाराष्ट्र के तीन

स्थानों पर सोयाबीन की फसल में अधिकतम उपज वृद्धि 5 कि.ग्रा. जिंक प्रति है. की दर से प्रयोग करने पर प्राप्त हुई जो 1.0 कि.ग्रा. प्रति है. बोरॉन के प्रयोग से हुई उपज वृद्धि से अधिक थी। लौह की विषाक्तता वाली मृदाओं में 40 कि.ग्रा. पोटाश के साथ 5.0 कि.ग्रा. जिंक प्रति है. का अन्य उर्वरकों की अनुशंसित मात्रा के साथ प्रयोग करने से धान की फसल में अधिकतम उपज वृद्धि (19%) देखी गई।

- आन्ध्र प्रदेश में मिर्च में जिंक व बोरॉन की अनुशंसित मात्रा का 50% कार्बनिक खाद के साथ एक माह तक इन्क्यूबेट करके फसल में प्रयोग करने से उत्तम परिणाम प्राप्त हुऐ। साथ ही जिंक व बोरॉन की उपयोग क्षमता में भी वृद्धि दर्ज की गई और उपज पर कोई नकारात्मक प्रभाव नही देखा गया। राया (RH-30) में भी पोटाश व गंधक के प्रयोग करने से दानों व भूसे मे वृद्धि दर्ज की गई।

- पशुओं हेतु सूक्ष्म तत्व युक्त चारा प्रबंधन हेतु किये गये प्रयोग के अंतर्गत चरी ज्वार में सूक्ष्म तत्वों के विभिन्न मात्राओं का प्रयोग करने पर हरे चारे की उपज में सार्थक वृद्धि हुई। अधिकतम हरे चारे की उपज 21.67 टन प्रति है. तब प्राप्त हुई जब उसमे संयुक्त रूप से सूक्ष्म तत्वों जैसे 0.50% ताँबा, जिंक, लौहा व मैग्नीज के साथ 0.05% बोरॉन का प्रयोग किया गया।

- खाद्यान्न फसलों के दानों में सूक्ष्म तत्वों की मात्रा बढ़ाने के लिए अनेक प्रकार के बायोफोर्टीफिकेशन तकनीकों का प्रयोग किया गया जिस के अंन्तर्गत कानपुर मे गेहूँ एवं अरहर, पालमपुर मे मक्का एवं गेहूँ और पंतनगर में धान एवं गेहूँ में जिंक की मात्रा बढ़ाने सम्बंधी प्रयोग कार्य हुऐ। इसी प्रकार लुधियाना में गेहूँ एवं धान में मैंगनीज की मात्रा बढ़ाने हेतु फसल परीक्षण किए गए। अनाजी फसलों में इसी प्रकार के प्रयोग हैदराबाद, भोपाल, कोयम्वटूर, जोरहट, भुवनेश्वर, कल्यानी एवं राँची में भी लगाए गऐ। लौह तत्व की मात्रा बढ़ाने हेतु पूसा में धान, गेहूँ एवं मक्का तथा आनंद में अरहर एवं चना पर प्रयोग किये गए। इस प्रक्रिया के अन्तर्गत विभिन्न सूचकों का उपयोग करके प्रत्येक फसल की विभिन्न प्रजातियों को दो समूहों में बाँटा गया। ऐसी प्रजातियाँ जो मृदा मे सूक्ष्म तत्वों की कमी वाली स्थिति में भी अच्छी उपज देने मे सक्षम होती हैं उन्हें एक समूह मे रखा गया तथा उन्हे अनुवाँशिकीय दक्ष माना गया जबकि जिन प्रजातियों मे इन तत्वों के इस्तेमाल न होने पर उपज एवं साँद्रण में भारी गिरावट देखी गई परन्तु सूक्ष्म तत्व डालने से उपज एवं दानों में सूक्ष्म तत्वों की मात्रा में वृद्धि दर्ज की गई उन्हें दूसरे वर्ग मे रखा गया तथा उन्हें सस्यीय रूप से दक्ष माना गया। औसतन यह देखा गया कि सूक्ष्म तत्वों का मृदा में प्रयोग के साथ–साथ उन्हीं तत्वों का पर्णीय छिड़काव दानों में इनकी मात्रा बढ़ाने की सबसे उत्तम तकनीक है।

- प्रदूषक तत्वों की विषाक्तता के दृश्य लक्षणों की तीव्रता मक्का में क्रमशः इस प्रकार रही Cr > Cd > Co > Ni > Pb जबकि फसल बुआई के बाद 56 दिन की अवस्था पर नियंत्रित मात्रा की अपेक्षा विषाक्त मात्रा वाले पौधों के जैव भार में कमी इस प्रकार रही Cr > Co > Cd > Ni > Pb। मक्का के पौधों में Cr को छोड़कर सभी भारी धातुओं (Cd, Cd, Ni और Pb) का अधिक अवशोषण पाया गया तथा पौधों के उपरी भागों में इनका अवशोषण बहुत कम पाया गया। जड़ों में तत्वों का अवशोषण क्रमशः इस प्रकार रहा Co (82%) > Pb (65%) > Cd (57%) > Ni (41%) > Cr (17%).

- महाराष्ट्र के नागपुर और औरंगाबाद शहरी क्षेत्रों के आसपास की मृदाओं में जहाँ सीवेज जल से सिंचाई की जाती है वहा उपलब्ध गंधक की मात्रा (29.8 मि.ग्रा. प्रति कि.ग्रा. मृदा) कुओं के जल से सिंचाई वाले क्षेत्रों की मृदा में प्राप्य गंधक (17.4 मि.ग्रा. प्रति कि.ग्रा. मृदा) की अपेक्षा अधिक पाई गई। साथ ही कुओं के जल से सिंचित मृदाओं की अपेक्षा सीवेज जल से सिंचित मृदाओं में DTPA-छनित सूक्ष्म तत्वों व भारी धातुओं की मात्रा भी अधिक देखी गई। पंतनगर में बकव्हीट (एक प्रकार का अनाज) में निकिल एवं कैडमियम की न्यूनतम विषाक्तता सीमा का निर्धारण किया गया एवं पाया गया कि गोबर की खाद का प्रयोग करने से इन भारी तत्वों की विषाक्तता को काफी हद तक कम किया जा सकता है।

INTRODUCTION

India's population is expanding continuously and projections anticipate that the country's population will reach 1.5 to 1.8 billion by 2050. According to the projection, food production on presently used land must be doubled in the next four decades to meet food demand of the growing population. To achieve the required massive increase in food production further, large enhancements in application of fertilizers was a major factor contributed to the "Green Revolution", along with intensive cropping, cultivation of high-yield genotypes, improved agricultural mechanization, and using modern irrigation systems. This has resulted in higher crop production per unit area and greater depletion of soil phyto-available micronutrients. Losses of micronutrients through erosion, leaching, liming of acid soils, decreased proportions of farmyard manure compared to chemical fertilizers, and use of marginal lands for crop production are other factors that have increased the incidence of micronutrient deficiency has become a limiting factor fir crop productivity in many agricultural soil. In order to obtain the genetic potential yields of crops, correcting micronutrients deficiencies is inevitable.

On the other hand, agricultural practices were usually targeted to higher crop production while minimizing costs. In addition, nutrient output of farming systems has never been a goal of either agriculture or of public policy. Thus the increase in crop yield in many agricultural systems as a result of chemical fertilizer application has been accompanied with reduced micronutrients concentrations in the edible parts of different crop. Hence, many food systems in country are not able to provide sufficient micronutrient concentration to meet the demands of their people especially low-income families. Presently, the poor soil fertility, low levels of available mineral nutrients in soil, improper nutrient management, along with the lack of plant genotypes having high tolerance to nutrient deficiencies or toxicities are major constraints contributing to food insecurity, malnutrition (i.e. micronutrient deficiencies).

During the initial years of introduction of the modern crop varieties, micronutrient deficiency disorders were discovered as an obstacle to their higher yields. In order to delineate the micronutrient deficient areas and to alleviate the nutrition stresses, the Indian Council of Agricultural Research initiated the All India Coordinated Scheme of Micronutrient in Soils and Plants in 1967 with its National Headquarter at the Punjab Agricultural University, Hisar (subsequently shifted to Punjab Agricultural University, Ludhiana in 1970) and 6 Coordinating centre located at Lucknow, Hisar, Jabalpur, Ranchi, Anand and Coimbatore. Later Ludhiana and Hyderabad centres were also created. Realizing the need for micronutrient researches three centers *viz.* Akola for Maharashtra, Bhubaneswar for Orissa and Pantnagar for Uttaranchal were established in the year 1996.

The deficiencies of secondary nutrients and toxicities of heavy metal elements were subsequently noticed in many parts of the country. In view of this, the project mandate was expanded and its objectives were enlarged to include researches on these aspects in the project. The name of the project was changed to All India Coordinated Scheme of Micro- and Secondary- Nutrients and Pollutant Elements in Soils and Plants. Currently, the Coordinating unit of the scheme is functioning w.e.f. 28.4.1988 at Indian Institute of Soil Science, Bhopal. In XI FYP five new centers were started which are CSKV, Palampur; AAU, Jorhat; BCKV, Mohanpur; CSAUAT, Kanpur and BAU, Ranchi. These centre become functional in the year 2009. Among these, the centre at Lucknow is involved mainly in physiological research on micronutrient nutrition of plants while the remaining centres concentrate their researches on the micro- and secondary - nutrients and pollutant elements in soils and plants. Since domain of micronutrients and heavy metal is expanding from soil-plant to soil-plant-animal/ human continuum, there is need to include some more centres to cover the whole country and address the micronutrient and heavy metal in soil-plant-animal/ human continuum. The basic objectives of the project are:

1. To delineate and/or reassess and mapping of micro- and secondary - nutrients (MSN) deficient and toxic areas using GPS/GIS, and developing amelioration techniques for their correction.

2. Micronutrients indexing for forecasting emerging micro- and secondary- nutrients deficiencies and toxicities in crops and soils in different soil, crops and management systems.

3. Revisiting the critical limits of micro and secondary nutrients and establishing phytotoxic limits of heavy metals in different soils and crops including vegetables.

4. To develop suitable techniques for increasing fertilizer-use-efficiency along with inclusion of nano fertilizers, organic manures, sewage sludge for ameliorating the MSN deficiencies in crops and soils.

5. To monitor health hazards from heavy metal or trace element pollutant in soils, plants and animals.

6. To develop agronomic biofortification approaches for micronutrients enrichment and to identify mechanism and processes of micronutrients enrichment and their role in reproductive physiology.

7. To study micronutrients in soil-plant-animal and /or human continuum

8. Dissemination of micronutrients technologies through frontline demonstration and suitable publication for enhancing the micronutrients use and its impact on soil, animal and human health and crop productivity.

Table 1: Location of the Project Head quarter and Cooperative centers

Location	Date of start	State	Agro-ecological region	Soil type
Project Coordinating Unit				
IISS, Bhopal	24.4.1988	Madhya Pradesh	Central high land (Malwa and Bundelkhand) hot sub-humid, Grid Northern Plain and Alluvial central hot semi-arid region	Medium and deep black alluvial soil
Cooperative Centres				
CCSHAU, Hisar	01.01.1967	Haryana	Western plain and Kutch peninsula hot arid	Desert & saline soils, silty-alluvial soils
RAU, Pusa	01.12.1967	Bihar	Eastern plain, hot sub-humid	Alluvial, clayey, red and lateritic
TNAU, Coimbatore	14.08.1967	Tamil Nadu	Eastern Ghats T.N. upland) & Deccan Plateau, hot semi-arid and hill soils	Red loamy soil black clay and red & lateritic soils
AAU, Anand	01.01.1967	Gujarat	Central (Malwa) high lands and Kathiawar	Medium and deep black, alluvial soils
Lucknow University	01.04.1967	Uttar Pradesh	Northern plain, hot sub-humid (Plant physiological research)	Alluvium derived and Tarai soils
JNKVV, Jabalpur	01.01.1967	Madhya Pradesh	Central high lands (Malwa & Bundelkhand hot sub-humid)	Medium and deep black soil, red and black, alluvial
PAU, Ludhiana	10.10.1970	Punjab	Northern plain and Central highland hot semi-arid	Alluvium derived (Alluvial, sand to sandy loam soils)
ANGAU, Hyderabad	01.08.1975	Andhra Pradesh	Deccan plateau & Eastern Ghats, hot semi-arid	Red and black soils
GBPUAT, Pantnagar	01.04.1996	Uttarakhand	Hill and *Tarai* region, hot sub-humid	Alluvium derived and Tarai soils
PDKV, Akola	01.04.1996	Maharashtra	Deccan Plateau , Hot semi-arid	Medium & Shallow black soil
OUAT, Bhubaneshwar	01.04.1996	Orissa	Eastern Ghats hot sub-humid	Red loam, red and lateritic soils
CSKHPKV, Palampur	1-4-2009	Himachal Pradesh	Hill, sub humid	Hill, mountaneous soils , Alfisols
CSUAT, Kanpur	1-4-2009	Uttar Pradesh	Northern plain , hot semi-arid	Alluvium derived Indo Gangetic alluvial soil
AAU, Johrat	1-4-2009	Assam	Hot sub-humid	Alluvium, hill, red, lateritic soils
BAU, Ranchi	1-4-2009	Jharkhand	Eastern Santhal pargana hot semi-arid,	Red loam, red and laterite soils
BCKV, Mohanpur	1-4-2009	West Bengal	Hot sub-humid	Alluvium, hill, red and lateritic soils

Table 2: Centre wise Budget allocation and funds released (ICAR Share)

Name of centre	Sanction 2010-11	Released 2010-11	Sanction 2011-12	Released 2011-12	Sanction 2012-13	Released 2012-13
Lucknow University	28.69	28.69	38.80	38.80	68.10	68.10
PAU, Ludhiana	24.45	24.45	74.25	74.25	76.13	76.13
HAU, Hisar	31.20	31.20	57.60	57.60	58.01	58.01
RAU, Pusa	22.20	22.20	72.04	72.04	65.53	65.53
AAU, Anand	27.30	27.30	67.75	67.75	75.40	75.40
JNKVV, Jabalpur	26.36	26.36	50.75	50.75	53.73	53.73
APAU, Hyderabad	23.93	23.93	72.80	72.80	66.10	66.10
TNAU, Coimbatore	26.70	26.70	54.89	54.89	66.49	66.49
PDKV, Akola	13.95	13.95	39.70	39.70	42.72	42.72
OUAT, Bhubaneswar	14.55	14.55	39.35	39.35	30.00	30.00
GBPUAT, Pantnagar	13.95	13.95	40.13	40.13	26.74	26.74
PC Unit IISS Bhopal	9.47	9.47	33.04	33.04	12.69	12.69
CSKHPKV, Palampur	8.65	8.65	15.70	15.70	19.00	19.00
AAU, Jorhat	7.15	7.15	17.70	17.70	20.25	20.25
BCKV, Kalyani	7.15	7.15	14.70	14.70	17.91	17.91
BAU, Ranchi	7.15	7.15	17.70	17.70	16.00	16.00
CSAUS&T, Kanpur	7.15	7.15	13.10	13.10	20.20	20.20
Total	**300.00**	**300.00**	**720.00**	**720.00**	**735.00**	**735.00**

CHAPTER –I

BASIC RESEARCH

Precise diagnosis is a key to know the nature of micronutrient disorders in soil and plants so as to suggest the efficient ways and methods for their correction and maximizing yields. The most common method employed for diagnosis and monitoring the nutritional disorders includes visual deficiency symptoms, soil and plant analysis and fertilizer response trials. The centers of AICRP micronutrients have carried out several studies on these aspects and salient findings are summarized below:

1.1 Effect of excess and low supply of Cu on physiological and biochemical changes in mustard

Biomass and seed yield

Four varieties of mustard (*Brassica campestris* L. var. Yellow Sarson) *viz.* BIO-902, Pusa Bold, Neha and Nidhi-1 were grown at three Cu levels: 0.001 µM (deficient), 1 µM (adequate) and 100 µM (excess) till maturity. At low Cu supply the young leaves developed interveinal chlorosis, chlorotic areas later turned papery while Necrotic symptoms were developed at excess Cu supply which was similar to Fe deficiency. The Cu deficiency symptoms were more marked in var. Nidhi-1 and BIO-902 as compared to Pusa Bold and Neha. Similar to deficiency excess Cu level, developed the interveinal chlorosis of young leaves was at 30 days and later on emerging young leaves were completely bleached. The effect of excess Cu was more distinct in variety Nidhi-1 as compared to other three varieties.

Both deficient and excess Cu supply decreased the biomass. The total biomass yield of mustard cultivars decreased 13 to 16% at 73 days and 29 to 41% at 96 days under deficient as well as excess Cu supply (Table 1.1). Similarly the total seed yield of mustard also decreased at deficient as well as excess Cu supply. The Cu content in different plant parts increased with increase in Cu supply from 0.001 to 100µM which was maximum in roots and least in young leaves at all levels of Cu supply. In general, the Hill reaction activity decreased at deficient and excess Cu supply except, in variety Nidhi-1 where the activity increased on protein basis by 5% at excess Cu supply (Table 1.1).

Enzyme activities

The specific activity of catalase increased at both low and excess Cu supply in Cv. Nidhi-1 as compared BIO-902 and Pusa Bold. However the specific activity of peroxidase decreased with an increase in Cu supply from deficiency (0.001µM) to excess level (100µM) in var. BIO-902 and Pusa Bold. Whereas in Cv. Neha the activity decreased under Cu deficiency and increased in Cu excess supply. In general, the cysteine and proline contents decreased, however, in Cv. BIO-902 and Nidhi-1, the cysteine contents increased by 43% and 70%, respectively at excess Cu supply. On the basis of these parameters, varieties Pusa Bold and Neha appeared to be tolerant to Cu stress while BIO-902 was susceptible to Cu deficiency and Nidhi-1 to Cu excess.

Table 1.1: Physiological and Biochemical changes, Chloroplast pigments, Hill reaction activity, Cysteine and Proline in leaves of four mustard varieties in relation to Cu stress (low and excess supply)

Cu supply (µM)	Mustard cultivars			
	BIO -902	Pusa Bold	Neha	Nidhi -1
Dry matter (g plant^{-1}) (at 96 DAS)				
0.001	2.75 (-41)	3.05 (-30)	3.36 (-29)	3.15 (-37)
1.00	4.70	4.39	4.72	4.98
100.0	4.02 (-14)	4.22 (-3)	4.50 (-4)	4.50 (-10)
Seed yield (g plant^{-1}) at (96 DAS)				
0.001	0.72 (-21)	0.47 (-19)	0.57 (-33)	0.99 (-23)
1.00	0.92	0.58	0.86	1.29
100	0.51 (-44)	0.50 (-13)	0.82 (-5)	0.95 (-26)
Total chlorophyll (mg g^{-1} fresh weight)				
0.001	1.15	1.03	1.10	1.11
1.00	1.23	1.20	1.27	1.41
100	1.25	1.37	1.44	1.12
Hill reaction activity (O.D. change 100 mg^{-1} fresh weight)				
0.001	0.51	0.72	1.47	1.15
1.00	2.00	2.49	2.22	2.89
100	1.49	1.41	1.00	2.76
Catalase (µ moles H_2O_2 decomposed mg^{-1} protein)				
0.001	259	256	211	160
1.00	161	160	187	250
100	223	161	368	270
Cysteine (n moles 100g^{-1} fresh weight)				
0.001	42	48	52	62
1.00	58	80	72	92
100	98	76	54	132
Proline (µ moles Proline 100 mg^{-1} fresh weight)				
0.001	69	118	57	115
1.00	233	592	215	335
100	230	131	138	336

Figures in parenthesis denote % increase (+) or decrease (-) over the control DAS = days after sowing

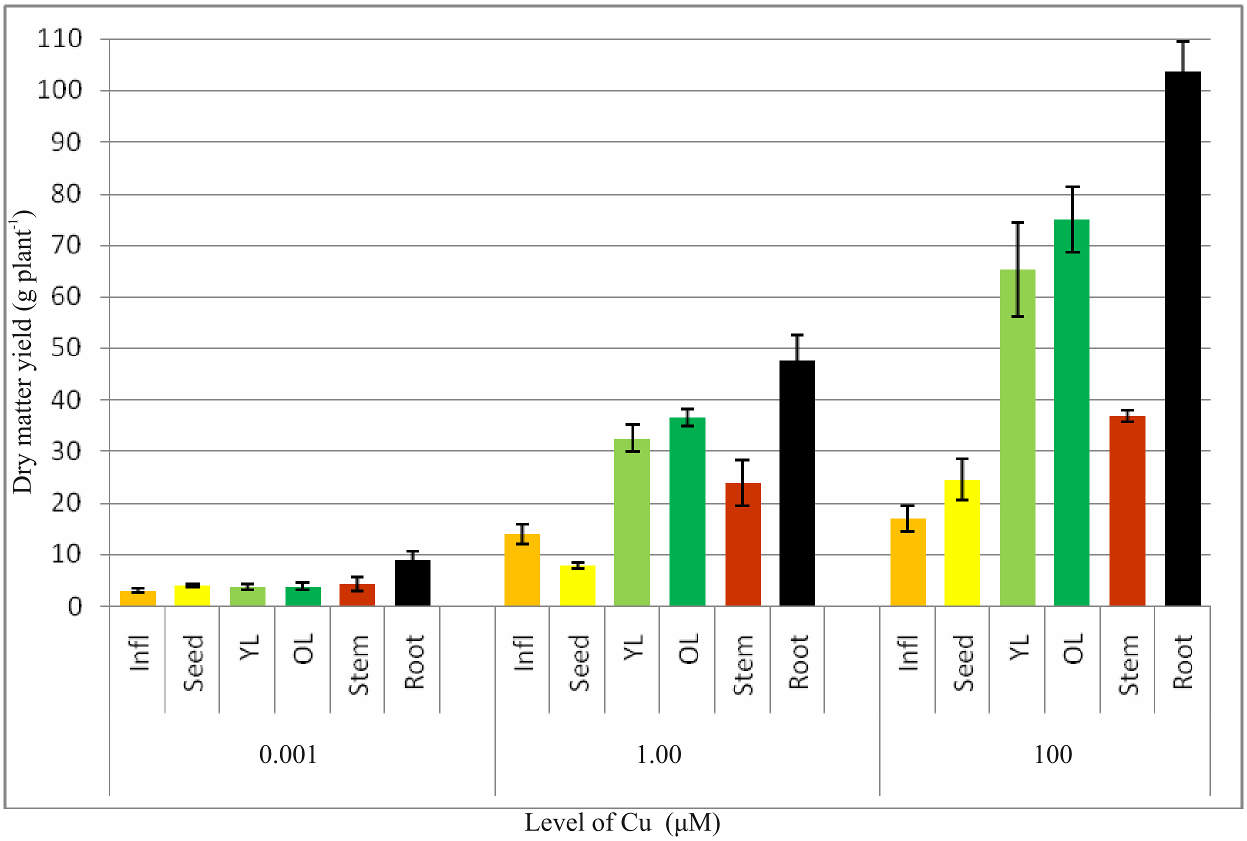


Fig. 1.1 Dry matter yield (g plant^{-1}) of various plant parts of different mustard varieties at 96 DAS, due to Cu stress (low and excess supply)

1.2 Quantifying role of micronutrients in enhancing use–efficiency of major nutrients and crop productivity

A. Effect of boron supply on phosphorus use efficiency in black gram

Black gram (*Vigna mungo* L.) cv. *Kala Urd*, plants were grown in refined sand at three levels of B i.e. low (3.0 µM), adequate (30 µM) and excess (60 µM), each at two levels of P i.e. normal (1.5 mM) and excess (2.25 mM). The effect of B deficiency was apparent in black gram at 30 DAS as symptoms of B deficiency were observed as interveinal chlorosis, initiated from apex and margins of young leaf lamina (Fig 1.2). With increase in age, the chlorotic spots turned brown and necrotic, covering almost the entire lamina and leaf size was markedly reduced. Plant growth at excess B (60 µM) supply was slightly decreased along with marginal chlorosis in old leaves at 45 DAS. Later on chlorotic margins became necrotic and dried. Both low as well as excess B supply reduced the phosphorus use for the synthesis of nucleic acids and enhanced its use for the formation of phospholipids and phosphoproteins, especially at low B–excess P. The symptoms of B deficiency were more marked at excess than normal P. Excess P aggravated the effects of B deficiency by further decreasing the biomass, economic yield, tissue B in different plant parts, photosynthetic pigments, concentration of total P and enhancing the inorganic P and specific activities of enzymes *viz.* polyphenol oxidase and peroxidase.

Phosphorus toxicity symptoms appeared as chlorosis of young leaves, starting from the base along the midrib of leaf lamina and the growth of plant was reduced. Later on the chlorotic areas turned necrotic on both sides of midrib followed by development of black colour. Phosphorus toxicity symptoms were observed with excess P supply at all levels of B supply and the toxicity was in the following order: adequate B+ excess P < excess B+ excess P < low B + excess P. At low B + excess P the growth depression was most distinct as compared to adequate B+ normal P. Compared to adequate B + normal P plants, B concentration increased with an increase in B supply in all plant parts (Table 1.2). Addition of excess P increased the concentration B in almost all plant parts at both the stages of growth (49 and 96 DAS). However, the concentration of B decreased in seeds, at excess B +excess P at 96 DAS. The concentration of P was higher at excess P than that of normal P at all three B levels and was more marked at low and excess B. Maximum P concentration was observed in low B + excess P treatment in all plant parts at both stages. A Normal P, low as well as excess B supply lowered the utilization of P by decreasing the concentration of lipid, nucleic acid and protein.

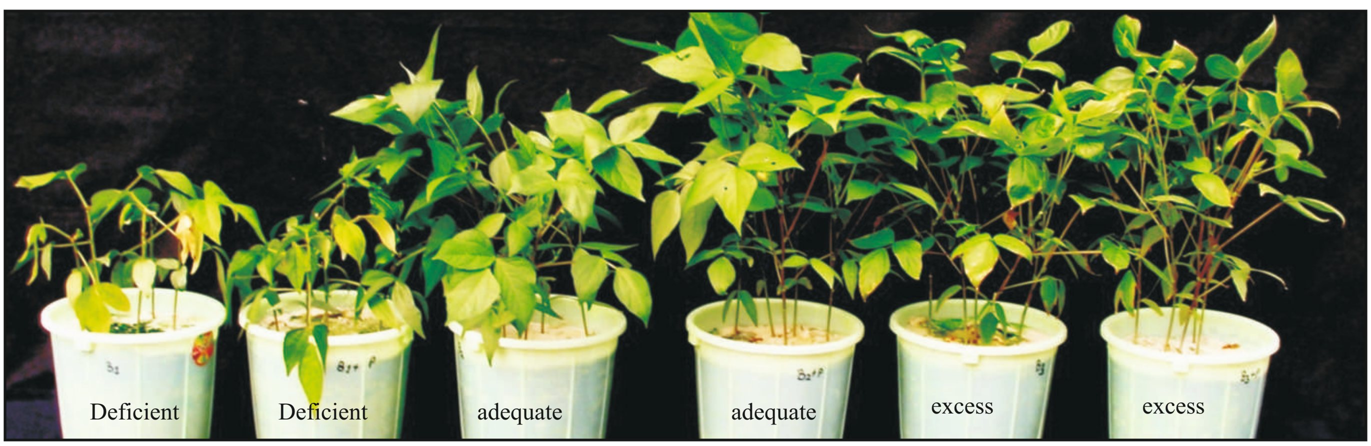


Fig. 1.2 Effect of boron supply on phosphorus use efficiency in black gram (From L to R) Deficient B, deficient B + P, adequate B, adequate B + P, excess B, excess B + P

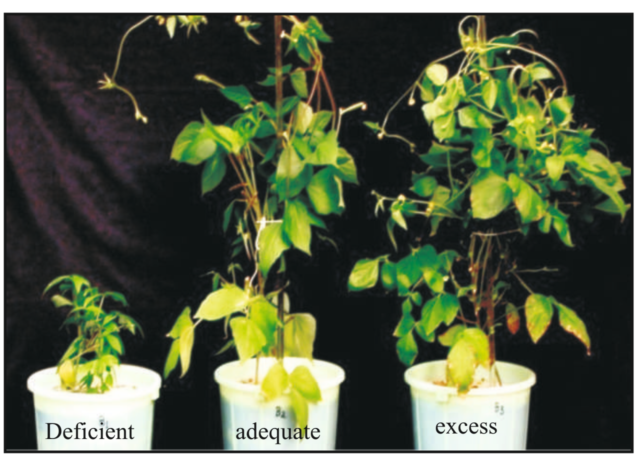


Fig. 1.3 Effect of B in black gram (From L to R) deficient, adequate and excess B

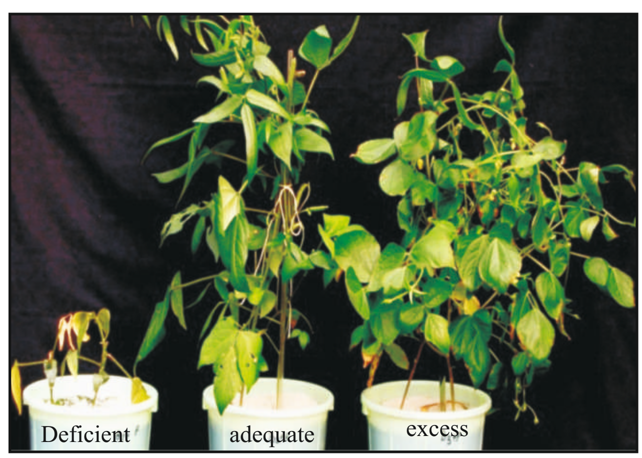


Fig. 1.4 Effect of B and P supply in black gram (From L to R) deficient + P, adequate B + P and excess B + P

Table 1.2 Effect of B and P supply on total dry matter and pod yield and percent distribution of B and P concentration in different plant part in black gram

Parameter	Plant part	P levels (mm)	µM Boron		
			3.0	30	60
Dry weight (g $plant^{-1}$) (at 96 DAS)	Whole Plant	1.50	4.59 (-76)	18.96	17.51 (-8)
		2.25	1.61 (-92)	16.46	13.67 (-28)
Weight of Pods (g $Plant^{-1}$)	Pod	1.50	--	9.83	4.66 (-52)
	Pod	2.25	--	6.95	7.38 (-25)
µg Boron g^{-1} dry matter (at 96 DAS)	Seeds	1.50	--	22.00	120 (445)
	Leaves		8 (-91)	90.00	266 (+196)
	Stem		14 (-30)	20.00	22 (+10)
	Roots		10 (-23)	13.00	52 (+300)
	Seeds	2.25	--	29.00	88 (+203)
	Leaves		18 (-81)	94.00	356 (+279)
	Stem		15 (-32)	22.00	28 (+27)
	Roots		10 (-64)	28.00	62 (+121)
P concentration (at 96 DAS)	Seeds	1.50	--	0.29	0.33 (+14)
	Leaves		0.07 (-46)	0.13	0.09 (-31)
	Stem		0.49 (+1125)	0.04	0.14 (+250)
	Roots		0.75 (+650)	0.10	0.24 (+140)
	Seeds	2.25	--	0.52	0.42 (-19)
	Leaves		1.08 (+332)	0.25	0.25 (0)
	Stem		1.95 (+474)	0.34	0.81 (+138)
	Roots		1.51 (+84)	0.82	0.77 (-6)

Data in parenthesis represents as % decrease (-) or increase (+) over control

The total chlorophyll content also decreased in black gram leaves both at low (3.0 µM B) and excess B (60 µM B) supply. However, excess P (2.25 mM) decreased the concentration of both chlorophyll a and b at all B levels. Excess P decreased the chlorophyll content more pronouncedly at low B+excess P than at adequate B+excess P and excess B+ excess P. At excess P the depression in chlorophyll a was more marked than that of chlorophyll b. The activity of Catalase (CAT) decreased at low and excess B supply. While specific activity of Peroxidase (POX) and polyphenol oxidase (PPO) was markedly increased at all levels of boron. Addition of excess P (2.25 mM) at each B level increased further the POX activity except in excess B + excess P supply (Table 1.3).

Table 1.3: Effect of B and P supply on phosphorus fractions, chlorophyll content and specific enzyme activities in black gram leaves

Parameter	P levels (mm)	µM Boron		
		3.0	30	60
Total P (% in fresh weight)	1.50	0.177 (-90)	0.186	0.145 (-22)
	2.25	0.411 (+122)	0.200 (+8)	0.300 (+61)
Inorganic P	1.50	0.070 (+52)	0.044	0.038 (-14)
	2.25	0.23 (+423)	0.063 (+43)	0.099 (+125)
Total Organic P	1.50	0.094 (-30)	0.135	0.110 (-19)
	2.25	0.140 (+4)	0.192 (+42)	0.160 (+19)
Chlorophyll a (mg g^{-1} fresh weight)	1.50	1.11 (-26)	1.50	1.11 (-26)
	2.25	0.53 (-63)	1.34 (-11)	1.09 (-27)
Chlorophyll b (mg g^{-1} fresh weight)	1.50	0.39 (-22)	0.50	0.41 (-18)
	2.25	0.26 (-48)	0.47 (-6)	0.41 (-10)
CAT (µ moles H_2O_2 decomposed)	1.50	852 (-56)	1836	562 (-69)
	2.25	480 (-74)	414 (-77)	304 (-83)
POX (Change in O.D.)	1.50	5.6 (+84)	3.2	5.60 (+75)
	2.25	11.5 (+259)	4.6 (+44)	4.87 (+52)

Data in parenthesis represents as % decrease (-) or increase (+) over control

B. Effect of molybdenum supply on nitrogen use efficiency in black gram

Black gram (*Vigna mungo* L.) var. Shyam. plants were raised at three levels of Mo i.e. low (0.002 µM), adequate (0.2 µM) and excess (2 µM) Mo for 70 days. At each Mo level, N was supplied with two levels, i.e. adequate (12mM) and excess (18mM). The increase in Mo supply from low (0.002 µM) to adequate (0.2 µM) enhanced the nitrogen use efficiency in black gram by increasing dry matter, seed yield, 100 seed weight, Mo concentration, nitrate reductase activity and seed protein content both at adequate and excess N supply. However, excess Mo supply significantly reduced the dry matter, seed yield, 100 seed weight and seed protein content despite increase in tissue Mo concentration and nitrate reductase activity.

Fig. 1.5 Effect of molybdenum supply on nitrogen use efficiency in black gram (From L to R) Deficient Mo, deficient Mo + N, adequate Mo, adequate Mo + N, excess Mo, excess Mo + N

At 20 DAS, reduction in growth was observed in black gram grown at low (0.002 µM) Mo supply. The Mo deficiency symptoms appeared at 25 DAS as interveinal chlorosis of young and middle leaves. Later, discoloration of lamina started from the tip and covered the entire marginal portion of lamina (Fig. 1.5). The chlorosis intensified with age and irregular necrotic spots appeared on these discolored interveinal areas which enlarged in size and gradually the whole leaf appeared necrotic. At 2 µM Mo, symptoms of excess Mo appeared late as young leaves showed inward curling followed by marginal scorching. The young and middle leaves of plants grown at excess Mo and excess N developed interveinal mottling and turned thick and fleshy.

The additional dose of nitrogen at low and adequate Mo level increased the dry matter and seed yield considerably but at excess Mo level it decreased both dry matter as well as seed yield (Table 1.4). The activity of nitrate reductase increased with an increase in supply of Mo from 0.002 to 2 µM both at adequate and excess N. At each Mo level the activity was comparatively low at excess N.

Table 1.4: Effect of Mo and N supply dry matter yield, economic yield, nitrate reductase activity and seed protein in black gram seeds

Parameter	Levels of N (mM)	Mo supply (µM)		
		0.002	0.2	2
Dry matter yield (g $plant^{-1}$) at 70 DAS	12	12.70	15.60	12.00
	18	14.10	16.90	11.80
Seed weight (g $plant^{-1}$)	12	5.45	6.70	5.53
	18	5.93	6.77	4.39
No. of seeds ($plant^{-1}$)	12	202.00	248.00	224.00
	18	212.00	264.00	186.00
µg Mo g^{-1} dry matter at 70 DAS	12	0.07	0.68	0.88
	18	0.07	0.72	0.91
Nitrate reductase (n moles NO_2 formed g^{-1} fresh weight h^{-1})	12	98.00	165.00	240.00
	18	94.00	122.00	186.00
Seed protein (% fresh weight)	12	7.56	16.50	15.40
	18	8.21	17.20	12.80

C. *Effect of molybdenum supply on nitrogen use efficiency in cowpea*

Cowpea (*Vigna ungiculata* L.) var. Pusa Komal, plants were raised at three levels of Mo *i.e.* low (0.002 µM), adequate (0.2 µM) and excess (2 µM) Mo for 75 days. Increase in Mo supply from low (0.002 µM) to adequate (0.2 µM), significantly enhanced the nitrogen use efficiency in cowpea by increasing dry matter, seed yield, 100 seed weight, Mo concentration, nitrate reductase activity and seed protein content. However, Mo in excess significantly reduced the dry matter, seed yield, 100 seed weight and seed protein content despite of increase in tissue Mo concentration and nitrate reductase activity.

The molybdenum deficiency symptoms appeared at 25 DAS as interveinal chlorosis of middle leaves. Later, discoloration of lamina started from the apical margins and covered entire lamina. The chlorosis intensified with age and irregular necrotic spots appeared on these discolored interveinal areas. Symptoms of excess Mo (2 µM) supply, appeared late on young leaves showing interveinal mottling with inward curling followed by marginal scorching. The leaves of plants turned thick and fleshy. A large percentage of flowers were shed prematurely resulting in poor settings of fruits (pods) at excess Mo supply. Total dry matter as well as seed yield decreased at low and excess Mo supply. The activity of nitrate reductase increased with an increase in supply of Mo from 0.002 to 2 µM while the seed protein content decreased both at low (0.002 µM) and excess (2 µM) Mo supply (Table 1.5).

Table 1.5: Effect of low and excess Mo supply on dry matter, economic yield, Mo concentration, nitrate reductase activity in leaves and protein content in seeds of cowpea

Parameter	Plant part	µM Mo		
		0.002	0.2	2.0
Dry matter yield (g $plant^{-1}$) 70 DAS	Whole plant	14.09	16.92	11.81
Seed weight (g $plant^{-1}$)	Seed	8.93	11.77	7.39
Mo concentration	Leaves	0.09	2.22	2.41
(µg Mo g^{-1} dry matter), 70, DAS	Seed	0.07	0.72	0.91
Nitrate reductase (n moles NO_2) formed g^{-1} fresh weight h^{-1} Leaves	Leaves	94.00	122.00	186.00
Seed protein (% fresh weight)	Seed	7.56	16.50	15.40

1.3 Amelioration of boron deficiency in cowpea using different modes of B application

Growth and visible symptoms

Cowpea (L.) cv. Pusa Komal, plants were grown in refined sand in glasshouse at an ambient temperature (15-32°) in polyethylene containers (10”). Pots with two plants in each pot were divided into two lots. Plants in first lot was grown with complete nutrient solution to serve as control, in second lot 0.3 µM boron were supplied as boric acid for 27 days. On 28th day, at initiation of visible symptoms cowpea plants at low boron (0.3 µM) level pots were divided in to four lots: (i) Low B (0.3 µM), (ii) Low B + 30 µM B through root, (iii) Low B + 300 µM B through spray, (iv) Low B + 30 µM B through root + 300 µM B through spray. Low boron reduced the biomass and seed yield and induced oxidative stress. This was brought back variably by different recovery treatments, but deficiency was markedly ameliorated and reached to near normal values when 30 µM B was supplied through roots and 300 µM through spray in low B treated plants at reproductive stage.

Growth of boron deficient plants appeared depressed at 28 DAS. In another 5-10 days, young leaves of these plants developed interveinal chlorosis from the tip and margins of the lamina. Later affected leaves appeared thick and turned necrotic. As deficiency progressed, condensation of internodes, death of apical growing point, inward curling of lamina of young leaves were observed in boron deficient plants (Fig 1.6). In acute B deficiency (0.3 µM), few pods and seeds were formed. Recovery treatments enhanced the formation of pod and seed formation. As compared to low B, maximum pod and seeds were formed when B was added through root and spray together.

The biomass of cowpea was reduced very significantly with low boron supply. This loss in biomass was recovered partially in different treatments (Table 1.6). The recovery in biomass of cowpea was maximum when boron was applied in both ways i.e. through roots (30µM) and the through spray (300 µM). Slight recovery from B deficiency was also observed when B was supplied either through spray alone or through roots.

Fig.1.6 Amelioration of boron deficiency in cowpea (L to R) Control; low B (0.3µM); low B + 30µM B through root ; low B + 300µM B through spray; low B + 30µM B through root + 300µM B through spray

Table 1.6: Effect of models of B application on biomass and economic yield, B concentration in plant parts and enzymatic activities in cowpea

Parameter	Plant part	Boron supply				
		30 µM	0.3 µM (Low B)	Low B +30 µM TR	Low B +300 µM TS	Low B +30 µM B TR+ 300 µM TS
Dry weight ($g\ plant^{-1}$) at 69 DAS	Whole plant	10.99±0.30	4.90±0.29	7.88±0.58	6.71±0.12	8.40±0.46
Seed weight ($g\ plant^{-1}$)	Seed	1.78±0.06	0.28±0.02	0.41 ±0.03	0.38±0.012	0.81±0.55
Boron concentration ($\mu g\ g^{-1}$ dry matter)	Husk	66.0±5.80	17.0±0.43	20.0±0.80	17.8±0	39.0±0.24
	Seed	23.0±2.88	10.8±1.72	10.0±0.85	33.0±0.58	36.0±0.36
	Y.L.	48.0±2.89	10.0±0.72	10.0±0.92	29.0±0	38.0±0.25
	O.L.	136.0±4.61	12.0±0.90	15.0±1.20	46.0±3.76	68.0±0.22
	Stem	38.0±3.46	4.0±0.58	30.0±1.69	33.0±0.58	35.0±0.12
	Root	25.0±4.04	17.0±3.5	16.0±0.25	17.0±1.15	29.0±0.00
Catalase (µ moles H_2O_2 Split)		1243±46	522±25	750±29	917±3.0	1080±310
Peroxidase (Change in O.D.)		2.48±0.17	6.36±0.05	5.54±0.27	3.56±0.32	2.81±0.12
SOD (EU)		2.34±0.09	10.27±0.05	7.76±0.02	7.05±0.01	5.58±0.01
MDA conc.(n mol 100 mg^{-1} fresh weight)		24.7±0.06	31.65±0.06	30.45±0.03	28.11±0.05	25.33±0.01
Proline (µ mol 100 mg^{-1})		44±1.42	9±0.72 2	35±0.49	37±0.42	41±0

TS = Through spray; TR = Through root; Y.L. = young leaves; O.L. = Old leaves

These results show that B applied either through roots (30µM) or spray (300 µM) could mitigate the visible effects of low B partially and recovered the growth and yield to some extent. Compared to the adequate B treated plants, the concentration of B was lowered variably in different plant part of cowpea at low B and ranged between 4 to 17 $\mu g\ g^{-1}$. This was brought back variably to near normal values 29 to 68 $\mu g\ g^{-1}$ dry matter when B was given through roots and spray (300 µM) together.

Enzyme activities and soluble protein

Compared to the enzyme activities at normal (control) plants, the activity of CAT decreased and that of POX increased in leaves of low B treated plants (Table 1.6). In different recovery treatments, the activity of catalase has been restored to the variable extent whereas the activity of peroxidase was lowered variably by different recovery treatments. Lowering of peroxidase activity was most pronounced when B was given through roots (30µM) as well as through spray (300 µM) together. In cowpea leaves, low B increased the activity of SOD manifold as compared to that obtained at normal level. When various treatments were applied the activity of enzyme was reduced, maximum reduction in SOD activity was observed when B was given in both ways. The activity of SOD in low B treated leaves was increased from that of control level (Table 1.6).

When the various recovery treatments were applied, the activity of SOD was lowered to the some extent. As compared to control plants, concentration of protein decreased at low B supply. In different recovery treatment the protein content increased markedly. Maximum protein content was obtained when B was given (30µM) through roots as well as through spray (300 µM). The concentration of proline was depressed significantly in cowpea by low B, but when B was supplied in variable ways, the recovery in proline concentration was also variable. Maximum recovery in proline concentration was observed when boron was applied through roots and spray together. Partial recovery in these parameters was also observed when B was supplied either through roots (300 µM) or through spray in low B treated cowpea (Table 1.6).

1.4 Alteration in uptake and translocation of essential nutrients in maize by zinc stress

In order to observe the effect of zinc stress on growth, development and concentration of other nutrients in different plant parts of maize (*Zea mays* L.) var. GIS-3017, plants were grown in refined sand with 0.01, 1, 10 and 100 µM zinc supply. The plants were examined periodically for visible symptoms and changes in growth parameters. On 36 and 92 DAS plants were harvested for biomass and concentration of zinc (Zn), iron (B), manganese (Mn) and phosphorus (P) in different plant parts. Zn stress, in general, reduced the biomass and seed yield and also affected the uptake and translocation of nutrients; for example, Fe and P uptake decreased in low and excess Zn supply, whereas Mn uptake decreased under low Zn and increased with excess Zn. Zinc uptake increased with an increase in Zn supply in different plant part of maize.

At low Zn (0.01 µM) supply, the young leaves were reduced in size and showed interveinal chlorosis along the base of the leaf lamina. With increase in age and persistent low zinc supply, the young leaf turned bleached and developed '*white bud of maize*'. The emerging leaf fails to unroll. Cob formation was markedly inhibited at low Zn supply. At excess Zn supply no marked visual symptoms was observed except slight interveinal chlorosis in young leaves and growth depression (Fig 1.7 & 1.8)

Table 1.7 Effect of Zn stress in biomass, cob, seed yield, uptake and concentration of nutrients (Zn, Fe, Mn, P) in different plant parts of maize

Parameter	Zinc Supply µM			
	0.01	1.0	10.0	100.0
Dry weight (g plant^{-1}) 92 DAS	15.28(-81)	78.56	53.78 (-32)	36.44 (-54)
Cob weight (g plant^{-1})	1.85 (-96)	46.39	23.11 (-50)	21.29 (-54)
Seed weight (g plant^{-1})	--	37.64	14.47 (-62)	9.55 (-75)

Table 1.8 Changes in Zn, Fe, Mn and P concentration in different plant parts of maize it various levels of Zn supply

Parameter		Zinc Supply µM			
		0.01	1.0	10.0	100.0
Zn concentration ($\mu g\ g^{-1}$)	Seed	--	21.6	58.5(+171)	67.6(+213)
	Husk	4.3(-76)	18.2	71.5(+290)	80.5(+342)
	Y.L.	3.8 (-89)	35.7	36.2 (+1)	43.2 (+21)
	O.L.	14.9(-68)	46.7	54.1(+16)	71.4(+53)
	Y.L.S.	8.8 (-52)	18.3	21.2(-50)	61.5(+236)
	O.L.S.	10.8 (-30)	15.5	29.6(+91)	42.2(+172)
	Y.S.	9.3 (-86)	26.7	138.6(+417)	164.9(+518)
	O.S.	8.2(-24)	10.8	57.2(+430)	163.6(+1415)
	Root	6.0(-72)	21.9	25.9(+18)	67.6(+209)
Fe concentration ($\mu g\ g^{-1}$)	Seed	--	95.2	53.2(-44)	49.9(-48)
	Husk	46.9 (-47)	89.3	52.5(-41)	47.3(-47)
	Y.L.	55.9(-81)	286.9	84.6 (-71)	41.0(-86)
	O.L.	56.5.0(-81)	304.9	113.8(-63)	67.4(-78)
	Y.L.S.	129.5(-5)	136.9	94.7(-31)	40.4(-70)
	O.L.S.	35.8(-78)	161.0	60.6(-62)	40.8(-74)
	Y.S.	28.9(-81)	155.8	55.4 (-64)	52.5(-66)
	O.S.	78.6(-51)	161.2	58.7(-64)	54.2(-66)
	Root	132.2(-44)	235.5	185.3(-21)	125.5(-47)
Mn concentration ($\mu g\ g^{-1}$)	Seed	--	7.2	9.1(+26)	9.1(+26)
	Husk	6.5 (-86)	46.8	10.1 (+56)	18.4 (+182)
	Y.L.	31.3(-29)	44.3	43.6(-2)	24.2(-45)
	O.L.	29.1(-69)	93.6	38.3(-59)	44.4(-53)
	Y.L.S.	24.2(-47)	42.9	29.0(-33)	44.9(+5)
	O.L.S.	17.2(-59)	42.2	17.2(-59)	46.4(+10)
	Y.S.	8.3(-67)	25.4	27.3(+8)	25.8(+1)
	O.S.	13.6(-1)	13.8	12.4(-10)	9.9(-28)
	Root	5.9(-63)	15.9	11.9(-25)	21.9(+38)
P concentration (%)	Seed	--	0.18	0.50(+177)	0.36(+100)
	Husk	0.11(-45)	0.20	0.16(-20)	0.28 (+40)
	Y.L.	0.11(-65)	0.31	0.25(-19)	0.36(+16)
	O.L.	0.25(-19)	0.31	0.14(-55)	0.25(-19)
	Y.L.S.	0.12(-29)	0.24	0.31(+29)	0.28(+17)
	O.L.S.	0.23(-4)	0.17	0.23(+35)	0.23(+35)
	Y.S.	0.19(-42)	0.33	0.43(+30)	0.42(+27)
	O.S.	0.18(-25)	0.24	0.28(+17)	0.21(-13)
	Root	0.22(-8)	0.24	0.14(-42)	0.28(+17)

Y.L.= young leaves; O.L.= Old leaves; Y.L.S. = young leaf sheath; O.L.S. = old leaf sheath
Y.S. = young stem; O.S.= Old stem. Data in parenthesis represents % decrease or increase over Normal Zn supply.

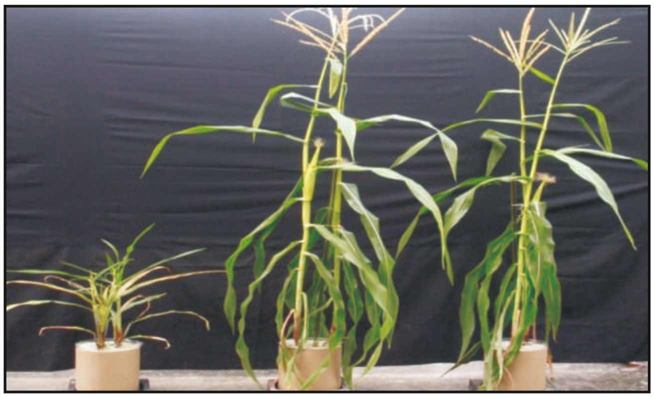


Fig. 1.7: Effect of low (0.1µM), adequate (1µM) and excess (100µM)) zinc supply in maize

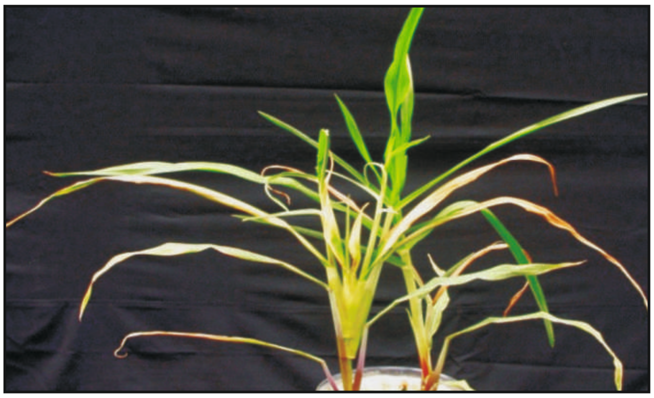


Fig. 1.8: Effect of low (0.1µM) zinc supply in maize

The biomass of maize decreased at both low and excess zinc supply (0.01 and 100 µM Zn) but reduction was pronounced at low Zn supply while little effect was seen under excess Zn supply. The reduction in dry weight of whole plant was 61% and 81% at low (0.01 µM) Zn, 27% and 54% at excess (100 µM) Zn as compared to standard supply (control). At low Zn The cob weight was 96% lesser than that of normal supply and no seeds were formed. At excess Zn i.e. 10 and 100 µM Zn, reduction in cob and seed weight was 54 and 75% respectively (Table 1.7). The concentration of Zn in leaves increased with an increase in zinc supply from 0.01 to 100 µM. The concentration of zinc in various parts of maize at optimum Zn supply was ranged between 10.8 to 46.7µg g^{-1} dry matter. At excess Zn supply, maximum Zn was accumulated in old stem (+1415%) and minimum in young leaves (+21%) as compared to standard supply. At low Zn supply maximum reduction in Zn concentration was found in young leaves (-89%) and minimum in old stem (-24%). It appears that the translocation of zinc from old stem to leaves was restricted.

1.5 Influence of excess cobalt on groundnut metabolism

In order to observe the tolerance limit of cobalt in groundnut (*Arachis hypogea* L.), plants were grown in purified sand and were supplied with complete nutrient solution (0.0001 mM Co) for 30 days. On 31st day, pots with plants were supplied with six graded levels of Co viz. 0.0001, 0.05, 0.1, 0.2 0.4, and 0.5 mM as cobalt sulphate were added. The plants were examined periodically for visible foliar symptoms and changes in growth parameters. At excess Co supply, the young leaves developed chlorosis from apex, gradually spreading towards the base. In severe toxicity (0.5 mM) necrotic spots developed on the chlorotic patches, enlarged in size, coalesced and a major portion of lamina turned necrotic and withered. Further growth of plants was checked due to death of the growing point. At later stages the young emerging leaves were distorted and had rudimentary leaflets at the top. At 0.4 mM Co, only a few flowers were formed, which were smaller, lighter in colour and most of these failed to produce pods. Flowering and fruiting was completely checked at 0.5 mM Co level. The effects of excess of Co were more pronounced at levels >0.1mM Co and less so at 0.05 mM Co (Fig 1.9)

The biomass of groundnut decreased (21-85%) with an increase in Co supply from 0.0001 to 0.5 mM. No seeds were formed at higher level of Co supply. At 59 DAS the concentration of Zn and Fe in different plant parts was decreased with increase in Co supply from 0.05 to 0.5 mM at both the stages of sampling i.e. 56 and 90 DAS (25 and 59 DAMS). The concentration of Fe and Zn was minimum followed by young leaves, old leaves, stem and roots (Table 1.9). The concentration of Co in different plant parts increased gradually with an increase in Co supply. Accumulation of Co was more in young leaves than in roots, old leaves and stem at all level of Co supply Compared to 0.98 ppm Co concentration in normal seeds, its concentration increased to 29.0 ppm in seed of plants grown at 0.4 mM Co. The concentration of chlorophyll a, b, malondialdehyde (MDA) and carotenoids decreased significantly in groundnut leaves at excess Co supply. However, the proline content in leaves increased with an increase in Co supply and the increase was 182 % at 0.5 mM Co than that of Control. The specific activities of catalase decreased, whereas activity of peroxidase, superoxide dismutase and ascorbate peroxidase increased with an increase in Co supply from 0.0001 to 0.5 mM in groundnut leaves.

Table 1.9 Effect of varying level of Co supply on dry matter and Fe, Zn and Cot concentration in different parts of groundnut

Parameter	Co supply mM						
	Plant part	0.0001	0.05	0.10	0.20	0.40	0.50
Dry weight (g plant^{-1} 41 DAS)	Whole plant	2.45	2.28 (-7)	2.26 (-8)	2.17 (-11)	2.06 (-16)	1.93 (-21)
Dry weight (g plant^{-1} 56 DAS)	Whole plant	6.88	4.76 (-40)	3.78 (-45)	3.45 (-50)	3.15 (-54)	2.77 (-60)
Dry weight (g plant^{-1} 90 DAS)	Whole plant	22.24	15.86 (-29)	10.95 (-51)	9.06 (-59)	6.5 (-71)	3.2 (-86)
Cobalt concentration (µg g^{-1} dry matter, 56 DAS)	Y.L.	ND	273	384	609	857	939
	O.L.	ND	28	42	68	123	322
	Stem	1.16	28	70	126	225	287
	Roots	0.6	201	500	677	816	907
	Seeds	ND	ND	5	16	29	--
Iron concentration (µg g^{-1} dry matter 90 DAS)	Seeds	80	60	47	38	13	--
	Y.L.	351	191	168	140	89	87
	O.L.	194	192	165	141	120	142
	Stem	205	210	196	172	169	158
	Roots	358	417	350	240	239	182
Zinc concentration (µg g^{-1} dry matter 90 DAS)	Seeds	61	29	26	25	24	--
	Y.L.	73	53	57	47	41	39
	O.L.	64	52	46	47	57	43
	Stem	100	70	67	64	72	56
	Roots	113	97	91	70	71	66
Figures in parenthesis denote % increase (+) or decrease (-) over the control. ND = not detectable							

Fig.1.9: Effect of co supply on ground nut

1.6 Critical concentration of Zn in different crop plants

Lucknow centre of AICRP-MSN established the severe deficiency, threshold of deficiency, sufficiency, threshold of toxicity and threshold of severe toxicity consult ration of Zinc of various crops. The values for each category varied among different crops and plant parts. The details are given in table 1.10

Table 1.10 Critical concentration of Zn in different crop plants

Crop	Growth Stage DAS	Plant part	Concentration in mg kg^{-1} denoting		
			Severe deficiency	Threshold (deficiency)	Sufficiency
Wheat	35	ML	< 15	20	22
Barley	35	ML	< 15	20	-
Rice	35	ML	< 15	20	22-100
Maize	50	ML	< 15	25	28
Sorghum	35	ML	< 15	20	22-50
Pearl millet	44	ML	< 20	40	42-100
Gram	60	ML	< 7	15	17
Pea	42	ML	< 12	20	22-80
Lentil	55	ML	-	10	11-50
Green gram	28	ML	< 15	20	22
Black gram	30	ML	< 12	25	27-45
Cowpea	32	LB	< 20	45	50-150
French bean	75	YL	36	50	60-120
Mustard	30	ML	< 25	30	33
Safflower	100	YL	22	27	30-60
Rapeseed	95	YL	17	22	25-50
Sunflower	73	L	< 20	40	45-100
Groundnut	45	YL	22	28	30-95
	100	Seed	12	16	20-30

1.7 Standardization and development of soil test methods and establishment of critical levels for micro and secondary nutrients in soils

A. Critical level of B Establishment of sandy soils for Toria

A wide range of soils differing in B content (0.10-1.71 mg kg^{-1}). Were collected from 20 sites of establishing critical limit of B for toria. The result revealed that a critical value of 0.51 mg HWS- B kg^{-1} soil differentiated B responsive soils (9 soils) from the non-responsive soils (11 soils) with toria as a test crop. In the glass house as well as field experiment higher content of B and its uptake was reported with 1.0 kg ha^{-1} B level. All the soils containing 0.51 mg kg^{-1} HWS- B or less than 0.51 responded to B application. A value of 0.51 mg kg^{-1} of HWS-B in the soil differentiated B responsive soils from the non-responsive soils considering that a soil is responsive which gave 80 percent of the maximum yield or more than that without B application is non-responsive to applied B. This confirmed that the soils under investigation were B deficient. Response to B application was observed in only 20 percent of the soils containing more than 0.51 mg HWS-B Kg^{-1} thus indicating a 94 per cent predictive value of HWS-B method.

The plants grown on such soils contained less B as compared to those grown in B sufficient soils (Table 1.11). The range of B content in plants (at 45DAS) grown on deficient soils (control) was 27.67 to 44.83 mg kg^{-1} and this increased to 37.50 to 50.33 mg kg^{-1} in B treated pots. On B sufficient soil, the B content in the control plants was 21.17 to 42.33 mg kg^{-1} whereas, the B content in the B fertilized plants was 22.33 to 48.00 mg kg^{-1}. This suggests that the plants grown on B deficient soils contain less B as compared to those grown in B sufficient soils. The critical level of B in green toria at 45 days, below which response to B fertilization could be expected, was 29.2 mg kg^{-1}. This critical level gave a predictability value of 94 percent. The B content was also significantly related to Bray's percent yield.

Table 1.11 Toria yield, B concentration and B uptake in Toria as influenced by graded doses of B

Treatment	Boron Levels (kg ha^{-1})				Mean
	0	0.5	1.0	2.0	
B concentration after 45 day (mg kg^{-1})	39.76	40.45	44.8 4	38.46	40.88
Grain yield at maturity (t ha^{-1})	0.51	0.58	0.63	0.53	0.56
B concentration in grains (mg kg^{-1})	28.83	33.00	37.50	30.67	32.50
B uptake in grains (g ha^{-1})	115.69	132.63	148.83	92.93	122.52
Straw yield at maturity (t ha^{-1})	0.92	0.96	1.21	1.03	1.03
B concentration in straw (mg kg^{-1})	39.33	39.33	43.33	40.17	40.54
B uptake in straw (g ha^{-1})	360.30	378.66	525.08	414.37	419.60

B. *Establishment of critical level of Cu in soil and plant for wheat*

Fifteen bulk surface (0-15 cm) soil samples were collected from Ludhiana, Ferozepur, Muktsar and Bathinda districts of Punjab having 0.119 to 1.253 mg Cu kg^{-1} soil. A greenhouse experiment was conducted to study the response of wheat to Cu application at 0 and 5 mg Cu kg^{-1} soil. The plants were harvested at three stages of crop growth i.e. 30 days after germination, 60 days after germination and at maturity. The observations on dry matter yield, grain yield, straw yield, Cu concentration and Cu uptake were recorded. The soil samples were extracted for available Cu by different extractants, i.e. 0.005M DTPA (Diethylene triamine penta acetic acid) (pH 7.3), 0.005M DTPA+1M NH_4HCO_3 (pH 7.6) 0.01M EDTA (Ethylene diamine tetra acetic acid) +1M NH_4HCO_3 (pH 8.6), 0.005M DTPA+0.1N HCl 0.1N HCl, Mehlich-1 and Mehlich-3 (Table 1.12).

Table 1.12 Physico- chemical properties of the soils and amount of copper extracted (mg kg^{-1} soil) by various extractants

Physico - chemical properties	Range	Mean ± SD	Amount of copper extracted (mg kg^{-1} soil)		
			Extractants	Range	Mean ± SD
pH	7.38-8.84	8.10±0.47	DTPA	0.11-1.253	0.409±0.35
EC	0.18-0.49	0.35±0.11	AB-DTPA	0.49-2.44	0.978±0.67
O.C. %	0.15-0.54	0.33±0.12	AB-EDTA	0.54-1.83	0.901±0.61
$CaCO_3$ %	0.0-5.14	1.86±1.40	DTPA -HCL	0.24-1.99	0.667±0.53
Available P_2O_5 (kg ha^{-1})	11.36-56.00	56±12.89	HCl	0.12-1.39	0.46±0.38
Available K_2O (kg ha^{-1})	123-363	245±57.87	Mehlich-1	0.29-1.45	0.56±0.34
Clay %	5.90-37.90	19.90±11.44	Mehlich-3	0.34-2.03	0.757±0.44

A significant mean increase of 17.4, 15.7, 15.7 and 15.2 per cent over control in dry matter yield of wheat at 30 days 60 days, grain and straw yield at maturity, respectively was observed with application of 5 mg Cu kg^{-1} soil irrespective of the soils used(Table 1.13). Mean Cu concentration in dry matter at 30 and 60 days, grain and straw at maturity in control treatment were 16.2, 8.74, 4.43 and 3.34 μg g^{-1}, respectively, which increased to 21.2, 10.12, 6.01 and 4.98 μg g^{-1}, with application of 5 mg Cu kg^{-1} soil irrespective of the soils. The relative Cu uptake by wheat at 30 and 60 days varied from 37.3 to 94.0 and 42.7 to 93.7 percent whereas relative uptake by grain and straw varied from 33.9 to 92.6 and 30.2 to 89.1 per cent, respectively.

Table 1.13 Effect of Cu application on dry matter yield at different growth stages, grain yield, relative bray's yield and Cu uptake in wheat crop

Parameter	Levels of Cu supply	Range	Mean±SD
Dry matter yield of wheat at 60-days growth, (g pot^{-1})	without Cu	7.71 -11.35	8.74±2.09
	with Cu	9.81 -12. 43	1013±2.52
	Relative dry matter yield (%)	79.41 -96.48	86.96±6.99
Grain yield of wheat at maturity, (g pot^{-1})	without Cu	3.17 -13.27	8.75±3.13
	with Cu	3.49 -15.22	10.13±2.86
	Relative grain yield (%)	70.69 -97.08	85.23±6.67
Cu uptake by wheat at 30-days after germination	without Cu	0.012 -0.049	0.024±0.011
	with Cu	0.013 -0.079	0.038±0.016
	Relative Cu uptake (%)	37.38 -94.02	66.49±19.62

Mean Cu extracted from soils by different extractants varied from 0.41 to 0.98 mg kg^{-1} soil. The least amount of mean available Cu was extracted by DTPA and the highest amount was extracted using AB-DTPA. The amount of Cu extracted by different extractants decreased in the following order: AB-DTPA > AB-EDTA > Mehlich-3 > DTPA-HCl > Mehlich-1 > 0.1N HCl > DTPA. Soil pH produced significant negative correlations with Cu extracted by DTPA ($r = -0.565^*$), AB-DTPA ($r=-0.584^*$), AB- EDTA ($r =-0.525^*$) and Mehlich-1 ($r=-0.529^*$). Copper extracted by DTPA+HCl, 0.1 N HCl and Mehlich-3 produced negative but non-significant correlation with soil pH. The amount of Cu extracted by AB-DTPA produced the highest value of positive correlation with Soil OC ($r=0.725^*$) followed by AB-EDTA ($r=0.705^*$), DTPA ($r=0.692^*$), Mehlich-1 ($r=0.655^*$), Mehlich-3 ($r=0.603^*$), 0.1 N HCl ($r=0.603^*$) and DTPA+HCl (r=0.512).

Of all the extractants used to extract available Cu in soils, the amount of Cu extracted by the most commonly used DTPA was highly significantly and positively correlated with relative grain yield ($r=0.688^*$), grain Cu concentration ($r=0.914^{**}$) as well as relative Cu uptake by wheat grain ($r=0.720^*$). The results revealed that the available Cu in these soils decreased with the increase in calcium carbonate and soil pH. Relative yield and Cu extracted by different extractants from soil or concentration of Cu in plant parts was employed for evaluation by various statistical models viz. quadratic, inverse, S-curve and Mitscherlich for estimating critical concentration of Cu in soils and plant parts.

The critical levels of Cu extracted by DTPA, AB-DTPA, AB-EDTA, DTPA+HCl, 0.1N HCl, Mehlich-1 and Mehlich-3 to produce 90 per cent of the maximum yield as estimated by Mitscherlich model, irrespective of the growth stage was found to be 0.21, 0. 61, 0.67, 0.40, 0.27, 0.37 and 0.75 mg kg^{-1} soil, respectively. The corresponding values of soil Cu measured by Cate and Nelson (1965) were 0.24, 0.63, 0.61, 0.50, 0.27, 0.35 and 0.57 mg kg^{-1} soil, respectively.

The critical value of Cu in dry matter at 30 and 60 days, grain and straw at maturity to produce 90 per cent of the maximum yield as measured by Cate and Nelson (graphical) procedure was observed to be 16.50, 11.50, 4.20 and 3.00 µg g^{-1}, respectively (Table 1.14). Corresponding values of Cu concentration to produce 90 per cent of the maximum yield estimated by Mitscherlich model were observed to be 14.17, 12.55, 4.09 and 2.37 µg g^{-1}, respectively. The critical value of Cu in dry matter at 30 and 60 days growth were found to be higher than that observed for grain and straw at maturity, thereby indicating that Cu requirement of wheat may be more during the early growth stages.

Table 1.14 Critical levels of Cu in wheat plants at 90% sufficiency level as measured by different equations

Models	µg g^{-1} dry matter		Grain	Straw
	30 DAS	60 DAS	Maturity	Maturity
Quadratic	17.46	13.29	4.75	3.46
Inverse	18.07	13.43	4.87	3.53
S-curve	18.32	13.48	4.92	3.55
Mitscherlich	14.17	12.55	4.09	2.37
Cate and Nelson	16.50	11.50	4.20	3.00

C. *Suitability of soil test methods for sulphur in vertisols and establishment of its critical limit in linseed*

Soil test methods are important in assessing the plant available sulphur in soil to optimize fertilizer and land use. Various soil test methods are being used but none of them is suitable for all types of soil, nutrient and crop. In view of the above fact four extractants have been studied to find out their suitability for predicting plant available sulphur in Vertisols at Jabalpur. Twenty soil samples varying in S content were collected. The result revealed that 0.15% $CaCl_2$ extractable sulphur varied from 3.9 to 26.6 mg kg^{-1} with mean value 13.4 mg kg^{-1}, Morgan's extractable sulphur varied from 4.6 to 31.5 mg kg^{-1} with a mean value of 14.5 mg kg^{-1}, 1% NaCl extractable sulphur varied from 4.6 to 29.5 mg kg^{-1} with a mean value of 14.4 mg kg^{-1} and KH_2PO_4 extractable sulphur varied from 1.6 to 21.2 mg kg^{-1} with a mean value of 10.2 mg kg^{-1}. The results indicated a wide variability in respect of sulphur extracted by different extractants. However correlation coefficients determined between extractable sulphur and Bray's per cent yield indicated that $CaCl_2$ and Morgan's extractants were significantly correlated with Bray's per cent yield (r=0.85 and 0.81) whereas 1% NaCl and KH_2PO_4 did not correlate well (Table 1.15). Thus 0.15% $CaCl_2$ (r=0.85**) was considered most suitable extractant for S extraction in vertisols. The Morgan's extractant was comparable to 0.15% $CaCl_2$.

Table 1.15 Sulphur extracted by different reagents (mg kg^{-1}) and its correlation "r" with Bray's yield

Extractants	Range	Mean	"r" value
0.15% $CaCl_2$	3.9-26.6	13.6	0.848**
Morgan's	4.6-31.5	14.5	0.810**
1% NaCl	4.6-29.5	14.4	0.300
KH_2PO_4	1.6-21.2	10.2	0.231
** Significant at 1 percent level of significant			

Critical limit of sulphur in soil and grain was established using the statistical method described by Cate and Nelson (1971). Available sulphur in medium black soils of Dewas district was extracted with 0.15%$CaCl_2$ and Morgan's extractants registered a significant correlation (r=0.85** and r=0.81**) with Bray's per cent yield of linseed. The scatter diagrams for Bray's yield versus soil sulphur by different methods are presented in Fig.1.10 and 1.11. Critical limit of soil sulphur was calculated to be 10.5 mg kg^{-1} by 0.15% $CaCl_2$ and 10.2 mg kg^{-1} by Morgan's extractant. As depicted in Fig.1.12 the critical concentration of sulphur in linseed grain, below which response to sulphur application is expected was calculated to be 2.15 g kg^{-1}.

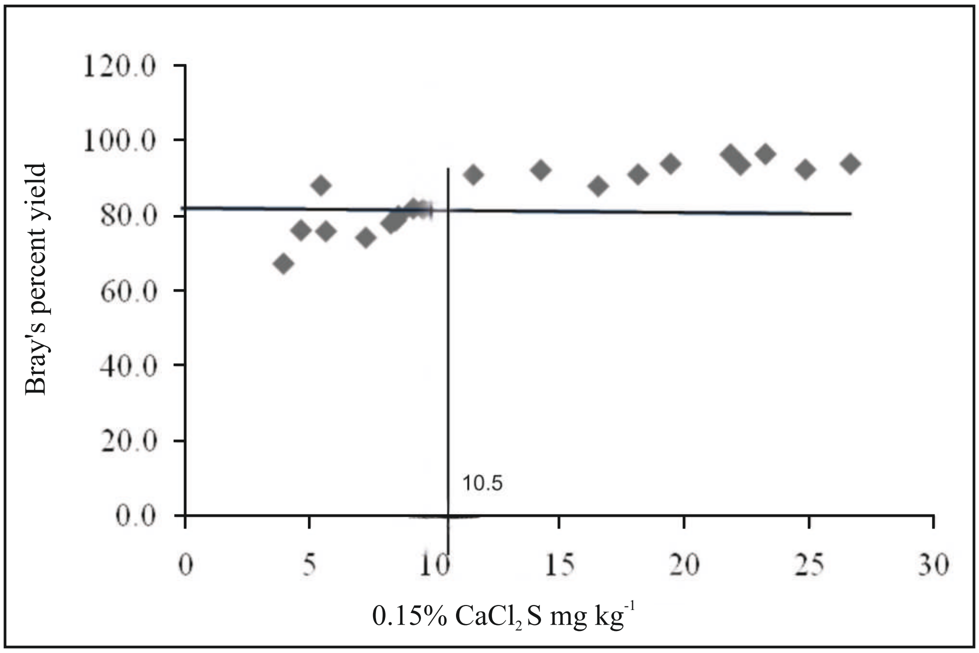


Fig.1.10 Bray's percent yield of linseed in relation to 0.15% $CaCl_2$ extractable-S in soil

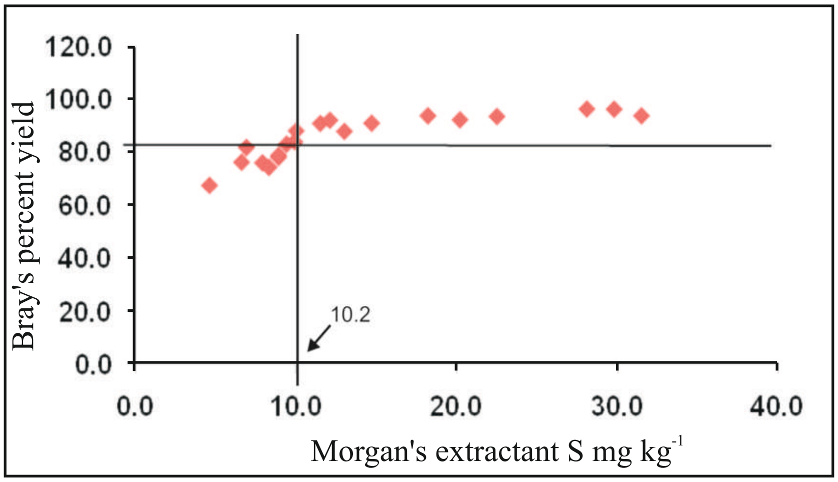


Fig.1.11 Bray's percent yield of linseed in relation to Morgan's reagent extractable-S in soil

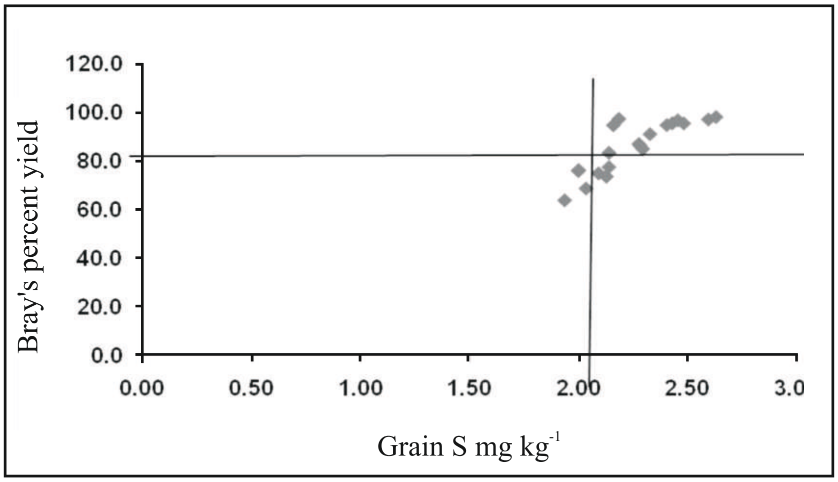


Fig.1.12 Bray's percent yield of linseed in relation to sulphur content in grain

1.8 Kinetics of micronutrients in plant-soil system

Many mathematical and mechanistic models are being used to have a better understanding of kinetics and mechanism involved in the process of nutrient uptake by plant roots. These models are based on ion transport from soil to roots by means of mass flow or diffusion as well as on nutrient uptake kinetics, mostly following Michaelis-Menten kinetics. Mechanistic models are useful tools for evaluating the significance of individual soil and plant parameter in the system through sensitivity analysis. At Anand centre, different experiments were set up to study the uptake pattern of Fe and Zn in different cultivars of pigeon pea, chickpea and wheat besides optimizing the level of Fe and Zn with respect to growth stages and varietal phenomenon (Table 1.16).

Table 1.16: Details of experimental set up for kinetics study at Anand

Crop	Element	Identified varieties		Treatment
		Efficient	Inefficient	
Pigeon pea	Fe	BDN-2, PKV-Trombay	C-11, AAU7-2007-08	Fe levels:0,20 and 40 mg Fe kg^{-1} Soil Harvest time: 40,55, 70 DAG
Chickpea		GG-1, GAG-735	ICCC-4 GJG-305	Fe Levels:0,20 and 40 mg Fe kg^{-1} Soil Harvest time: 20,40 DAG & at maturity
Wheat	Zn	GW-190, Lok-1	GW-399 GW-403	Zn levels: 0,10 20, mg Zn kg^{-1} Soil Harvest time: 20,50 DAG & at maturity

To carry out sensitivity analysis of the rhizosphere (effect of each soil and plant parameter on Fe/ Zn influx and uptake, while considering that all the parameters are independent of one another), recent version of NST 3.0 nutrient uptake model was used. Different soil parameters *viz.* Fe/ Zn concentration in soil solution and diffusion coefficient and several plant parameters *viz.* maximum net influx (I_{max}), mean root radius (r_0), root length (RL_0), Michaelis-Menten constant (K_m), Mean half distance between two roots (r_1), root surface area, water influx (v0), relative root growth rate, relative shoot growth rate and Fe/Zn uptake kinetics were taken in to account.

Pigeon pea

The root and shoot growth as well as Fe content in pigeon pea plant and other parameters like relative root growth rate, relative shoot growth rate and root length were less hampered in low Fe condition. Nutrient uptake model described the sensitivity of Fe uptake by pigeon pea, which suggested that the higher values of r_o, I_{max} and C_{Li} are desirable, while low K_m increased uptake of Fe by pigeon pea. Mechanistic model closely described Fe uptake, which suggests that the parameters were estimated accurately and the calculated uptake were realistic. Thus, the application of Fe @ 40 mg kg^{-1} on Fe deficient soil was found beneficial for better growth and development of Fe inefficient pigeon pea varieties besides better Fe content in plant.

Chickpea

In chickpea, parameters like fresh and dry weight of root were not adjudged as ideal parameters for screening of varieties under Fe-efficient and Fe-inefficient. Proliferate root development might have attributed to enhanced iron acquisition efficiency in chickpea. The ICCC-4 instead of GG-1 and GAG-735 could be a rational choice to grow on Fe-deficient soils to get seed with dense Fe content. It is likely that initial seed Fe reserves contribute to a higher performance of ICCC-4 variety over other varieties. The application of Fe at 20 mg kg^{-1} on Fe-deficient soil was found beneficial for better growth and development of Fe-inefficient chickpea varieties besides better Fe content in plant. Relative root growth rate, shoot growth rate, shoot demand on roots, water influx, iron influx were maximum in Fe-inefficient varieties; however, root length was higher in Fe-efficient varieties. Root radius (r_o) and initial soil solution Fe concentration (C_{Li}) were found most sensitive factor/parameters which influenced uptake of Fe in varieties of chickpea.

Wheat

The root and shoot growth as well as Zn content in wheat plant and other parameters like relative root growth rate, relative shoot growth rate and root length were less hampered in low Zn condition. Nutrient uptake model described the sensitivity of Zn uptake by wheat, which suggested that the higher values of r_o, I_{max} and C_{Li} are desirable, while low k_m increased uptake of Zn by wheat. Under Zn stress condition, in absence of Zn application it is better to grow Zn efficient verities while the application of Zn at 20 mg kg^{-1} soil on Zn deficient soil is beneficial for better growth and development of Zn inefficient wheat varieties besides better Zn content in plant.

CHAPTER –II

DELINEATION OF MICRO-AND SECONDARY NUTRIENTS DEFICIENT AREAS

Information on status of micro- and secondary nutrients for different soil types, districts, regions as well as for the country is highly essential to determine the nature and extent of their deficiencies/ toxicities and to formulate strategies for their correction. Almost all the centres are engaged in delineation of the deficient areas for micro- and secondary nutrients. With the advent of GPS technology, its use in delineation programmes has been introduced to collect samples from different sites under the AICRP (MSPE) and so far 70,759 soil samples with GPS point-wise data have been collected from 174 districts of the 13 states of the country. The GPS based soil sampling helps in preparation of the micronutrient fertility maps which are useful for planners and policy makers and other stake holders. The micronutrients *viz.* Fe, Mn, Zn and Cu were analyzed using DTPA extraction method outlined by Lindsay and Norvell (1978) while B using hot water extraction method. Available sulphur was estimated following extraction with 0.15% $CaCl_2.H_2O$. The database of delineation programmes conducted at different centres across the country has been summarized in this chapter with country's perspectives. List of state-wise districts from where GPS based soils samples were drawn is given in Table 2.1. Last five years data has been included in this chapter in order to give a comprehensive picture of micronutrients deficiencies.

2.1 Extent of Sulphur deficiency

Total 63,243 soil samples from 12 states of country were collected by different AICRP (MSPE) centres and analyzed for available Sulphur (Fig 2.1). Among the states, 46.5% soils of delineated districts of West Bengal were low in available S (<10 ppm S) marginally followed by Bihar (46.4%), Gujarat (43.3%), Haryana (35.8%) and Uttar Pradesh (32.5%). Interestingly, sulphur deficiency was more than 20% in all districts, except in Tamil Nadu (16.5%). Overall S deficiency in Indian soils (27.8%) is a cause of concern for framers and other stake holders.

Table 2.1: State-wise list of districts delineated for micro- and secondary- nutrients using GPS

State	District
Andhra Pradesh	Anantpur (1329), Kurnool (552), YSR- Kadapa (582), Mehbub Nagar (900), Ranga Reddy (468), Nizamabad (522), Karim Nagar (630), Guntur (402), Krishna Nagar (594), West Godawari (486), Nalgonda (59), Adilabad (499), E. Godavari (692), Prakasham (699), Vishakhapattnum (500), Srikakulam (459), Medak (407)
Assam	Jorhat (341), Sibsagar (521), Lakhimpur (391), Morigaon (246), Dibrugarh (357), Golaghat (410), Barpeta (420), Sonitpur (540), Nagaon (595), Darang (365), Kamrup (610), Tinsukia (350)
Bihar	Katihar (351), Arwal (144), Kishanganj (221), Patna (208), Purnea (224), Araria (201), Rohtas (423), Shiekhpura (151), Samastipur (472), Nalanda (171), Muzaffarpur (397)

Gujarat	Mehsana (510), Banaskantha (149), Sabarkantha (860), Ahmedabad (445), Dahod (76), Kheda (436), Panchmahals (665), Vadodara (731), Gandhinagar (67), Patan (465), Kutch (144), Anand (280), Bharuch (390)
Haryana	Sirsa (510), Kaithal (385), Kurukshetra (396), Fatehabad (464), Hisar (607), Faridabad (95), Yamuna nagar (102), Mewat (94), Mohindergarh (347), Rewari (90), Bhiwani (551), Panipat (326), Sonipat (140), Ambala (86), Panchkula (76), Karnal (362), Rohtak (142), Jhajjar (95), Gurgaon (116), Jind (440), Palwal (249)
Madhya Pradesh	Chattarpur (205), Reewa (204), Satna (202), Dewas (202), Balaghat (200), Panna (205), Chindwara (205), Mandla (752), Seoni (948), Bhopal (294), Katni (516), Jabalpur (636), Indore (360), Narsingpur (516), Shahdol (408), Raisen (205), Sehore (264), Tikamgarh (283), Morena (105)
Maharashtra	Wardha (190), Hingoli (166), Nanded (384), Osmanabad (191), Akola (498), Bhandra (462), Gondia (167), Buldhana (606), Yavatmal (858), Washim (414), Amravati (768), Chandrapur (888), Aurangabad (612), Jalna (576), Nagpur (258), Beed (259), Parbhani (276), Latur (246)
Odisha	Puri (484), Boudh (27), Nayagrah (184), Sambalpur (282), Dhenkanal (301), Sonepur (140), Kendrapada (150), Kandhmal (122), Bhadrak (358), Naupada (82), Kalahandi (201), Bargarh (43), Jagatsinghpur (82), Angul (225)
Punjab	Ropar (151), Faridkot (112), Gurudaspur (390), Jalandhar (225), Bhatinda (100), Taran tarn (120)
Tamil Nadu	Nagapattinam (1631), Virudhunagar (1308), Theni (598), Cuddalore (1943), Krishnagiri (1344), Villupuram (3430), Kanyakumari (617), Toothukudi (1658), Pudukkotai (2028)
Uttar Pradesh	Farrukhabad (300), Etawah (300), Varanasi (240), Gorakhpur (598), Sitapur (225), Agra (200), Kannauj (201), Kanpur (180), Lakhimpur kheeri (672), Unnao (208), Ramabai nagar (189), Rai bareli (570), Pilibheet (258), Allahabad (647)
Uttarakhand	Haridwar (200), Chamoli (200), Tihri (200), Dehradun (200), Almora (177), Champawat (200), U. S. Nagar (161), Nanital (147), Pithoragarh (202), Bageshwar (125), Rudraprayag (200), Uttarkashi (200)?
West Bengal	Hooghly (250), Jalpaiguri (301), Pargana (349), Nadia (247), Coochbehar (252), Burdwan (258), N. Dinajpur (267), S. 24 Pargana (247)
Note: Value in parenthesis indicates number of soil samples collected from respective district	

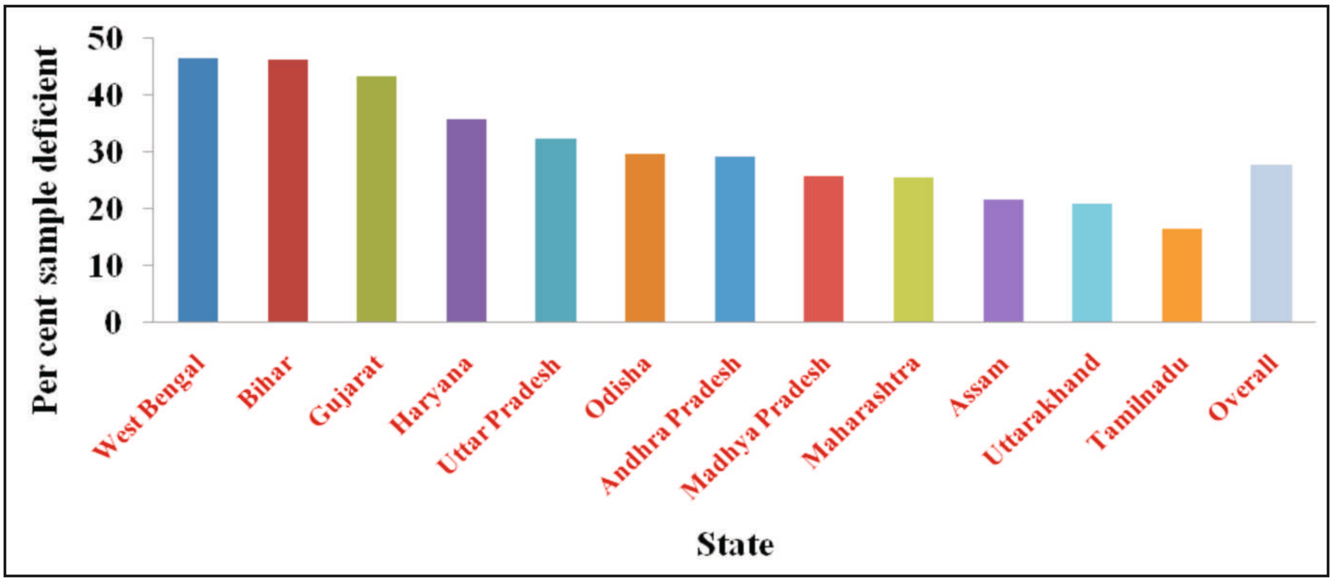


Fig. 2.1 Sulphur deficiency status in soils of different states of India

Table 2.2: Different categories of Per cent Sample Deficiency of sulphur and districts of different states falling under categories

State	Categories of S deficiency (Per cent Sample Deficiency)				
	>10%	10-20%	20-30%	30-40%	>40%
Tamil Nadu	Cuddalore, Villupuram, Kanyakumari, Toothukudi	Virudhunagar, Theni, Krishnagiri, Pudukkotai	-	-	Nagapattinam
Gujarat	-	Bharuch	Mehsana, Sabarkantha, Patan, Kutch	-	Banaskantha, Ahmedabad, Dahod, Kheda, Panchmahals Vadodara, Gandhinagar, Anand
Assam	Lakhimpur, Morigaon, Dibrugarh, Golaghat, Barpeta, Sonitpur, Nagaon	Darang, Tinsukia	-	-	Jorhat, Sibsagar, Kamrup
Uttar Pradesh	Sitapur	Kanpur	Gorakhpur, Agra, Kannauj	Etawah, Lakhimpur Kheeri, Unnao, Ramabai nagar, Raibareli, Allahabad	Farrukhabad, Pilibheet

Odisha	Boudh	Puri, Angul, Kendrapada, Kandhmal, Jagatsinghpur,	Kalahandi, Bargarh, Bhadrak, Naupada	Sambalpur, Sonepur	Nayagrah, Dhenkanal
Haryana	Sonipat, Jind	Sirsa, Mewat, Panipat	Kaithal, Yamuna nagar	Hisar, Karnal, Faridabad, Panchkula, Gurgaon	Kurukshetra, Fatehabad, Mohindergarh, Rewari, Ambala, Bhiwani, Palwal Rohtak, Jhajjar,
Madhya Pradesh	Balaghat Seoni	Shahdol	Mandla, Bhopal, Jabalpur, Raisen, Sehore, Tikamgarh	Chattarpur, Satna, Chindwara, Narsingpur	Reewa, Dewas, Panna, Morena
Maharashtra	Wardha, Bhandra	Hingoli, Osmanabad, Yavatmal, Amravati	Buldhana, Washim, Chandrapur, Aurangabad, Jalna, Beed	Nagpur, Latur, Parbhani	Nanded, Akola, Gondia
Uttarkhand	Chamoli, Almora, U. S. Nagar, Pithoragarh, Bageshwar	Haridwar, Rudraprayag, Uttarkashi	Tihri, Nanital	-	Dehradun, Champawat
West Bengal		Hooghly	Nadia		
Bihar	-	-	Araria, Shiekhpura, Samastipur, Nalanda, Muzaffarpur	Katihar	Arwal, Rohtas Kishanganj Patna, Purnea
Andhra Pradesh	-	Ranga Reddy, Krishna Nagar, W. Godawari	Anantpur, YSR- Kadapa, Mehbub Nagar, Nizamabad, Guntur	-	Kurnool, Karim Nagar, Nalgonda

2.2 Extent of deficiency of micronutrients in soils of various states

2.2.1 Cationic micronutrients

The deficiency of DTPA- micronutrients varies widely among soil types, agro climatic conditions, types of crops grown and other agronomic practices. Overall, 39.1 per cent of 70, 759 samples collected across the country were found to be deficient in available Zn. As evident from Table 2.3 deficiency of Zn in different states varied among states with a minimum of 8.5% in West Bengal to as high as 62.2% in Tamil Nadu. Besides Tamil Nadu, Zn deficiency in states like Madhya Pradesh (60.3), Maharashtra (60.3) and Bihar (44.2), was reported more than 40%. Almost one third of the soils of Gujarat and Uttar Pradesh were found to be deficient in available Zn while about every fourth sample was low in available Zn content in states like Assam, Andhra Pradesh and Punjab. Deficiency of Zn was less than 10 per cent reported in Uttarkhand and West Bengal.

Though overall Fe deficiency in India stayed close to 13% but in some of the states like Gujarat (23.6%), Maharashtra (22.8%), Haryana (21.6%) and Andhra Pradesh (17.3%) its deficiency is increasing rapidly. Manganese deficiency in the country was found to be 5.0% but its deficiency is alarming in Punjab (26.8%), Tamil Nadu (8.9%). While, overall Cu deficiency (4.3%) is close to the Mn however, it is a cause of concern in the states like Tamil Nadu and Uttar Pradesh where 13.1 and 6.3%, samples were found deficient in Cu.

Table 2.3: Status of DTPA-micronutrients deficiency in different states

State	No. of soil samples	Percent Samples Deficient			
		Zn	Fe	Mn	Cu
Andhra Pradesh	9,780	22.8	17.3	2.9	1.5
Assam	5,146	27.4	8.6	0.0	3.9
Bihar	2,963	44.2	5.8	2.9	2.7
Gujarat	5,218	34.2	23.6	6.6	0.4
Haryana	5,673	15.3	21.6	6.1	5.2
Madhya Pradesh	6,713	60.3	9.8	1.6	0.2
Maharashtra	7,819	53.7	22.8	4.0	0.2
Odisha	2,621	20.5	1.7	1.0	0.3
Punjab	1,098	21.9	5.8	26.8	3.5
Tamil Nadu	14,557	62.2	9.5	8.9	13.1
Uttar Pradesh	4,788	33.1	7.6	6.5	6.3
Uttarakhand	2,212	9.8	1.7	5.5	1.4
West Bengal	2,171	8.5	0.8	1.7	1.1
Total	**70,759**	**39.9**	**12.9**	**6.0**	**4.3**

Table 2.4: Different categories of Per cent Sample Deficiency of Zinc and Districts of different states falling under categories

State	Categories of Zn deficiency (Per cent Sample Deficiency)				
	<10	10-20	20-30	30-40	>40
Tamil Nadu	—	—	Nagapattinam	Kanyakumari	Virudhunagar, Theni, Cuddalore, Krishnagiri, Villupuram, Toothukudi, Pudukkotai
Gujarat	Dahod Gandhinagar	Kheda, Panchmahals, Vadodara	Anand	—	Mehsana, Banaskantha, Sabarkantha, Ahmedabad, Patan, Kutch, Bharuch
Assam	—	—	Sibsagar, Lakhimpur, Morigaon, Golaghat, Barpeta, Sonitpur, Nagaon, Darang, Tinsukia	Jorhat, Dibrugarh, Kamrup	—
Uttar Pradesh	Varanasi	Etawah	Farrukhabad Kannauj	Gorakhpur, Sitapur, Agra, Kanpur, Lakhimpur kheeri	Unnao, Ramabai nagar, Rai bareli, Pilibheet Allahabad
Odisha	Puri, Nayagrah, Sambalpur, Bargarh, Kendrapada, Kandhmal, Naupada, Jagatsinghpur	Dhenkanal, Kalahandi	Bhadrak	Sonepur	Boudh, Angul
Haryana	Kaithal, Kurukshetra, Faridabad, Yamuna nagar, Rewari, Sonipat, Ambala, Panchkula, Jind, Palwal	Sirsa, Fatehabad, Hisar, Mewat, Karnal, Rohtak, Jhajjar, Gurgaon	Panipat	Mohinder-garh, Bhiwani	—

Madhya Pradesh	—	—	Indore	Sehore	Chattarpur, Reewa, Satna, Dewas, Balaghat, Panna, Chindwara, Mandla, Seoni, Bhopal, Katni, Jabalpur, Narsingpur, Shahdol, Raisen, Tikamgarh, Morena
Punjab	Faridkot, Jalandhar	Bhatinda, Taran tarn	Ropar	Gurudaspur	—
Maharash-tra	—	Gondia	Osmanabad	Nanded, Nagpur, Latur	Wardha, Hingoli, Akola, Bhandra, Buldhana, Yavatmal, Washim, Beed, Amravati, Chandrapur, Aurangabad, Jalna,Parbhani
Uttara-khand	Chamoli, Tihri, Almora, Champawat, Pithoragarh, Bageshwar, Rudraprayag	Haridwar, Dehradun, Nanital, Uttarkashi	U. S. Nagar	—	—
West Bengal	Hooghly, Jalpaiguri, Nadia, Coochbehar, Burdwan	—	Pargana, N. Dinajpur	—	—
Bihar	—	—	—	Rohtas, Shiekhpura, Samastipur	Katihar, Arwal, Kishanganj, Patna, Purnea, Araria, Nalanda, Muzaffarpur
Andhra Pradesh	Nalgonda E. Godavari	YSR- Kadapa, Ranga Reddy, Nizamabad, Guntur, Medak, Krishna Nagar, W. Godawari, Prakasham, Vishakhapattnum	Mehbub Nagar Karim- Nagar Srikakulam	Kurnool	Anantpur Adilabad

Table 2.5: Different categories of Per cent Sample Deficiency of Iron and Districts of different states falling under categories

State	Categories of Fe deficiency (Per cent Sample Deficiency)				
	>5	5-10	10-15	15-20	>20
Tamil Nadu	Nagapattinam, Toothukudi, Pudukkotai	Theni, Cuddalore, Kanyakumari	—	Virudhunagar, Krishnagiri, Villupuram	—
Gujarat	—	Sabarkantha, Panchmahals, Bharuch	—	Dahod	Mehsana,Anand Banaskantha, Ahmedabad, Kheda, Vadodara, Gandhinagar, Patan, Kutch
Assam	Jorhat, Sibsagar, Lakhimpur, Morigaon, Dibrugarh, Golaghat, Barpeta, Sonitpur, Nagaon, Darang, Tinsukia	—	Kamrup		—
Uttar Pradesh	Varanasi, Sitapur, Kanpur, Ramabai nagar, Allahabad	Etawah, Gorakhpur, Agra, Unnao, Rai bareli, Pilibheet	Kannauj, Lakhimpur kheeri	Farrukhabad	—
Odisha	Puri, Boudh, Nayagrah, Sambalpur, Dhenkanal, Sonepur, Kendrapada, Kandhmal, Naupada, Bargarh, Angul, Jagatsinghpur	Bhadrak	Kalahandi	—	—
Haryana	Kaithal, Kurukshetra, Faridabad, Yamuna nagar, Mewat, Rewari, Panipat, Ambala, Sonipat, Gurgaon, Panchkula	Karnal, Jind, Palwal	Jhajjar	—	Sirsa, Hisar, Mohindergarh, Fatehabad, Bhiwani, Rohtak
Madhya Pradesh	Reewa, Dewas, Balaghat, Chindwara, Mandla, Seoni, Katni, Shahdol, Sehore, Tikamgarh	Chattarpur, Satna, Jabalpur	Indore, Raisen, Morena	Panna	Bhopal, Narsingpur

Maharashtra	Osmanabad, Bhandra, Latur, Gondia, Nagpur, Buldhana, Yavatmal,	Hingoli	Nanded	—	Wardha, Akola, Washim, Beed, Amravati, Chandrapur, Aurangabad, Jalna, Parbhani
Uttarkhand	Haridwar, Chamoli, Tihri, Dehradun, Almora, Champawat, U. S. Nagar, Nanital, Pithoragarh, Bageshwar, Rudraprayag, Uttarkashi	—	—	—	—
West Bengal	Hooghly, Pargana, Nadia, Coochbehar, Burdwan, N. Dinajpur	Jalpaiguri	—	—	
Bihar	Katihar, Arwal Kishanganj, Purnea, Araria, Rohtas, Shiekhpura, Nalanda	Patna, Muzaffarpur	—	—	Samastipur
Andhra Pradesh	E. Godavari, Srikakulam	Ranga Reddy, Krishna Nagar, Medak, Nalgonda	YSR Kadapa, Mehbub Nagar, Guntur, Karim Nagar, W. Godawari	Adilabad, Vishakhapattnum	Anantpur, Kurnool, Nizamabad, Prakasham
Punjab	Ropar, Gurudaspur, Jalandhar, Taran tarn	Faridkot	—	—	Bhatinda

Table 2.6: Different categories of Per cent Sample Deficiency of Manganese and Districts of different states falling under categories

State	Categories of Fe deficiency (Per cent Sample Deficiency)				
	>5	5-10	10-15	15-20	>20
Tamil Nadu	Nagapattinam, Virudhunagar, Theni, Cuddalore, Pudukkotai, Toothukudi, Kanyakumari	Kris hnagiri	—	—	Villupuram
Gujarat	Mehsana, Banaskantha Sabarkantha, Dahod, Bharuch Panchmahals, Gandhinagar,	Ahmedabad, Kutch, Anand	Kheda, Vadodara, Patan	—	—
Assam	Jorhat, Sibsagar, Lakhimpur, Morigaon, Dibrugarh, Golaghat, Barpeta, Sonitpur, Nagaon, Darang, Kamrup, Tinsukia	—	—	—	—
Uttar Pradesh	Varanasi, Gorakhpur, Sitapur, Agra, Kanpur, Unnao, Ramabai nagar, Rai bareli, Allahabad	Kannauj, Pilibheet	Etawah	Farrukhabad, Lakhimpur kheeri	
Odisha	Puri. Boudh, Nayagrah, Sambalpur, Dhenkanal, Sonepur, Kendrapada, Kandhmal, Bhadrak, Naupada, Kalahandi, Bargarh, Jagatsinghpur, Angul	—	—	—	—
Haryana	Kaithal, Faridabad, Yamuna nagar, Mewat, Mohindergarh, Rewari, Panipat, Sonipat, Ambala,	Sirsa, Kurukshetra	Bhiwani	His ar, Karnal	Fatehabad
Bihar	Katihar, Arwal, Patna, Araria, Rohtas, Shiekhpura, Nalanda, Muzaffarpur	Kishanganj, Purnea, Samastipur	—	—	—

Maharashtra	Hingoli, Nanded, Osmanabad, Bhandra, Gondia, Buldhana, Yavatmal, Washim, Chandrapur, Jalna, Nagpur, Parbhani, Latur	Wardha, Aurangabad, Beed	Akola, Amravati	—	—
Uttarkhand	Tihri, Dehradun, Almora, Champawat, U. S. Nagar, Nanital, Pithoragarh, Bageshwar, Uttarkashi	Haridwar	Chamoli	—	Rudraprayag
West Bengal	Hooghly, Pargana, Nadia, Coochbehar, Burdwan, N. Dinajpur	Jalpaiguri	—	—	—
Madhya Pradesh	Chattarpur, Reewa, Satna, Dewas, Balaghat, Chindwara, Mandla, Seoni, Bhopal, Katni, Jabalpur, Indore, Narsingpur, Shahdol, Raisen, Sehore, Tikamgarh, Morena	Panna	—	—	—
Andhra Pradesh	Anantpur, YSR-Kadapa, Mehbub Nagar, Karim Nagar, Guntur, Krishna Nagar, Nalgonda, Adilabad, E. Godavari, Prakasham, Vishakhapattnum, Srikakulam, Medak	Kurnool, Nizamabad, W. Godawari	—	—	Ranga Reddy
Punjab	Ropar, Jalandhar	—	—	Tarantaran	Faridkot, Gurudaspur, Bhatinda

Table 2.7: Different categories of Per cent Sample Deficiency of Copper and Districts of different states falling under categories

States	Categories of Cu deficiency (Per cent Sample Deficiency)		
	<5	5-10	>10
Tamil Nadu	Virudhunagar, Krishnagiri, Cuddalore	—	Theni, Villupuram, Pudukkotai, Kanyakumari
Gujarat	Mehsana, Dahod, Kheda, Patan Banaskantha, Vadodara, Kutch Sabarkantha, , Ahmedabad, Anand,Panchmahals,Gandhinagar,Bharuch	—	—
Assam	Lakhimpur, Morigaon, Dibrugarh, Golaghat, Barpeta, Sonitpur, Nagaon, Darang, Kamrup, Tinsukia	—	Jorhat, Sibsagar
Uttar Pradesh	Varanasi, Gorakhpur, Sitapur, Ramabai nagar, Agra, Kanpur, Pilibheet Allahabad	Etawah, Unnao, Rai bareli	Farrukhabad, Kannauj, Lakhimpur kheeri
Odisha	Puri, Boudh, Nayagrah, Bargarh Sambalpur, Dhenkanal, Sonepur, Kendrapada, Kandhmal, Bhadrak Naupada, Kalahandi, Angul, Jagatsinghpur	—	—
Haryana	Sirsa, Kaithal, Mewat, Bhiwani Kurukshetra, Fatehabad, Sonipat Mohindergarh, Panipat, Karnal, Ambala, Panchkula, Rohtak, Rewari Jhajjar, Jind Palwal	Hisar, Yamuna nagar	—
Madhya Pradesh	Chattarpur, Reewa, Satna, Dewas, Balaghat, Panna, Chindwara, Raisen Mandla, Seoni, Bhopal, Jabalpur, Indore, Narsingpur, Shahdol Katni	—	Sehore, Tikamgarh, Morena
Punjab	Ropar, Faridkot, Gurudaspur, Jalandhar, Taran tarn	—	Bhatinda
Maharashtra	Wardha, Hingoli, Nanded, Osmanabad Akola, Bhandra, Gondia, Buldhana, Yavatmal, Washim, Amravati, Chandrapur, Aurangabad, Jalna, Nagpur, Beed, Parbhani, Latur	—	—
Uttarakhand	Haridwar, Chamoli, Tihri, Dehradun Almora, Champawat, U.S. Nagar, Nanital, Pithoragarh, Bageshwar, Rudraprayag, Uttarkashi	—	—
West Bengal	Hooghly, Pargana, Nadia, Cooch behar, Burdwan, N. Dinajpur	—	Jalpaiguri
Bihar	Katihar, Kishanganj, Patna, Purnea, Araria, Rohtas, Shiekhpura, Samastipur, Nalanda, Muzaffarpur	—	Arwal
Andhra Pradesh	Anantpur, Kurnool, YSR Kadapa, Mehbub Nagar, Ranga Reddy, Guntur, Nizamabad, Karim Nagar, Krishna Nagar,Nalgonda, Adilabad, Medak, E. Godavari, Prakasham, Srikakulam Vishakhapattnum	West Godawari	—

2.2.2 Frequency distribution of Zn status in soils of different states of India

In order to have a clear picture about the frequency distribution DTAP-Zn in soils of different states and zones the status of delineated area were worked out in different categories. A critical analysis of the data in table 2.8 suggested that maximum percentage of samples fall in the category 0.6-1.2 mg Zn kg^{-1} soil. This further indicated that if not managed properly these soils will come down to the Zn deficient category sooner than later.

Table 2.8: Frequency distribution of Zn status in soils of different states of India

Name of state	Categories of DTPA- extractable Zn mg kg^{-1} (per cent soil in category)				
	<0.2	**0.20 -0.4**	**0.4 -0.6**	**0.6 -1.2**	**>1.2**
Assam	0.2	5.2	21.9	61.1	11.5
North East India	**0.2**	**5.2**	**21.9**	**61.1**	**11.5**
Bihar	4.7	12.6	18.4	37.4	27.0
Odisha	2.0	6.8	9.0	31.2	50.9
West Bengal	9.3	3.5	3.3	31.3	52.5
East India	**5.0**	**8.3**	**11.3**	**33.7**	**41.6**
Punjab	4.6	5.1	12.2	27.8	50.3
Haryana	0.5	4.8	10.3	30.1	54.4
Uttar Pradesh	0.5	13.4	19.2	33.5	33.5
Uttarakhand	0.4	2.9	6.5	24.8	65.4
North India	**0.8**	**7.7**	**13.2**	**30.4**	**48.0**
Madhya Pradesh	12.1	26.2	21.6	27.1	12.9
Maharashtra	3.4	24.1	25.4	32.0	15.1
Gujarat	3.4	11.3	18.6	38.0	28.7
West India	**5.9**	**19.8**	**21.7**	**32.9**	**19**.7
Tamil Nadu	2.6	12.3	15.6	31.9	37.6
Andhra Pradesh	1.6	7.3	15.7	45.7	29.7
South India	**2.2**	**10.3**	**15.6**	**37.5**	**34.4**
Overall	***3.2***	***12.3***	***17.1***	***35.9***	***31.5***

In north India, less than 1% soil samples fall in the category of 0.2 mg kg-1 while in east and west India more than 5% soils samples fall in the this category. In ≥0.2- ≤0.4 category, the highest no. of samples fall in Western India (19%) while lowest 5.2% in north eastern parts. About 30-35% samples in ≥0.4- ≤0.6 category in all the regions except in north east India, where more than 60% samples fall under this category.

2.2.3 Boron

Owing to B deficiency in soils, yield of almost all the crops grown in states like Odisha, West Bengal, Gujarat and Bihar is generally low despite application of recommendation N, P, K and Zn. From the results of 52,423 samples analyzed for available B, deficiency of B in highly calcareous soils of Bihar, Odisha and Gujarat are more common (Fig 2.2). Little more than half of the samples analyzed from Odisha state fell in the category of low B availability followed by West Bengal (46.3%), Gujarat (35.1%), Bihar (33.2%), and Assam (17.7%). Interestingly, in Uttar Pradesh also 16.2% soils were found to be low in B availability which was little higher than another intensively cultivated state Tamil Nadu (10.2%).

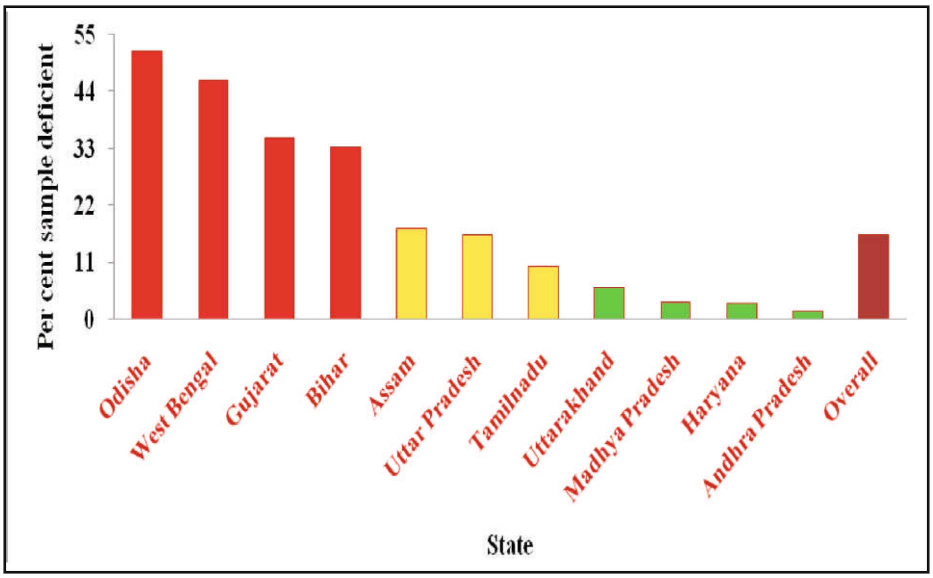


Fig 2.2: Deficiency status of Boron in soils of different states of country

Table 2.9: Different categories of Per cent Sample Deficiency of Boron and Districts of different states falling under categories

State	Categories of B deficiency (Per cent Sample Deficiency)				
	<10	10-20	20-30	30-40	> 40
Tamil Nadu	Nagapattinam, Cuddalore, Villupuram, Toothukudi	Virudhunagar, Theni	Krishnagiri, Kanyakumari	Pudukkotai	—
Gujarat	Dahod, Kheda	—	—	Banaskantha, Ahmedabad, Vadodara, Kutch, Anand, Bharuch	Mehsana, Sabarkantha, Panchmahals, Gandhinagar and Patan
Assam	Kamrup	Sibsagar, Golaghat, Morigaon, Barpeta, Sonitpur, Nagaon, Darang, Tinsukia	Jorhat, Lakhimpur, Dibrugarh	—	—
Bihar	—	Purnea, Araria	Katihar, Shiekhpura, Samastipur	Arwal, Kishanganj, Nalanda	Patna, Rohtas, Muzaffarpur

Uttar Pradesh	Farrukhabad, Etawah	Gorakhpur, Kannauj, Kanpur, Lakhimpur kheeri, Unnao, Allahabad, Pilibheet, Ramabai nagar	Raibareli	—	—
Odisha	Jagatsinghpur	Kalahandi	Bhadrak and Bargarh	Nayagrah, Kendrapada and Naupada	Puri, Boudh, Sambalpur, Dhenkanal Sonepur, Angul, Kandhmal
Haryana	Sirsa, Kaithal, Fatehabad, Hisar, Mewat, Jhajjar, Yamuna nagar, Mohindergarh Rewari, Sonipat, Bhiwani, Ambala, Panchkula, Jind Rohtak, Palwal	Faridabad Gurgaon	—	—	—
Madhya Pradesh	Chattarpur, Satna, Reewa, Dewas, Panna, Mandla, Chindwara, Raisen, Sehore, Tikamgarh, Morena	Balaghat	—	—	—
Uttarakhand	Chamoli, Haridwar, Almora, Dehradun, Nanital, Champawat, U. S. Nagar, Bageshwar, Rudraprayag	Pithoragarh, Uttarkashi	—	—	Tihri
West Bengal	—	—	Hooghly	—	—
Andhra Pradesh	Anantpur, Kurnool, Guntur, YSR- Kadapa, Mehbub Nagar, Ranga Reddy, Nizamabad, Karim Nagar, Krishna Nagar, W. Godawari	—	—	—	Nalgonda

2.2.4 *Multiple nutrients*

Besides individual nutrients deficiency, deficiencies of multiple micronutrients in crops in Indian soils due to depletion in fertility are an emerging issue in agriculture. Within a time frame of last two decades multiple nutrient deficiencies were reported in crops for Zn+S, Zn+B, Zn+Cu, S+B, Zn+Fe, Zn+Mn, Fe+Mn, Zn+S+B, Zn+Fe+Mn (Table 2.10). Multinutrient deficiencies are emerging for Zn + S in Bihar, Madhya Pradesh, Maharashtra, Gujarat and Uttar Pradesh while for Zn+B in same states including Odisha. Multi-micronutrient deficiencies for Zn+Cu, Zn+Fe, Zn+Mn and Fe+Mn are observed at more localized level which might be much more common than based on only Zn, Fe, Mn and Cu in future. The Zn + B deficiency was found more prevalent in acid leached Alfisols, red and Lateritic soils of India

Table 2.10: Status of multi-micronutrients deficiency in different states of India

Name of State	Zn+S	Zn+B	Zn+Cu	S+B	Zn+Fe	Zn+Mn	Fe+Mn
Andhra Pradesh	6.51	8.81	10.41	1.76	6.77	6.52	1.46
Assam	13.65	13.24	0.31	16.27	9.33	3.07	2.99
Bihar	6.74	6.72	1.52	4.12	3.01	0.00	0.00
Gujarat	13.09	6.80	2.46	5.83	2.99	2.34	1.98
Haryana	5.84	11.03	0.15	16.18	0.31	0.23	0.04
Madhya Pradesh	6.49	0.74	2.22	1.76	6.40	1.82	1.99
Maharashtra	16.62	2.13	0.13	1.20	7.57	1.34	0.03
Odisha	NA	NA	1.55	NA	1.37	8.56	2.82
Punjab	14.22	NA	0.10	NA	13.03	2.90	2.49
Tamil Nadu	2.22	0.68	0.68	0.99	0.36	0.99	0.59
Uttar Pradesh	2.84	1.09	0.55	23.36	0.00	0.51	0.23
Uttarakhand	20.15	15.93	1.05	16.30	2.73	1.86	0.54
West Bengal	6.64	0.10	0.59	0.57	6.45	0.86	0.77
Overall	9.76	6.68	2.84	5.81	6.22	2.70	1.29

Even though the deficiency of Zn+S+B is not more than 1%, in most of the states but in states like Bihar, Gujarat the severity of deficiency is more than 5% (Fig 2.3). Similarly, for Zn+Fe+Mn also the deficiency in most of the states is 1% but its status in Maharashtra and Haryana is on the higher side (Fig 2.4).

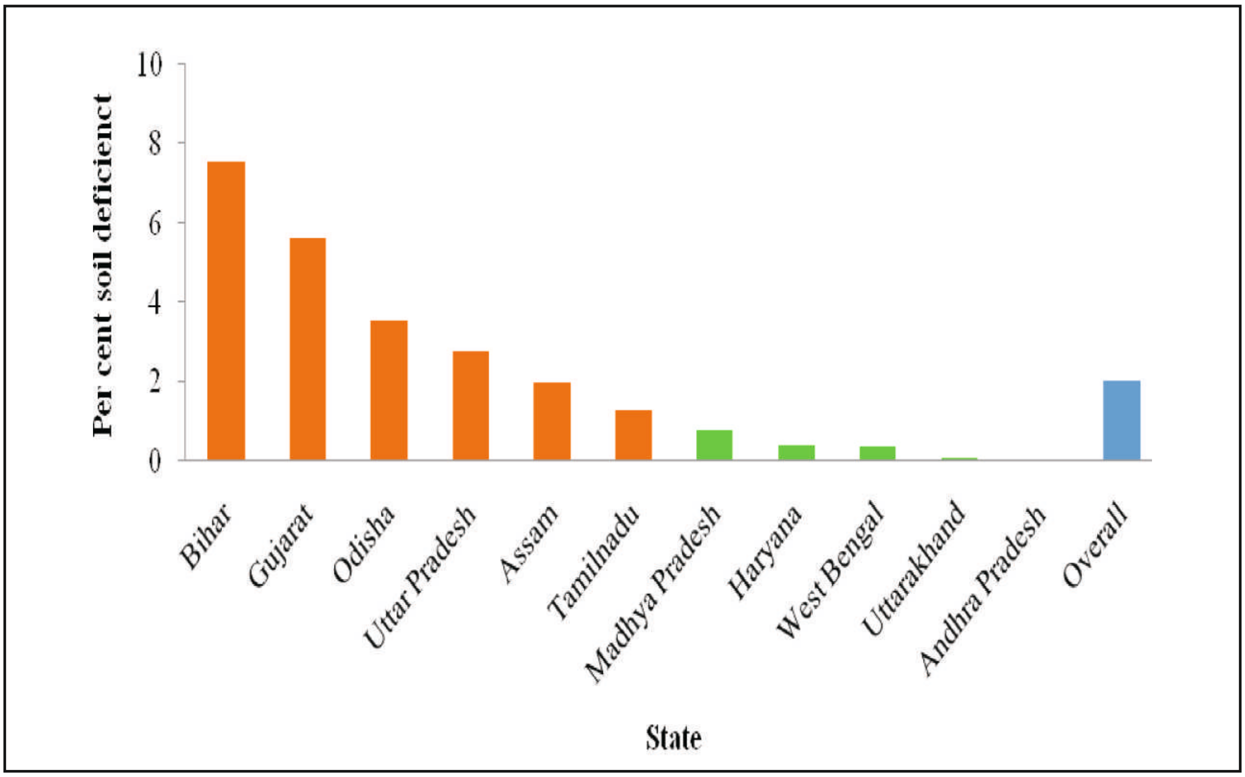


Fig 2.3: Multiple nutrients deficiency status for Zn+S+B in soils of different states of country

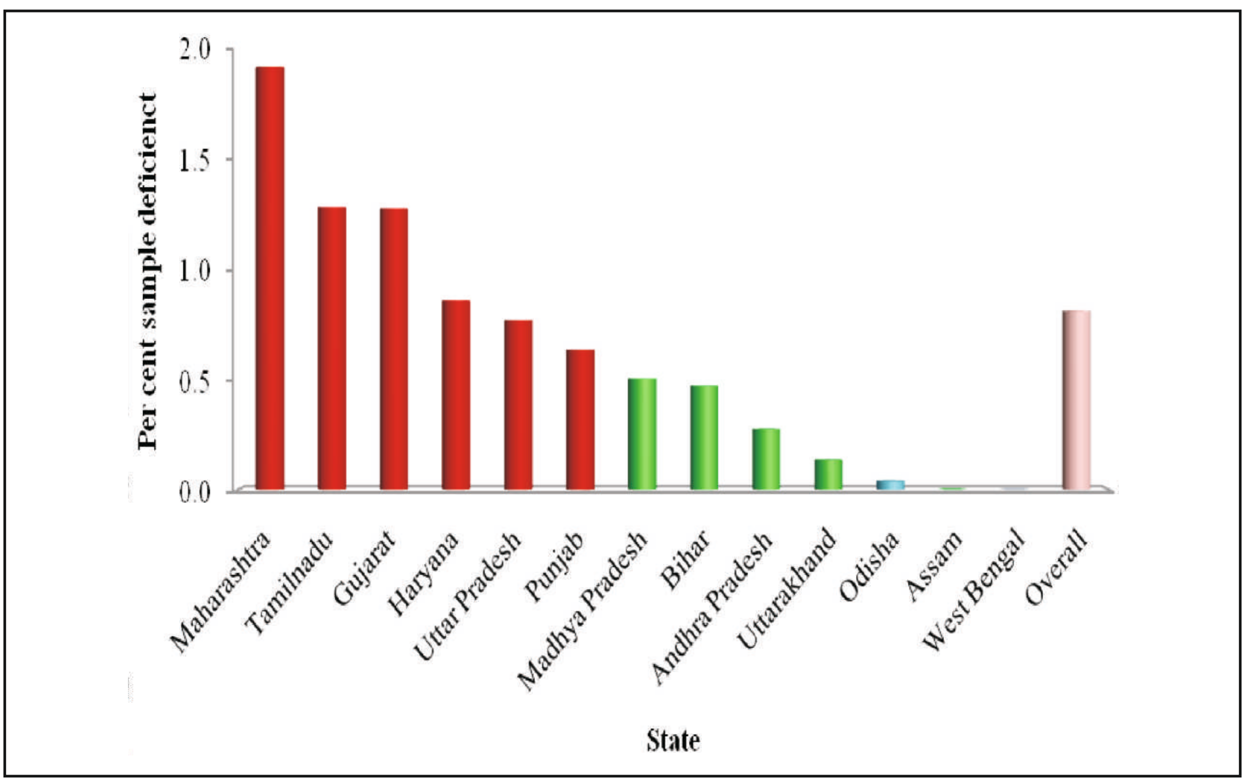


Fig 2.4: Multiple nutrients deficiency status for Zn+Fe+Mn in soils of different states of country

CHAPTER –III

RESPONSE OF CROPS TO MICRO- AND SECONDARY NUTRIENTS APPLICATION

Fertilizer response trials are most important tools to monitor the nutrient deficiencies in soils and plants as they confirm the actual state of the nutritional disorders in soil and plants and the levels of benefits which can be accrued on the application of said element to be deficient. In order to demonstrate the magnitude of deficiency or response of the crops to micro and secondary nutrients, all the centres of AICRP-MSPE conducted experiments on research farms as well as farmer's fields. The data obtained in these experiments are summarized below.

3.1 Response to zinc (Zn) application

Generally, deficiency of micronutrients is noticed due to intensive cultivation of high yielding varieties of various crops coupled with non-inclusion of micronutrients in fertilizer schedule. Consequently, efficiency of major nutrients is reduced due to micronutrients deficiency which in turn results into decline in crop productivity. Centres of AICRP-MSPE conducted several on farm trils to demonstrate benefits accrued from Zn application in a range of crops. Results of on-farm trials conducted by Akola centre Vidarbha region of the Maharashtra indicated 7.4-9.0 per cent increase in the rice grain yield on Zn deficient soils following soil application of $ZnSO_4$ @ 50 kg ha^{-1} over control. The yield was further increased by 390 kg ha^{-1} with additional 50 kg $ZnSO_4$ ha^{-1} (Table 3.1).

The scale of increase in grain yield of wheat (WH-711) in response to Zn application @ 5.0 and 10.0 kg ha^{-1} at two locations in Haryana was found to be 6.30 and 11.61%, respectively. While in Vidarbha (over 5 locations), 4.8 per cent increase in wheat grain yield was noticed with soil application of $ZnSO_4$ @ 100 kg ha^{-1} over $ZnSO_4$ @ 50 kg ha^{-1}. Farmers were advised to use Zn fertilizer in deficient soil at 3 years interval.

Coimbatore centre conducted field experiments in Coimbatore district to demonstrate the response of Maize to Zn fertilization in Zn deficient soils. The results obtained on the yield at all four locations showed that addition of 25 kg $ZnSO_4$ ha^{-1} as soil application along with recommended NPK recorded the highest grain yield (8546 kg ha^{-1}) irrespective of locations. The yield increase was 24.02 per cent for soil application and 10.77 per cent for foliar addition of Zn to maize. Addition of $ZnSO_4$ significantly increased the soil Zn status to sufficient level (1.27 mg kg^{-1}) however foliar spray of Zn failed to increase the soil Zn availability.

The results showed that soil application of Zn @ 5 kg ha^{-1} in combination with the recommended dose of N, P, K was found to be beneficial in increasing grain yield of green gram to 1.03 t ha^{-1} over control (0.85 t ha^{-1}) in Zn deficient soils besides enhancing Zn content and uptake in grain and haulm. Foliar spraying of Zn was also found effective in alleviating soil Zn deficiency and increasing the yield of green gram.

Table 3.1: Responses of crops to zinc application (grain yield)

Location	Akola				Hisar		Coimbatore			
Crop	Paddy (5)		Wheat (5)		Wheat (2)		Hybrid maize (4)		Green gram (1)	
Treatments	Average Yield (t ha^{-1})	% response (range)	Average Yield (t ha^{-1})	% response (range)	Average Yield (t ha^{-1})	% response (range)	Average Yield (t ha^{-1})	% response (range)	Average Yield (t ha^{-1})	% response (range)
Control	3.90	-	2.05	-	3.90	-	6.89	-	0.85	-
Soil application ($ZnSO_4$ @ 25 kg ha^{-1})	-	-	-	-	4.15	6.30	8.55	24.02	1.03	21.17
Soil application ($ZnSO_4$ @ 50 kg ha^{-1})	4.22	8.2 (7.4-9.0)	2.31	12.8 (8.0-16.4)	4.55	11.61	-	-	-	-
Soil application ($ZnSO_4$ 100 kg ha-^{1})	4.39	11.5 (10.1-13.2)	2.42	18.0 (11.0-24.0)	-	-	-	-	-	-
Soil application + 0.50 % $ZnSO_4$ foliar spray thrice	-	-	-	-	-	-	7.63	10.77	0.91	7.05

Value in parenthesis next to crop indicates number of trials.

3.2 Response to iron (Fe) application

Three field demonstrations were conducted in the farmer's fields at Coimbatore district by Coimbatore Centre to demonstrate the response of Maize to Fe fertilization in Fe-deficient soils. The yield increase ranged from 16.23 to 25.97 per cent as mean grain yield was varied from 6766 to 8523 kg ha^{-1}. Similar results were noticed with stover yield also and the yield was varied from 8720 to 10855 kg ha^{-1}. Although foliar application of Fe increased the grain and stover yield of maize over NPK check, the effect was not marked as that of soil application. Soil application of $FeSO_4$ improved the post-harvest soil Fe availability while the foliar spray did not have marked effect on Fe availability in all locations. Similarly, the results of FLDs in green gram and groundnut to Fe fertilization on Fe deficient soils of Coimbatore district revealed that soil application of $FeSO_4$ @ 50 kg ha^{-1} in combination with the recommended dose of N, P, K is found to be beneficial. Increase in the grain and haulm yield of green gram by 20.0 per cent and 35 per cent in Groundnut over control were recorded. However, foliar spraying of $FeSO_4$ was found ineffective in alleviating Fe deficiency. Soil application of $FeSO_4$ @ 50 kg ha^{-1} also increased the DTPA-Fe over foliar spray and control (Table 3.2).

Table 3.2: Grain yield of crops as influenced by Fe application

Location	Coimbatore			
Crop	**Maize Hybrids (3)**		**Green gram (1)**	
Treatment	**yield (t ha^{-1})**	**% response**	**yield (t ha^{-1})**	**% response**
No Fe	6.766	-	711	-
50 kg $FeSO_4$ ha^{-1} as basal	8.523	25.97	891	25.31
1.0 % $FeSO_4$ foliar spray thrice	7.864	16.23	763	7.31

Value in parenthesis next to crop indicates number of trials.

3.3 Response to manganese (Mn) application

The results of four field experiments conducted in Fatehabad district on manganese application in wheat, conducted by Hisar centre revealed that response of Mn in wheat was to the tune of 13.26% at 50 kg $MnSO_4$ ha^{-1} level and 15.40 % at three foliar sprays of 0.5% MnSO4. The Mn uptake was also found maximum with foliar application and a B: C ratio of 5.32:1 was observed at 0.5 % foliar spray of $MnSO_4$ (Table 3.3).

Table 3.3: Response of Mn in wheat (mean of 4 trials)

Treatment	Yield ($t\ ha^{-1}$)	Per cent Response	Mn uptake ($g\ ha^{-1}$)		B:C ratio
	Grain		Grain	Straw	
Control	3.93	—	71.28	63.99	—
50.0 ($kg\ ha^{-1}$)	4.32	13.26	105.23	107.85	1.57
0.5% foliar spray	4.53	15.40	138.49	155.42	5.32

Value in parenthesis next to crop indicates number of trials.

Seven experiments on wheat at cultivators' field were conducted by Ludhiana centre on severely deficient soils having available manganese ranging from 1.5 to 2.1 mg kg^{-1} (less than 2.5 mg kg^{-1} to test the validity of the recommendation that minimum four sprays are required for getting the maximum yield. The grain yield of wheat in control treatment varied from 1.5 to 2.5 t ha^{-1} with the mean values of 2.03 t ha^{-1}. The grain yield of wheat ranged between 3.1 to 4.4 t ha^{-1} with mean value of 3.69 t ha^{-1} and 3.40 to 4.83 t ha^{-1} with a mean value of 4.03 t ha^{-1} at the application of three and four sprays of 0.5% $MnSO_4.H_2O$ solution (Table 3.4). The results thus revealed that in fields testing less than 2.5 mg Mn kg^{-1} soil, the average wheat grain yield obtained with 4 sprays was 0.34 t ha^{-1} higher than that with 3 sprays. The increase in grain yield with four sprays was on an average 9.5 percent higher compared to application of three sprays

Table 3.4: Effect of manganese application on wheat grain yield ($t\ ha^{-1}$) in soil of Punjab

Site	DTPA –Mn mg/kg soil	Grain yield ($t\ ha^{-1}$)			% response	
		No spray	3 sprays	4 sprays	3 sprays	4 sprays
Site1	1.5	1.9	3.6	4.0	89.5	110.5
Site 2	2.1	2.2	3.5	3.8	59.1	72.7
Site 3	1.8	2.2	3.1	3.6	40.9	63.6
Site 4	2.0	2.1	4.4	4.7	109.5	123.8
Site 5	1.5	1.8	3.1	3.4	72.2	88.9
Site 6	1.9	2.5	3.7	3.9	48.0	56.0
Site 7	1.6	1.5	4.4	4.8	193.3	222.0
Range		1.5 -2.5	3.1 -4.4	3.4 -4.8	40.9-193.3	56.0-222.0
Mean		2.0	3.7	4.1	94.1	112.8
SD±		0.33	0.54	0.54	-	-

3.4 Response to boron (B) application

In field experiment on paddy (HKR-47), conducted at Hisar showed no response to application B @ 0.5 and 1.0 kg ha^{-1}, (Table 3.5). A very little increment in grain yield was obtained amounting to just 0.50 and 0.29% increase over control yield. However, in 3 FLDs conducted at Hisar in B deficient soil of farmer's field the maximum yield of cauliflower curds was obtained with the application of 1.0 kg B ha^{-1} at one location and foliar spray of 0.25 % borax at another location (Table 3.5). The B uptake increased with increasing levels of B and maximum uptake was obtained with the application of 1.0 kg B ha^{-1}.

The results from a similar field experiment at Coimbatore centre showed that soil application of optimum Borax (11 kg ha^{-1}) to cauliflower in a B deficient soil recorded the higher cauliflower curd yield, fresh leaf biomass yield and curd diameter with a yield increase of 26.3 per cent over NPK check. Comparing the soil and foliar application of B, soil application of borax was the best in increasing the yield of cauliflower, B availability in soil and its uptake by plants (Table 3.5).

A field experiment was conducted by Ludhiana centre to study the response of boron applied through granubor on onion (var. PRO6) on a soil deficient in hot water soluble boron. The crops, though, did not show any visual symptoms of B deficiency in control plots the growth of the crop was poor compared with B treated plots. The bulb yield of onion crop increased with the application of boron at all levels of its application over control. This was expected because of the low content of available boron in the soil. But the significant increase in the bulb yield of garlic was noticed when B was applied at the rate of 1 kg ha^{-1} (Table 3.5). It increased from 26.32 t ha^{-1} to 30.38 t ha^{-1}, thus registering an increase of 15.4 percent over control. Increasing the application rates to 1.25 and 1.50 kg B ha^{-1} caused no significant change in bulb yield. It is evident from the results that the application of boron at the rate of 2 kg ha^{-1} through granubor rather decreased the bulb yield of onion compared to application rate of 1 kg ha^{-1}. The mean B concentration in onion bulb increased significantly from 14.42 $\mu g g^{-1}$ in control treatment to 16.58, 17.37, 19.63 and 20.5 $\mu g g^{-1}$ when boron was applied at the rates 1.0,1.25, 1.50 and 2 kg ha^{-1} through granubor. Highest total uptake of 604.6 g ha-[1] was recorded with application of boron at the rate of 2 kg ha^{-1}.

Table 3.5: Response of boron application on yield of crops

Location	Hisar		Coimbatore		Hisar				Ludhiana	
Crop	Paddy (1)		Cauliflower (1)		Cauliflower (3)		Okra (1)		Garlic (1)	
Treatment	Yield (t ha^{-1})	% response	Yield (t ha^{-1})	% response	Yield (t ha^{-1})	% response	Yield (t ha^{-1})	% response	Yield (t ha^{-1})	% response
Control	69.22	-	19.5	-	15.92	-	8.14		26.23	-
0.5 kg B ha^{-1}	69.57	0.50	-	-	16.40	3.02	8.60	5.65	27.01	2.62
0.75 kg B ha^{-1}	-	-	-	-	-	-	--	--	27.33	3.84
1.0 kg B ha^{-1}	69.52	0.29	25.0	26.26	18.00	13.07	8.86	8.85	30.38	15.43
1.25 kg B ha^{-1}	-	-	-	-	-	-	-	-	30.13	14.48
1.5 kg B ha^{-1}	-	-	-	-	-	-	-	-	30.27	15.01
2.0 kg B ha^{-1}	-	-	-	-	-	-	-	-	29.53	12.20
0.25 % foliar spray of borax (2)	-	-	-	-	17.60	10.55	8.50	4.42	-	-
1.0 kg B + Foliar spray of 0.2 % boric acid (3)	-	-	22.5	13.64	-	-	-	-	-	-

Value in parenthesis next to crop indicates number of trials.

In a field trial at Ludhiana showed that bulb yield of the onion increased with the application of boron through granubor fortified with DAP at all levels of its application over control (Table 3.6). But the significant increase in bulb yield of onion was observed with the application of boron with the treatment involving 0.60% B fortified with DAP. Mean bulb yield of onion increased significantly from 18.14 q ha^{-1} to 20.27 t ha^{-1} thus registering the mean bulb yield response of the onion to the tune of 2.13t/ha and per cent response which comes about to 10.5 percent. It is evident from the results that there was no decline in bulb yield of onion when applied through granubor fortified with DAP at all levels of its application.

Similar response in Bt cotton (RCH-134) was also observed as the data presented in Table 3.6 revealed that the response of cotton in terms of seed cotton yield, number of monopods, number of sympods to varying rates of boron supplied through granubor fortified with 30 kg P_2O_5 supplied through DAP was not observed even though the available content of boron in the soil was marginal. This may be attributed to due to additional supply of B through irrigation; therefore input of B from this source is to be considered before formulating the response doze.

Table 3.6 Effect of rates of B (fortified with DAP) on the bulb yield of onion and seed yield of cotton at Ludhiana

Treatment	Onion bulb yield (t ha^{-1})	% Response	seed yield of cotton	% Response
Control	18.14	__	2.28	__
0.10% fortified with DAP	18.12	-0.11	2.32	1.75
0.20% fortified with DAP	18.59	2.44	2.35	3.07
0.30% fortified with DAP	18.75	3.31	2.39	4.82
0.45% fortified with DAP	19.71	8.53	2.42	6.14
0.60% fortified with DAP	20.27	11.57	2.42	6.14
0.75% fortified with DAP	20.40	12.28	2.43	6.58
CD (5%)	1.74	—	NS	—

3.5 Response to sulphur (S) application

In Haryana several field trials were conducted at farmer's fields to observe the response of sulphur in wheat, gram, cotton and mustard. A mean response of 7.05 % in yield of wheat was obtained at 20 kg S ha^{-1} and 7.49 % at 40 kg S ha^{-1} level over control (Table 3.7). The uptake of S increased at each level of S application and B: C ratio was 8.36 at 20 kg S ha^{-1} level. While in case of mustard, the maximum response (26.81 %) to S application was observed at 40 kg ha^{-1} over control (Table 3.7). The uptake of S increased at both the levels in seed and straw of mustard over control and a B: C ratio of 9.60:1 was found at 40 kg S ha^{-1}.

The per cent response of S in grain yield of gram was found to be 17.15 and 36.15 % upon application of S at the rate of 20 and 40.0 kg S ha^{-1}, respectively. The uptake of S increased at each level of S application over control with a B: C ratio of 7.50:1 was found at 20 kg S ha^{-1}. Mean response of S at the two locations of cotton yield was of the magnitude of 8.07, 17.59 and 27.78 % with the application of 20.0, 40.0 and 60.0 kg S ha^{-1}, respectively (Table 3.7). The uptake of S in cotton as well as sticks increased at each level of S application at all the three locations over its preceding level.

Table 3.7: Response of sulphur application in wheat, mustard, gram and cotton at Hisar

S level	Grain/ seed yield (t ha^{-1})	% Response	Grain/ seed S uptake (kg ha^{-1})	B:C Ratio
Wheat (4 locations)				
Control	4.07		3.92	
10 kg S ha^{-1}	4.20	3.22	7.51	3.33
20 kg S ha^{-1}	4.36	7.05	12.56	8.36
40 kg S ha^{-1}	4.38	7.49	17.36	5.57
Mustard (2 locations)				
Control	1.533	-	0.09	-
20 kg S ha^{-1}	1.742	13.63	0.26	6.80
40 kg S ha^{-1}	1.944	26.81	0.39	9.60
Gram (1 locations)				
Control	0.921	----	0.23	----
20 kg S ha^{-1}	1.079	17.15	0.30	7.50
40 kg S ha^{-1}	1.254	36.15	0.38	7.00
Cotton (2 locations)				
Control	1.76	----	0.91	----
20 kg S ha^{-1}	1.90	8.07	1.54	7.90
40 kg S ha^{-1}	2.07	17.59	2.87	12.85
60 kg S ha^{-1}	2.30	27.78	4.83	16.60

3.6 Response to multi-micronutrients application

Centres of AICRP on MSPE conducted various trials to assess the response of different crops to multi-micronutrients application on farmers' field. In Pusa, results from trial conducted for correction of multi-nutrients deficiencies on mustard, lentil and chickpea revealed that S, Zn and B when applied in different combinations were slightly beneficial as compare to single nutrient application (Table 3.9). In all three crops, maximum response (19.0, 33.0 and 33.0%, respectively) was observed following application of 5.0 kg Zn + 40 kg S +1.5 kg B (Table 3.9) over Zn, B and S alone. Sulphur in combination either with Zn or B was more useful than S alone in these crops and secondly crops were also very responsive to B application in either of the combinations.

In a bid to demonstrate usefulness of multi-micronutrients supplementation, Pantnagar centre conducted FLDs in green gram, *toria* and lobia (Table 3.9). The results revealed that besides Zn being the most crucial nutrient for green gram, a response of 49.6 % were recorded when it was applied alone and application of S and B along with Zn resulted decrease in yield. Thus it is indicated that B and S was not needed for crop if soil is not severely deficient in these elements. However, addition Mo in fertilizer mixture showed added advantage over Zn, B and S application alone. In Toria also as high as 60.24% response was observed following application of Zn alone however, addition of Cu, S, and B along with Zn could not result in better yield rather response was reduced when S, B, Cu and Mo were added along with Zn. In lobia, application of S+B+Zn had synergistic effect over single nutrient application. However, in pigeon pea, negative response in yield were observed when S was applied but when combined with B+Zn and B+Zn+Mo the response were positive.

Similarly, in some vegetable crops at Pantnagar positive response of multi-micronutrients were demonstrated on farmers' fields. Boron was found to be the most important nutrient for vegetable crops namely tomato, cabbage and French bean as response of 6.8, 26.3 and 32.8%, respectively over control was observed in these crops (Table 3.8). Molybdenum in combination B+Zn was proved beneficial for the legume vegetable French bean but there was marginal improvement over single nutrients without having statistical significance. Over all these results suggest conducting systematic studies in future by following omission plot techniques. So that importance of multi-nutrients mixture could be assessed over single nutrients application.

Table 3.8: Response of different vegetable crops to multi-micronutrients application (economic yield in t ha^{-1})

Location	Pantnagar					
Crop	Tomato (1)		Cabbage (1)		French bean (1)	
Treatments (kg ha^{-1})	Fruit Yield	% response	Head Yield	% response	Seed Yield	% response
Control	30.54		33.1		2.93	
10 kg Borax	32.63	6.84	41.8	26.28	3.89	32.8
10 kg Borax + 25 kg ZnSO	33.64	10.15	34	2.72	3.5	19.5
10 kg Borax + 25 kg $ZnSO_4$+ 1 kg Amm. molybdate	31.76	3.99	39	17.82	3.21	9.6
0.2% borax spray (twice)	33.52	9.76	33.6	1.51	3.03	3.4
0.2% borax + 0.5% $ZnSO_4$ spray (twice)	30.58	0.13	-		2.72	-7.2
0.2% borax + 0.5% $ZnSO_4$ spray + 0.1% Amm. molybdate (twice)	31.36	2.69	-		3.38	15.4

Table 3.9: Response of different crops to multi-micronutrients application (economic yield in t ha^{-1})

Location	Pusa						Pantnagar							
Crop	Mustard (3)		Lentil (1)		Chickpea (1)		Green gram (1)		Toria (1)		Lobia (1)		Pigeon pea (1)	
Treatments (kg ha^{-1})	Seed Yield	% respo-nse	Grain Yield	% Resoi-nse	Grain Yield	% Respo-nse	Grain Yield	% Respo-nse	Grain Yield	% Respo-nse	Grain Yield	% Respo-nse	Grain Yield	% Respo-nse
Control	0.98	-	0.89	-	1.0	-	0.84	-	0.84	-	0.98	-	1.52	-
5.0 kg Zn	1.21	23.1	1.10	23.6	1.2	20.0	1.26	49.64	1.35	60.24	1.29	30.72	2.10	38.16
1.5 kg B	1.09	10.9	0.94	5.6	1.12	12.0	0.88	4.64	1.16	38.57	1.05	6.92	2.16	42.11
2.5 kg Cu	-	-	-	-	-	-	1.04	23.33	1.09	29.76	1.26	28.38	1.75	15.13
0.5 Kg Mo	-	-	-	-	-	-	1.04	23.33	1.11	32.02	1.18	20.35	1.58	3.95
40 kg S	1.09	10.9	1.01	12.9	1.05	5.0	0.95	13.10	1.09	30.00	1.06	8.24	1.50	-1.32
5.0 kg Zn + 40 kg S	1.32	34.4	1.29	44.9	1.30	30.0	1.28	51.79	1.12	33.57	1.07	9.26	1.38	-9.21
5.0 kg Zn + 1.5 kg B	1.32	34.7	1.20	34.8	1.35	35.0	1.06	26.67	0.89	5.48	1.29	31.23	1.31	-13.82
5.0 kg Zn + 40 kg S + 1.5 kg B	1.45	48.0	1.33	48.9	1.40	40.0	1.03	22.38	1.02	20.95	1.52	55.04	2.06	35.53
1.5 kg B + 40 kg S	1.38	30.95	1.15	29.2	-	-	-	-	-	-	-	-	-	-
5.0 kg Zn + 40 kg S + 1.5 kg B + 0.5 kg Mo	-	-	-	-	-	-	1.32	57.38	0.98	16.55	1.16	18.41	1.88	23.68
5.0 kg Zn + 40 kg S +1.5 kg B +2.5 kg Cu	-	-	-	-	-	-	0.86	1.79	1.14	35.48	1.06	7.63		
5.0 kg Zn + 40 kg S +1.5 kg B + 2.5 kg Cu+0.5 kg Mo	-	-	-	-	-	-	0.83	-1.31	0.80	-4.64	1.22	24.31		

Value in parenthesis next to crop indicates number of trials.

CHAPTER –IV

AMELIORATION OF MICRO- AND SECONDARY NUTRIENT DEFICIENCIES

Once the deficiency of a micronutrient is detected it becomes important to find out the best fertilizer material and technique to ameliorate the same. The choice of a corrective measure for combating micronutrient deficiency is largely determined by the nature of disorder, growth stage, condition and nutritional status of plant and soil. In order to ameliorate the deficiencies of micro- and secondary nutrients and to enhance the fertilizer use efficiency; centres of AICRP (MSPE) conducted several experiments to find out the best carrier, mode and time of their application to crops grown in different soils. The summary of these results is presented here.

4.1 Development of IPNS technology for ameliorating zinc deficiency in rice-rice cropping system

Two field experiments were carried out by Coimbatore centre during *kharif* and *rabi* seasons, 2010-2011 at Agricultural Research Station, Bhavanisagar. The treatments consisted of seven main plot treatments (FYM at 0, 2.5, 5.0, 7.5, 10.0, 12.5 and 15.0 t ha^{-1}) and five sub plot treatments ($ZnSO_4$ at 0, 12.5, 25.0, 37.5 and 50 kg ha^{-1}**).** It was inferred from the experimental results that the IPNS technology involving combined application of FYM at 12.5 t ha^{-1} with $ZnSO_4$ at 37.5 kg ha^{-1} to the main crop (*kharif)* alone had performed better in increasing significantly the cumulative rice productivity of 28672 kg ha^{-1} (grain + straw of two seasons) in rice-rice cropping system in a zinc deficient soil (Table 4.1).

This treatment combination had recorded the highest net return from the produce of two rice crops. Besides improving soil fertility status, a saving of 12.5 kg $ZnSO_4$ was observed by adoption of the above IPNS technology for rice- rice cropping system as whole, instead of applying 25 kg $ZnSO_4$ ha^{-1} for each crop.

Higher soil available Zn content after harvest of residual rice crop observed in the treatment plots received higher levels of FYM and $ZnSO_4$ indicates that soil might be able to contribute extended Zn supply to the succeeding crop (beyond two rice crops), which requires further study. For ameliorating Zn deficiency in soil, the above mentioned IPNS technology may be applicable for rice-rice cropping system of similar location specific conditions, to realize higher productivity and net returns to the farmers besides improving soil fertility. It is suggested to carry out similar field studies with selected treatments in other rice growing tracts, soil types, and rice cultivars for wider scale adoption of this IPNS option to curb Zn deficiency in rice soils.

4.2 Effect of Zn fertilizer application methods on yield and grain Zn concentration in Basmati rice-wheat crops

A field experiment on effect of Zn fertilizer application methods and phosphatic fertilizer by Basmati rice-wheat crops was set-up at Pantnagar. The main effect of P doses averaged over Zn levels failed to influence grain yields of Basmati rice significantly (Table 4.2). However, the main effect of Zn application influenced the grain yield of basmati rice significantly. The foliar spray of 2 kg Zn ha^{-1} at 30 and 60 days after planting increased the grain yield of basmati rice by 8.8 percent over the control. The interaction effect of P and Zn fertilizers had no statistically significant effect on the grain yield of basmati rice. However, the highest grain yield of basmati rice (3.29 q ha^{-1}) was recorded with the application of 40 kg P_2O_5 ha^{-1} and foliar application of Zn (2 kg ha^{-1}) at 30 and 60 d after transplanting. The straw yield of basmati rice was not influenced by either P or Zn application or

Table 4.1: Effect of FYM and $ZnSO_4$ on grain yield and Zn content in grain of *kharif* and *Rabi* rice in rice-rice cropping system at Coimbatore.

Treatment	Kharif rice						Rabi rice					
FYM, t ha^{-1}	Zinc levels (t ha^{-1})						Zinc levels (kg ha^{-1})					
	0	12.5	25.0	37.5	50	Mean	0	12.5	25.0	37.5	50	Mean
Grain yield (kg ha^{-1})												
0.0	5.59	5.73	5.83	6.02	6.18	5.87	4.72	4.85	5.18	5.42	5.26	5.09
2.5	5.72	5.89	6.12	6.13	5.97	5.97	4.88	4.93	5.22	5.51	5.31	5.17
5.0	5.82	5.93	6.04	6.19	6.14	6.02	4.93	5.16	5.26	5.58	5.38	5.26
7.5	5.98	6.07	6.25	6.28	6.21	6.16	5.21	5.28	5.37	5.52	5.44	5.36
10.0	6.04	6.21	6.47	6.35	6.32	6.28	5.27	5.32	5.48	5.62	5.61	5.46
12.5	6.11	6.74	6.55	6.37	6.26	6.41	5.32	5.38	5.56	6.03	5.64	5.59
15.0	6.09	6.61	6.52	6.32	6.12	6.33	5.34	5.41	5.58	5.71	5.51	5.51
Mean	5.91	6.17	6.25	6.24	6.17	6.15	5.06	5.15	5.35	5.61	5.44	5.35
CD (P=5%)	M	S	M at S		S at M		CD	M	S	M at S		S at M
	0.09	0.03	0.11		0.08		(P=5%)	0.08	0.3	0.12		.09
Grain Zn content (mg kg^{-1})												
0.0	24.6	25.3	26.1	28.3	27.3	26.3	21.6	22.3	23.0	24.9	24.0	23.2
2.5	25.1	25.6	26.3	28.6	27.7	26.7	22.1	22.6	23.1	25.2	24.4	23.5
5.0	25.9	26.3	26.7	28.7	27.8	27.1	22.8	23.2	23.5	25.3	24.5	23.8
7.5	25.9	26.6	27.3	29.4	28.3	27.5	22.8	23.4	24.0	25.9	24.9	24.2
10.0	26.5	26.7	27.7	29.5	28.6	27.8	23.3	23.5	24.4	26.0	25.1	24.5
12.5	27.1	26.9	28.2	30.0	29.5	28.4	23.9	23.7	24.9	26.4	26.0	25.0
15.0	26.9	26.8	27.8	29.8	29.0	28.1	23.7	23.6	24.5	26.3	25.6	24.7
Mean	26.0	26.3	27.2	29.2	28.3	27.4	22.9	23.2	23.9	25.7	24.9	24.1
CD (P=5%)	M	S	M at S		S at M		CD	M	S	M at S		S at M
	0.33	0.20	0.59		0.55		(P=5%)	0.29	0.18	NS		NS

M = FYM S= Zn

by the interaction effect of P and Zn significantly over the control.

The grain yield of subsequent wheat crop was significantly influenced by both P and Zn levels. The main effect of P indicated that application of 40 and 60 kg P_2O_5 ha^{-1} increased the grain yield of subsequent wheat crop by 9.7 and 8.2 percent over the control, respectively. Averaged over the P levels, the foliar application of 2.0 kg Zn ha^{-1} at 30 and 60 days after emergence increased the grain yield of wheat crop by 6.5 percent over the control. The interaction effect of Zn and P levels had no statistically significant effect on grain yield of wheat. The highest grain yield of wheat (5.08 t ha^{-1}) was recorded in the treatment receiving 40 kg P_2O_5 ha^{-1} + foliar application of 2.0 kg Zn at 30 and 60 days after emergence. Like straw yield of basmati rice, the straw yield of subsequent wheat crop was not significantly influenced by the main effects of P and Zn or their interaction effect.

Table 4.2: Effect of Zn application methods and P levels on grain yield and grain Zn concentration of basmati rice (cv. Pusa basmati 1) and wheat (UP 2425) at Pantnagasr.

P_2O_5 (kg ha^{-1})	Zn (t ha^{-1})				Zn (kg ha^{-1})			
	0	2.5	2.0 Zn FL	Mean	0	2.5	2.0 Zn FL	Mean
	Grain yield (t ha^{-1})				Grain Zn concentration (mg kg^{-1})			
Basmati rice								
0	2.83	3.00	3.13	2.97	11.83	14.35	12.05	12.74
20	2.92	3.04	3.17	3.04	12.10	14.70	12.72	13.17
40	3.04	3.13	3.29	3.15	11.70	12.38	11.98	12.02
60	3.00	3.08	3.25	3.11	11.05	13.37	11.88	12.10
Mean	2.95	3.06	3.21	3.07	11.67	13.70	12.16	12.51
Effect	P_2O_5 levels	Zn levels	P_2O_5 × Zn levels		P_2O_5 levels	Zn levels	P_2O_5 × Zn levels	
S. Em. ±	0.45	0.39	0.78		0.43	0.37	0.74	
C.D. (5%)	NS	1.2	NS		NS	1.09	NS	
Wheat								
0	4.38	4.55	4.55	4.49	25.55	25.67	29.38	26.87
20	4.43	4.73	4.90	4.69	26.63	25.72	26.85	26.40
40	4.81	4.90	5.08	4.93	28.78	27.33	27.55	27.89
60	4.73	4.84	5.02	4.86	26.68	26.65	30.12	27.82
Mean	4.38	4.55	4.55	4.49	26.91	26.34	28.48	27.24
Effect	P_2O_5 levels	Zn levels	P_2O_5 × Zn levels		P_2O_5 levels	Zn levels	P_2O_5 × Zn levels	
S. Em. ±	0.07	0.06	0.1.2		0.29	0.25	0.51	
C.D. (5%)	0.20	0.17	NS		NS	NS	NS	

Results on Zn concentration in grain of basmati rice and wheat revealed that soil application of 2.5 kg Zn ha^{-1} increased the concentration of Zn in grains of basmati rice by 17.4 percent over no Zn, respectively (Table 4.2). The interaction effect of Zn and P_2O_5 levels had no significant effect on Zn concentration in grains of basmati rice. In the case of wheat crop, the main effects of Zn and P or their interaction effects fail to influence Zn concentration in grains however, the main effect of Zn averaged over P levels significantly influenced the concentration of Zn in grains. Foliar application of 2.0 kg Zn ha^{-1} at 30 and 60 days after emergence increased the concentration of Zn in wheat grains by 5.8 percent over the control.

4.3 Integrated management of zinc in rice – rice cropping system

In intensively rice growing areas of Odisha at

Bhubaneswar, application of graded level of Zn and its combination with organics significantly increased the grain yield of rice (Table 4.3). Highest yield of 45.33 q ha^{-1} was obtained when Zn was applied @ 2.5 kg ha^{-1} with FYM. So application of Zn @ 2.5 kg ha^{-1} along with FYM may be suggested for better yield response. The Zn uptake of 0.543 kg ha^{-1} was recorded highest with application of Zn @ 2.5 kg ha^{-1} along with FYM incorporation.

Table 4.3: Effect of integrated management of Zinc on the yield and Zn uptake by rice Bhubaneshwar.

Treatments	Grain Yield ($t\ ha^{-1}$)	Zn uptake ($g\ ha^{-1}$)		Total uptake ($g\ ha^{-1}$)
		Grain	Straw	
Control (No Zinc)	3.25	74.0	180.0	254.0
Zn @ 2.5 kg ha^{-1}	3.73	87.0	280.0	367.0
Zn @ 5.0 kg ha^{-1}	4.35	115.0	330.0	445.0
Residue incorporation	3.82	90.0	200.0	290.0
Zn @ 2.5 kg ha^{-1} + Residue incorporation	4.36	114.0	400.0	514.0
FYM @ 5 t ha^{-1}	4.01	98.0	280.0	378.0
Zn @ 2.5 kg ha^{-1}+ Residue incorporation	4.53	123.0	420.0	543.0
0.25 % spray as ZnSO4	4.03	122.0	400.0	522.0
CD (0.05)	0.47	0	-	-

4.4 Optimizing salt concentration for improving Zn use efficiency of rice in Vertisols at Jabalpur.

In order to assess sensitivity of crops to unneutralized solution of Zn salts for scorching effect on foliage of rice crop and improvement in yield, a field experiment was conducted. The results revealed that application of 0.5, 1 and 1% + lime spray of different sources of Zn increased the rice grain and straw yield over control (Table 4.4). However, the 1% spray of all the Zn salts unneutralized was found statistically significant over control. The 0.5% salt spray of Zn EDTA, $ZnSO_4$ and $Zn_3(PO_4)_2$ were found significant over control but other sources were found non-significant at the same concentration. The 1% spray of Zn EDTA, ZnO and Zinc sulphate were found significant over their 0.5% spray and 1% salt spray with 0.5% lime. The maximum grain yield was observed with 1% foliar spray of Zn EDTA (4.63 t ha^{-1}) followed by Zinc oxide (4.44 t ha^{-1}) and Zinc sulphate (4.32 t ha^{-1}). The 1% Zn salts neutralized with 0.5% lime gave less grain yield which might be due to less absorption of Zn in presence of Ca. The zinc phosphate and zinc chloride gave lower yield as compared with other Zn salts due to their less solubility. These treatments were found non-significant for straw yield of rice.

Application of 0.5% ZnO and 1% zinc phosphate and Zn-EDTA significantly increased the Zn content in rice grain over control but other sources with different concentration were found non-significant (Table 4.4). The different concentration of zinc salts were found at par amongst themselves. The maximum Zn content

11.17 mg kg^{-1} in rice grain was observed with 1% Zn EDTA application. The 1% conc. of Zinc sulphate was found significant over their 0.5% salt conc. as well as over 1% salt and 1% salt + 0.5% lime concentration of $ZnCl_2$, $Zn_3(PO_4)_2$ and ZnO except 1% salt of ZnO. The maximum Zn content 20.33 mg kg^{-1} was observed with 1% $ZnSO_4$.

Application of Zn EDTA and Zinc sulphate significantly increased the Zn use efficiency over Zinc chloride, Zinc phosphate and Zinc oxide at 05%, 1% and 1% salt concentration with 0.5% lime. However , the maximum Zn use efficiency 16.05, 12.06 and 9.04% with Zn EDTA and 10.99, 10.83 and 6.98 with Zinc sulphate were observed at 0.5, 1% and 1% + 0.5% lime respectively . The Zn use efficiency at 0.5% Zn EDTA was found significantly superior to Zinc sulphate at the same rate of Zn salt concentration but other salt concentrations were found at par.

Table 4.4: Effect of different Zn salts spray on yield and Zn content of rice and Zn use efficiency

Treatments	Rice yield (t ha^{-1})		Zn conc.(mg kg^{-1})		Zn use efficiency (%)
	Grain	Straw	Grain	Straw	
NPK +Water spray (Control)	3.27	6.13	8.59	11.03	-
NPK+0.5% Zinc Sulphate	3.71	6.81	9.85	16.54	10.99
NPK+1.0% Zinc Sulphate	4.32	7.71	10.79	20.33	10.83
NPK+1.0% Zinc Sulphate + Lime	3.76	6.85	10.38	18.16	6.98
NPK+0.5% Zinc Chloride	3.65	7.13	8.76	15.78	4.54
NPK+1.0% Zinc Chloride	4.11	7.32	10.42	16.36	3.09
NPK+1.0% Zinc Chloride + Lime	3.73	6.96	10.05	16.02	2.44
NPK+0.5% Zinc Phosphate	3.69	6.54	9.99	13.51	2.49
NPK+1.0% Zinc Phosphate	4.05	6.52	10.88	16.72	2.48
NPK+1.0% Zinc Phosphate + Lime	3.71	6.61	10.81	14.94	1.82
NPK+0.5% Zinc Oxide	3.65	6.71	9.10	15.79	2.36
NPK+1.0% Zinc Oxide	4.44	6.94	10.64	16.94	1.83
NPK+1.0% Zinc Oxide+ Lime	3.72	6.75	10.24	16.23	1.44
NPK+0.5% Zinc EDTA	3.69	6.57	10.34	16.94	16.05
NPK+1.0% Zinc EDTA	4.63	7.13	11.17	17.72	12.06
NPK+1.0% Zinc EDTA + Lime	3.80	6.83	10.44	17.24	9.04
S. Em.	0.137	0.44	0.77	1.23	1.11
C.D (5%)	0.402	NS	2.25	3.61	3.18

4.5 Effect of zinc levels on yield and Zn content in wheat in a Vertisol

Application of increasing levels of Zn significantly increased the wheat grain and straw yield over control, at Jabalpur (Table 4.5). However, the 5 and 10 kg Zn ha^{-1} significantly increased the wheat grain and straw yield, respectively over 1.25 or 2.5 kg Zn ha^{-1} but higher than that Zn levels were found at par amongst themselves for grain and straw yield. Application of 2.5 kg Zn or higher Zn levels significantly increased the Zn content in grain and straw over control. However, Zn content in grain at 20 kg Zn ha^{-1} was found significantly higher than that of at 2.5 or 5 kg Zn ha^{-1} but difference between the Zn content at 10 and 20 kg Zn level was found non-significant. While the Zn content in straw at 5 kg Zn or higher than that levels were found at par. The maximum Zn content in grain 36.14 mg kg^{-1} and in straw 14.09 mg kg^{-1} was observed at 20 kg Zn ha^{-1}.

Application of increasing levels of Zn significantly increased the Zn content in soil over control. However, the significantly increased available Zn content in soil was observed up to 2.5 kg Zn ha^{-1} but the Zn levels @ 2.5,5 and 10 kg ha^{-1} were found at par amongst themselves. However, 20 kg Zn ha^{-1} level was found significantly superior to 10 kg Zn ha^{-1} for available Zn in soil. The maximum available Zn 2.84 mg kg^{-1} was observed at 20 kg Zn ha^{-1}.

Table 4.5: Effect of Zn levels on yield and Zn concentration in Wheat crop

Treatments	Yield (t ha^{-1})		% Response		Zn conc. (mg kg^{-1})		Post harvest Zn (mg kg^{-1}) in soil
	Grain	Straw	Grain	Straw	Grain	Straw	
Control	4.05	5.61	-	-	27.05	6.20	0.82
1.25 kg Zn ha^{-1}	4.30	6.24	6.3	11.3	30.13	8.92	1.23
2.5 kg Zn ha^{-1}	4.46	6.31	10.3	12.5	31.49	12.53	1.70
5.0 kg Zn ha	4.69	6.37	16.0	13.6	31.74	12.72	1.79
10.0 kg Zn ha^{-1}	4.83	6.65	19.4	18.6	34.87	13.46	1.86
20.0 kg Zn ha^{-1}	4.80	6.54	18.7	16.7	36.14	14.09	2.84
S. Em. ±	0.07	0.10	-	-	1.15	0.94	0.09
CD (P=0.05)	0.20	0.32	-	-	3.55	2.82	0.27

4.6 Method, rates, frequency of boron application to rice

In a field experiment on *Inceptisol* of Bhubaneshwar to evaluate the method, rates and frequency of Boron application in rice crop (cv. Lalat) the grain yield of rice crop varied from 3.63 to 5.04 t ha^{-1} whereas straw yield varied from 4.35 to 6.55 t ha^{-1} (Table 4.6). It was also observed from the result that application of B @ 1 kg ha^{-1} gave significant and highest grain yield (5.04 t ha^{-1}) of rice which was 39 percent higher than control. It was found that the boron content in grain ranged from 1.58 to 2.21 mg kg^{-1}. The total uptake in control is 0.014 kg ha^{-1} and the highest uptake of 0.030 kg ha^{-1} was obtained when boron was applied @ 1.0 kg ha^{-1} to all crops.

Table 4.6: Effect of B treatments on grain yield, B content and uptake by rice at Bhubaneshwar.

Treatment	Grain yield ($t\ ha^{-1}$)	Grain B content ($mg\ kg^{-1}$)	Grain B uptake ($kg\ ha^{-1}$)
Control (No boron)	3.63	1.58	6.00
0.5 kg ha^{-1} to first crop	4.40	1.78	8.00
0.5 kg ha^{-1} to alternate crop	4.13	1.80	7.00
0.5 kg ha^{-1} to all crops	4.57	1.93	9.00
1.0 kg ha^{-1} to first crop	4.42	2.06	9.00
1.0 kg ha^{-1} to alternate crop	4.66	2.14	10.00
1.0 kg ha^{-1} to two crop interval	4.31	2.12	9.00
1.0 kg ha^{-1} to all crops	5.04	2.21	11.00
2.0 kg ha^{-1} to first crop	4.69	2.05	10.00
2.0 kg ha^{-1} to two crop interval	4.42	2.04	9.00
2.0 kg ha^{-1} to three crop interval	4.57	2.19	10.00
Borax @ 0.25% as foliar spray	4.30	2.02	9.00
CD (0.05)	0.32	0.62	-

4.7 Effect of zinc and boron on yield and uptake of nutrients by soybean

The results pertaining to grain and straw yield of soybean during three years of experimentation on three locations in Maharashtra i.e. Washim, Buldhana and Amravati and pooled means are presented in Table 4.7. The grain yield of soybean was recorded significantly highest with application of micronutrients over control. Significantly highest grain yield of soybean was observed with application of zinc @ 5 kg ha^{-1} which was significantly superior over all the treatments followed by application of boron @ 1.0 kg ha^{-1}. In case of boron, application boron @ 1.0 kg ha^{-1} was recorded highest grain and straw yield of soybean as compare to treatment of 0.5 kg ha^{-1} and boron @ 2 kg ha^{-1}.

The total uptake of Zn was found significantly superior over control in all the micro-nutrient treatments. Significantly highest uptake of Zn was observed in soybean with application of zinc @ 5 kg ha^{-1} which was significantly superior over all the treatments followed by application of Zn @ 2.5 kg ha^{-1} followed by B at all three levels (Table 4.7). Overall, the pooled data revealed that application of zinc @ 5 kg ha^{-1} was recorded higher yield of soybean followed by application of boron @ 1 kg ha^{-1}. The total uptake of nitrogen, phosphorus, potassium, zinc and boron was recorded significantly higher in the treatment of zinc @ 5 kg ha^{-1} followed by boron @ 1 kg $ha^{-1.}$ Highest number of nodules was noticed in the treatment of zinc @ 5 kg $ha^{-1.}$ Availability of N, P, K, Zn and B was found to be enhanced in high magnitude in the treatment of zinc 5 kg $ha^{-1.}$ Highest gross monetary return, net monetary return and B:C ratio was recorded in the treatment of zinc @ 5 kg ha^{-1} and boron @ 1 kg ha-$^{1.}$

Table 4.7: Pooled analysis of soybean yield and total Zn uptake as influenced by various treatment at three locations in Maharashtra during 2008-11.

Treatment	Locations			
	Washim	Buldhana	Amravati	Pooled
	Grain Yield (t ha $^{-1}$)			
Control	1.43	2.03	0.94	1.46
Zinc @ 2.5 kg ha^{-1}	1.57	2.19	1.16	1.64
Zinc @ 5 kg ha^{-1}	1.74	2.29	1.26	1.76
Boron @ 0.5 kg ha^{-1}	1.59	2.14	1.08	1.60
Boron @ 1 kg ha^{-1}	1.64	2.25	1.15	1.68
Boron @ 2 kg ha^{-1}	1.59	2.11	1.03	1.58
S. Em. ±	0.07	0.02	0.04	0.02
CD at 5 %	0.19	0.06	0.11	0.05
	Total Zn (uptake g ha $^{-1}$)			
Control	188	219	47	151
Zinc @ 2.5 kg ha^{-1}	219	244	79	180
Zinc @ 5 kg ha^{-1}	231	259	82	190
Boron @ 0.5 kgha^{-1}	218	240	78	179
Boron @ 1 kg ha^{-1}	219	252	76	182
Boron @ 2 kg ha^{-1}	214	244	60	173
S. Em. ±	-	-	-	2.53
CD at 5 %	-	-	-	7.12

4.8 Effect of Zinc and FYM on yield of maize in maize – wheat sequence in Vertisols

Direct effect on maize

The results of a field experiment, conducted at Jabalpur revealed that application of Zn @ 5 and 10 kg ha^{-1} significantly increased the maize grain and stover yield over control but the difference between the two Zn levels was found non-significant. However, the maximum maize grain yield 4.21 t ha^{-1} and stover yield 10.77 t ha^{-1} was found at 10 kg Zn ha^{-1}. While the application of 10 t ha^{-1} FYM significantly increased the maize grain and stover yield over control but the lower levels were found non-significant. The maximum grain yield of 4.2 t ha^{-1} and straw yield 10.87 t ha^{-1} was observed at 10 t FYM ha^{-1}. The interaction between FYM and Zn levels for grain and stover yield of maize was found non-significant (Table 4.8).

Application of increasing levels of Zn significantly increased the Zn content in maize grain and stover except at 2.5 kg Zn for Zn content in grain (Table 4.8). The maximum Zn content in grain 29.63 mg kg^{-1} and in stover 13.62 mg kg^{-1} was observed at 10 kg Zn ha^{-1}. While application of 10 t FYM significantly increased the Zn content in grain over control but lower levels were found non-significant. Whereas FYM application @ 5 and 10 t ha^{-1} significantly increased the Zn content is maize stover. The maximum Zn content in grain 29.63 mg kg^{-1} and in stover 13.62 mg kg^{-1} was recorded at 10 t FYM ha^{-1}. The interaction between Zn and FYM was found non-significant for Zn content of seed and stover.

Application of 5 kg Zn and 10 t FYM significantly increased the available Zn in soil over their respective control but the lower levels of Zn and FYM were found non-significant over control (Table 4.8). The maximum available Zn 1.27 mg kg^{-1} and 1.18 mg kg^{-1} was recorded at 10 kg Zn and 10 t FYM ha^{-1} level, respectively. The interaction between Zn and FYM levels was found non-significant.

Table 4.8: Effect of Zn and FYM levels on yield, Zn content of maize and available Zn in Soil at Jabalpur.

Treatment	Maize yield (t ha^{-1})		Zn content (mg kg^{-1})		Available Zn (mg kg^{-1}) in soil
Zn (kg ha^{-1})	**Grain**	**Stover**	**Grain**	**Stover**	
0	3.45	8.95	24.27	10.93	0.91
1.50	3.76	9.64	25.26	11.77	0.94
5.00	3.99	10.22	27.03	12.62	1.06
10.00	4.21	10.77	29.63	13.62	1.27
FYM (t ha^{-1})					
0	3.59	9.19	25.60	11.43	0.97
2.5	3.77	9.66	25.93	11.86	1.00
5.0	3.85	9.85	26.65	12.35	1.04
10.0	4.20	10.87	28.00	13.31	1.18
S. Em.± (Zn /FYM)	0.13	0.31	0.39	0.19	0.05
CD (P = 0.05)	0.36	0.88	1.15	0.55	0.16
S. Em.± (ZnXFYM)	0.25	0.61	0.79	0.38	0.11
CD(P = 0.05)	NS	NS	NS	NS	NS

Residual effect on Wheat

The residual effect of increasing levels of Zn increased the wheat grain and straw yield over control (Table 4.9). However, residual effect of 10 kg Zn ha^{-1} application significantly increased the grain and straw yield over control but lower Zn levels were found non-significant for grain and straw yield of wheat. The maximum yield of wheat grain 5.77 and straw 8.33 t ha^{-1} was observed at 10 kg Zn ha^{-1}. The increasing levels of FYM also increased the wheat grain and straw yield over control. However, the application of 5 t FYM significantly increased the wheat grain and straw yield over control but the difference between 5 and 10 t FYM ha^{-1} treatment was found non-significant for grain and straw yield of wheat. The maximum yield of wheat grain 5.85 and straw 8.44 t ha^{-1} was found at 5 t FYM level. The interaction between Zn and FYM levels were found non-significant for grain and straw yield of wheat.

Table 4.9: Residual effect of Zn and FYM levels on yield and Zn content of wheat and available Zn

Treatment	Wheat yield ($t\ ha^{-1}$)		Zn content ($mg\ kg^{-1}$)		Post harvest Zn ($mg\ kg^{-1}$) in soil
Zn ($kg\ ha^{-1}$)	**Grain**	**Straw**	**Grain**	**Straw**	
0	5.29	7.67	25.68	8.03	0.85
2.5	5.63	7.91	29.22	9.26	0.85
5.0	5.71	8.15	30.09	9.78	0.98
10.0	5.77	8.33	30.56	10.35	1.11
FYM ($t\ ha^{-1}$)					
0	5.39	7.43	26.39	8.91	0.89
2.5	5.55	7.88	28.20	9.02	0.93
5.0	5.85	8.44	29.24	9.46	0.96
10.0	5.61	8.32	31.73	10.02	1.04
S. Em.± (Zn /FYM)	0.15	0.22	0.79	0.26	0.02
CD (P = 0.05)	0.42	0.64	2.28	0.75	0.05
S. Em.± (ZnXFYM)	0.30	0.44	1.58	0.52	0.04
CD(P = 0.05)	NS	NS	NS	NS	NS

Residual effect of increasing levels of Zinc significantly increased the Zn content in wheat grain and straw over control but the Zn levels were found at par amongst themselves except 10 kg Zn which produce significant higher Zn content in straw than that of 2.5 kg Zn ha^{-1} (Table 4.9). But the difference between the lower levels of Zn (2.5 and 5 kg Zn) was found non-significant for Zn content in straw. However, the maximum Zn content in grain 30.56 mg kg^{-1} and in straw 10. 35 mg kg^{-1} was found at 10 kg Zn ha^{-1} levels.

The residual effect of increasing levels of FYM increased the Zn content in wheat grain and straw over control. However, the residual effect of 5 and 10 t FYM significantly increased the Zn content in wheat grain. While the significant increase of Zn content in straw was found at 10 t FYM ha^{-1} over control but the lower levels of FYM were found non-significant. The maximum Zn content in grain 31.73 mg kg^{-1} and in straw 10.02 mg kg^{-1} was recorded at 10 t FYM ha^{-1}. The interaction between Zn and FYM level were found non-significant for Zn content in grain and straw. The residual effect of increasing levels of Zn increased the Zn content in soil over control (Table 4.9). However, the residual effect of 5 and 10 kg Zn ha^{-1} significantly increased the available Zn content in soil. The maximum available Zn 1.11 mg kg^{-1} was found at 10 kg Zn ha^{-1}. While residual effect of 5 and 10 t FYM significantly increased the available Zn content in soil. The maximum available Zn 1.04 mg kg^{-1} was found at 10 t FYM ha^{-1}. The interaction between Zn and FYM levels was found non-significant.

4.9 Interaction of potassium and zinc on rice in iron toxic soil

Field experiment was conducted during 2010, *kharif* at Central Farm, OUAT to study the interaction of K and Zn in rice on iron toxic soil.

The results showed that the grain yield of treatments varied from 2.75 to 4.22 t ha^{-1} (Table 4.10). The highest grain yield of 4.22 t ha^{-1} was obtained with the application of K_{80} $Zn_{5.0}$ (HI of 46.4) which was at par with $K_{40}Zn_{5.0}$. It may be suggested that the application of K @ 40 kg ha^{-1} and Zn @ 5.0 kg ha^{-1}along with recommended dose of fertilizer gave highest grain yield of rice in iron toxic soil. The grain yield of rice was increased by about 19 percent when Zn @ 5.0 kg ha^{-1} was applied over control.

The contents of Zn, Fe and K in grain and straw of rice as influenced by different treatments in iron toxic soil are presented in table 14. It was revealed that the iron content in grain and straw ranged from 53.53 to 92.33 mg kg^{-1} and 167.07 to 302.96 mg kg^{-1}, respectively. Zinc content in grain and straw ranged from 22.83 to 32.97 mg kg^{-1} and from 32.25 to 60.37 mg kg^{-1}, respectively. The potassium percentage in grain and straw ranged from 0.15 to 0.22 and from 1.18 to 1.94, respectively. It was found that with increasing level of K, Fe content in grain decreased. Further decrease was noticed with the addition of increasing level of zinc. On the similar trend, the uptake of Fe, Zn and K was increased with increasing level of zinc.

Table 4.10: Effect of Potassium and Zinc on yield, Zn and K content of rice in iron toxic soil

Treatment Details	Yield (t ha^{-1})		Zn content (mg kg^{-1})		K (%)	
	Grain	Straw	Grain	Straw	Grain	Straw
K_0Zn_0	2.75	3.40	28.37	36.33	0.15	1.94
K_0 $Zn_{2.5}$	3.23	3.88	32.97	33.93	0.15	1.40
K_0 $Zn_{5.0}$	3.43	4.08	30.90	32.53	0.18	1.18
K_{40} Zn_0	3.34	3.99	28.03	34.83	0.19	1.37
K_{40} $Zn_{2.5}$	3.70	4.35	30.63	46.27	0.18	1.19
K_{40} $Zn_{5.0}$	4.01	4.66	28.97	43.40	0.17	1.05
K_{80} Zn_0	3.41	4.06	23.57	43.23	0.20	1.41
K_{80} $Zn_{2.5}$	3.85	4.50	29.33	47.80	0.21	1.42
K_{80} $Zn_{5.0}$	4.22	4.87	28.13	49.27	0.22	1.60
K_{120} Zn_0	3.44	3.94	29.53	60.37	0.22	1.70
K_{120} $Zn_{2.5}$	3.61	4.24	22.83	38.53	0.18	1.62
K_{120} $Zn_{5.0}$	3.70	4.29	25.04	32.25	0.21	1.57
CD (0.05)	0.59	0.58	7.44	10.68	0.06	0.87

4.10 Effect of Zinc and Boron in enhancing nitrogen use efficiency and crop productivity of maize crop in maize - wheat sequence

Direct effect on maize

The results in Table 4.11 indicated that application of N @ 60,120 and 180 kg ha^{-1} significantly increased grain yield of maize.

However, the maximum grain yield of 4.45 tons ha^{-1} was observed with 180 kg N ha^{-1} level. Besides obtaining maximum grain yield of 4.45 tons ha^{-1} with 180 kg N ha^{-1}, application of 10 kg Zn ha^{-1} and 1.0 kg B ha^{-1} application significantly increased the grain yield over control but their combined application was found non-significant over control. However, the maximum grain yield of 3.11 t ha^{-1} was observed with 1 kg B ha^{-1} application.

Table 4.11: Effect of N, Zn and B level on grain yield of maize

Main/ Sub treatment	Grain yield (t ha^{-1})				
	Zn_0 B_0	Zn_{10} B_0	Zn_0 B_1	Zn_{10} B_1	Mean
N_0	1.07	1.15	1.19	1.37	1.19
N_{60}	1.95	2.26	2.59	2.02	2.20
N_{120}	4.13	3.93	3.97	3.77	3.95
N_{180}	3.89	5.04	4.70	4.17	4.45
Mean	2.76	3.10	3.11	2.83	2.95
				S. Em	C.D. (5%)
Comparison of N level mean				0.09	0.31
Comparison of Zn and B level mean				0.07	0.21
Comparison of two Zn/B level at same level of N				0.14	0.41
Comparison of two N level at same or different level of Zn/B				0.20	0.58

The interaction amongst the N, Zn and B levels were found significant. The application of 1 kg B significantly increased the grain yield over control at 60 kg N ha^{-1} and 180 kg N ha^{-1} level. Similarly 10 kg Zn 180 kg N significantly increased the grain yield over control or combined application of 10 kg Zn+ 1.0 kg B. The application of 10 kg Zn and 1.0 kg B ha^{-1} alone significantly increased grain yield with increasing levels of N. The effect of N was also found significant up to 120 kg N at Zn_0 B_0 and Zn_{10} +B_1kg ha^{-1}. The maximum grain yield of 5.04 tons ha^{-1} was recorded with N_{180}+ Zn_{10} level.

Results further indicated that nitrogen use efficiency was decreased with increasing N levels (4.12). However, the maximum N use efficiency 71.60% was observed at N_{60} level. While the application 10 kg Zn, 1.0 kg B and combined application of 10 kg Zn+1.0 kg B increased N use efficiency over control. The application of 1 kg B ha^{-1} was found significant over control but 10 kg Zn and combined application of 10 kg Zn + 1.0 kg B were found at par. The maximum N use efficiency 55.72 % was observed at 1.0 kg B application. The interaction amongst the N, Zn and B levels were found non-significant.

Table 4.12: Effect of N, Zn and B level on nitrogen use efficiency

Main/ Sub treatment	N use efficiency (%)				
	Zn_0 B_0	Zn_{10} B_0	Zn_0 B_1	Zn_{10} B_1	Mean
N_0	-	-	-	-	-
N_{60}	64.90	55.91	88.07	77.50	71.60
N_{120}	63.43	59.51	77.34	78.47	69.69
N_{180}	38.32	61.83	57.46	47.20	51.20
Mean	41.66	44.31	55.72	50.79	48.12
				S. Em±	C.D. (5%)
Comparison of N level mean				2.49	9.78
Comparison of Zn and B level mean				4.03	11.84
Comparison of two Zn/B level at same level of N				6.98	NS
Comparison of two N level at same or different level of Zn/B				7.43	NS

Residual effect on wheat

While assessing the residual effect in *rabi* season, application of increasing levels of N significantly increased the wheat grain and straw yield up to 120 kg N ha^{-1} but the yield at 180 kg N was found at par with 120 kg N ha^{-1} (Table 4.13). The maximum wheat grain yield 5.97 t ha^{-1} and straw yield 7.77 t ha^{-1} was observed at 180 and 120 kg N ha^{-1}, respectively. Residual effect of 10 kg Zn, 1 kg B and their combined application significantly increased the wheat grain yield over control but these treatments were found at par amongst themselves. The maximum yield of wheat grain 5.68 t ha^{-1} and straw 7.21 t ha^{-1} was observed at 1 kg B ha^{-1} level and 10 kg Zn respectively. Application of 10 kg Zn, 1 kg B and their combined application significantly increased the wheat grain yield over control at N_0 and N_{60} level. However, the combined application of 10 kg Zn + 1 kg B was found significantly superior to 1 kg B alone at N_0 level. However, at N_{120} level application of 1 B was found significantly superior to control but other treatments were found at par amongst themselves at N_{120} as well as at N_{180} kg N ha^{-1}.

Table 4.13: Effect of N, Zn and B level on grain yield of wheat

Main/ Sub treatment	Wheat grain yield (t ha^{-1})				
	Zn_0 B_0	Zn_{10} B_0	Zn_0 B_1	Zn_{10} B_1	Mean
N_0	4.26	4.88	4.81	5.24	4.80
N_{60}	4.77	5.41	5.75	5.76	5.42
N_{120}	5.57	5.82	6.05	5.85	5.82
N_{180}	5.88	6.13	6.11	5.76	5.97
Mean	5.12	5.56	5.68	5.65	5.50
				S. Em±	C.D. (5%)
Comparison of N level mean				0.11	0.38
Comparison of Zn and B level mean				0.06	0.174
Comparison of two Zn/B level at same level of N				0.12	0.349
Comparison of two N level at same or different level of Zn/B				0.26	0.755

Application of 120 and 180 kg N application significantly increased the wheat yield over N_0 level at Zn_0 B_0, Zn_{10} and B_1 level. Though 60 kg N also gave significantly higher wheat yield over N_0 level at 1 kg B level. The 180 kg N ha^{-1} level was also found significantly superior to N_{60} level at Zn_0B_0. The maximum wheat yield 6.13 t ha^{-1} was observed at 180 N 10 kg Zn ha^{-1}. The residual effect of 10 kg Zn, 1 kg B and their combined application as well the interaction amongst N, Zn, and B levels were found non-significant for straw yield.

Application of increasing levels of N decreased the N use efficiency (Table 4.14). However, the N use efficiency at 180 kg N ha^{-1} was found significantly lower than that of 60 or 120 kg N ha^{-1} but the N use efficiency at 60 and 120 kg N ha^{-1} was found at par. The maximum N use efficiency 64.87% was observed at 60 kg ha^{-1} followed by 55.99% and 35.22% at 120 and 180 kg N ha^{-1} respectively. The residual effect of 10 kg Zn, 1 kg B and their combined application were found non-significant for N use efficiency. However, the maximum N use efficiency 41.74% was recorded with 1 kg B application.

Table 4.14: Effect of levels of N, Zn and B on N use efficiency in wheat

N (kg ha^{-1})	N use efficiency (%)
0	-
60	64.80
120	56.00
180	35.22
S. Em.	4.80
C.D (5%)	18.70
Control	41.71
Zn10 B0	35.68
Zn0 B1	41.74
Zn10 B1	36.95
S. Em.	2.99
C.D (5%)	NS

4.11 Effect of zinc and boron incubated with FYM on yield, apparent use efficiency and uptake in chillies

Micronutrient fertilizer use efficiency is generally very low. Previous study at Hyderabad indicated that apparent zinc use efficiency can be increased by incubating zinc fertilizer with small quantities of organic materials for thirty days prior to its application in rice crop**.** This enrichment of vermicompost or FYM with zinc would reduce the cost incurred on zinc sulphate fertilizer as its dosage could be reduced from 50 to 37.5 kg zinc sulphate ha^{-1} in paddy grown on *Alfisols* of southern Telangana zone. In a similar study in chillies, fruit yield of chilly (dry chilly) increased significantly due to application of zinc or boron at different levels / modes when compared to that of control. Application of zinc resulted in 33% increase in yield while boron application helped in 26% increment in yield. Application of zinc at recommended level (25 kg zinc sulphate ha^{-1}) or recommended zinc sulphate + 200 kg FYM or 12.5 kg zinc sulphate + foliar spray or 12.5 kg zinc sulphate + FYM incubation resulted on par yields in the range of 35.3 to 49.15 q ha^{-1} fruit yield, though the yield was slightly lower at 12.5 kg zinc sulphate / ha + foliar spray application. Similar trend in yield due to boron application was also observed in the experiment (Table 4.15).

Table 4.15: Effect of zinc and boron incubated with FYM on chilly yield (t ha^{-1})

Treatment details	Fruit yield (t ha^{-1})	
	Zn	B
Recommended Dose (25 kg ZS /10 kg B /ha)	4.63	4.40
½ Recommended Dose (12.5 kg ZS/ 5 kg B/ha)+FS	4.21	3.97
Recommended Dosenriched to 200 kg FYM	4.92	4.62
½ Recommended Dose enriched to 200 kg FYM	4.59	4.24
Mean for individual elements	4.59	4.31
Control		3.53
Experimental mean		4.35
CD(P=0.05)		0.41

Zinc and boron content along with its uptake in the dry chilly samples are presented in table 2c. The highest zinc content in chillies was recorded (54.15 mg kg^{-1}) when full dose of Zn was applied after incubating with 200kg FYM prior to its application to crop. Even the half recommended dose of zinc sulphate incubated with 200 kg FYM prior to its application also resulted in similar zinc concentration in chillies (52.91 mg kg^{-1}) which was on par with that of the treatments receiving full recommended dose of zinc sulphate or half recommended dose of zinc sulphate + two foliar sprays (1.16 and 50.57 mg kg^{-1}, respectively) . Thus half recommended dose of zinc sulphate incubated with 200kg FYM was found to be good in terms of maintaining on par concentration of zinc in chilly with other treatments. Similar trend was followed in terms of zinc uptake in chillies (Table 4.16).

Table 4.16: Effect of zinc and Boron enriched to FYM on zinc and boron content (mg kg^{-1}) its uptake in dry Chillies samples and Zn and B use efficiency

Treatment Details	Zinc content (mg kg^{-1})	Zinc uptake (g ha^{-1})	Boron content (mg kg^{-1})	Boron uptake (g ha^{-1})	App Zn use efficiency (%)	App B use efficiency (%)
RD of $ZnSO_4$ @ 25 kg ha^{-1}	51.16	237	42.52	197	1.88	--
½RD (12.5 kg $ZnSO_4$ ha^{-1})+FS	50.57	213	43.26	182	2.55	--
RD enriched in 200 kg FYM	54.15	266	48.92	240	2.46	--
½ RDenriched in 200 kg FYM	52.91	243	45.82	210	3.96	--
Mean for Zn treatments	**52.19**	**240**	**45.13**	**207**	**--**	**--**
RD of B @10kg ha^{-1}	45.70	201	52.46	231	--	9.2
½ RD (5 kg Bha ha^{-1})+FS	44.46	177	50.30	200	--	10.6
RD enriched in 200 kg FYM	47.85	221	57.70	266	--	12.8
½ RD enriched in 200 kg FYM	46.48	197	50.96	216	--	15.6
Mean for B treatments	**46.12**	**199**	**52.85**	**228**	**--**	**--**
Control	40.66	**144**	**39.18**	**138**	**--**	**--**
Overall mean (9 treatments)	**46.32**	**194**	**45.72**	**191**	**--**	**--**
CD (P=0.05)	**4.58**	**21.22**	**5.01**	**21.06**	**--**	**--**

Boron content in chillies was in the range of 50.3 to 57.7 mg kg^{-1} with mean of 52.85 mg kg^{-1} in boron treated plots. Though boron content in chilly was highest when recommended dose of boron was applied after incubated with 200 kg FYM (prior to its application), the half recommended dose of boron incubated with 200 kg FYM was also found to result in good boron content in chilly (50.96 mg kg^{-1}) which was 11% higher that of control (45.72 mg kg^{-1}). The data presented in Table 4.16 also revealed that the mean zinc content in chillies was 52.19 mg kg^{-1} in zinc treated plots and 46.12 mg kg^{-1} in boron treated plots with a variation of 13%. But when chillies of control plot were compared, the mean increase in zinc was 28% due to zinc treatments (52.19 vs. 40.66). Thus, the application of boron resulted in 13% increase in zinc (though not receiving zinc fertilizer) content (46.12 and 40.66 mg kg^{-1}) of chillies while application of zinc as such resulted in 28% increase in zinc content. Similarly, zinc application increased boron content of chilly by 15% (45.13 and 39.18 mg kg^{-1}) where as boron application as such increased boron content by 34% in chillies (52.85 and 39.18 mg kg^{-1}).

The apparent zinc use efficiency by chilli fruit was 3.96% when 12.5 kg $ZnSO_4$ incubated with 200 kg FYM was applied to crop. This use efficiency was higher when compared to that of application of 25 kg zinc sulphate/ha alone (1.88%), or 25 kg zinc sulphate + 200 kg FYM incubated treatment (2.46%) or 12.5 kg zinc sulphate + 2 foliar spray (2.55%) indicating that small quantities of FYM/organics when used to incubate could reduce zinc sulphate dose and also helps in enhancing the use efficiency of zinc in crops. This is probably due to chelation of metals of micronutrient fertilizer with functional groups of FYM and thereby helping in slow release of metals.

Thus, it was observed that when application of 25 kg zinc sulphate ha^{-1} was done with incubation (FYM), apparent zinc use efficiency by chilli fruit was higher by 31% when compared to that of application of 25 kg zinc sulphate alone. At lower doses of zinc sulphate, it was observed that the apparent use efficiency of zinc increases by 55% when FYM incubated 12.5 kg zinc sulphate (3.96%) was applied when compared to that of combined application to 12.5 kg zinc sulphate + 2 foliar spray (2.55%) (Table 4.16).

When application of recommended dose of 10 kg borax ha^{-1} was done without incubating with FYM, apparent boron use efficiency by chilli fruit (12.8 %) was higher by 39% when compared to that of application of 10 kg borax alone (9.2%). When incubated 5 kg borax + FYM were applied, the apparent use efficiency of boron increased by 47 % (15.6%) compared to that of combined application of 5 kg borax + 2 foliar spray (10.6%). This use efficiency (15.6%) was higher when compared to that of 10 kg borax ha^{-1} alone (9.2%), 10 kg borax + 200 kg FYM incubated treatment (12.8%) and 5 kg borax + 2 foliar spray (10.60%). Thus the experimental results of chilli crop revealed that application of 50% Recommended dose of Zn and B incubated with organic for a month is found to be useful as it resulted in highest Zn and B use efficiency of 3.96 and 15.6% when compared to those of soil application of 100 % recommended dose of zinc and boron (1.88 and 9.2%, respectively) without any detrimental effect on yields.

4.12 Quantifying role of micronutrients in enhancing major nutrient-use -efficiency and crop productivity

In a field experiment at Coimbatore, combined application of N@ 200 kg with Zn @ 10 kg and 1 Kg B significantly recorded the highest grain yield (7.19 t ha^{-1}) and stover yield (13.7 t ha^{-1}) of maize (Table 4.17) and the lowest was observed in control treatment (N_0+ Zn_0B_0). The individual application of N @ 200 kg ha^{-1} registered the grain and straw yield of 5.94 and 12.5 t ha^{-1} respectively while the single application of micronutrient alone i.e. treatment application of Zn @ 10 kg with 1 kg B ha^{-1} recorded the grain and straw yield of 5.57 and 11.4 t ha^{-1}, respectively (Table 4.17).

The combined application of N @ 150 with micronutrients Zn @ 10 + B @1 kg ha^{-1} registered the maximum agronomic efficiency (25.4 kg grain kg^{-1} N), followed by N_{150}+ Zn_{10} (23.5 kg grain kg^{-1} N) and the minimum (9.4 kg grain kg^{-1} N) was at N_{250}+ $B_{0.5}$ (Table 38).Among the different N levels, the application of N_{150} registered the maximum agronomic efficiency of (19.8 kg grain kg^{-1} N) while in the micronutrient levels, maximum was observed in $Zn_{10}B_1$,(14.1 kg grain kg^{-1} N). In the case of the physiological efficiency, maximum (81.9 kg grain kg^{-1} N) was noticed in N_{150}+ $Zn_{10}B_1$ and the minimum (27.7 kg grain kg^{-1} N) was at N_{250}+ Zn_{10}. The levels N_{150}+ Zn_{10}, N_{150}+ Zn_5, N_{200}+ $Zn_{10}B_1$ were statistically on par with each other (Table 4.18).

Table 4.17: Effect of nitrogen and micronutrients on grain yield (t ha^{-1}) of maize

N levels (kg ha^{-1})	Micronutrients level (kg ha^{-1})						
	Zn_0B_0	Zn_5	Zn_{10}	$B_{0.5}$	B_1	$Zn_{10}B_1$	Mean
	Grain yield (t ha^{-1})						
N_0	2.15	2.74	2.85	2.55	2.69	2.99	2.66
N_{150}	4.35	6.15	6.38	4.89	5.19	6.74	5.62
N_{200}	4.65	6.39	6.49	5.25	5.65	7.19	5.94
N_{250}	4.56	5.77	5.34	4.89	5.15	5.36	5.18
Mean	3.93	5.26	5.39	4.39	4.67	5.57	4.85
CD (P= 0.05)	Nitrogen		Zinc+Boron		N at Zn+B		Zn+B at N
	0.09		0.14		0.27		0.28
	Zn uptake by maize grain (g ha^{-1})						
N_0	98.2	110.6	113.1	104.9	109.9	117.5	109.0
N_{150}	128.4	134.8	136.3	131.0	132.3	138.0	133.5
N_{200}	141.6	149.0	151.4	143.3	147.1	172.6	150.8
N_{250}	119.3	125.5	126.8	120.4	122.6	127.7	123.7
Mean	121.9	130.0	131.9	124.9	128.0	138.9	129.3
CD (P=0.05)	Nitrogen		Zinc+Boron		N at Zn+B		Zn+B at N
	3.05		3.52		7.10		7.05
	B uptake by maize grain (g ha^{-1})						
N_0	56.4	53.4	51.7	58.3	60.2	61.6	56.9
N_{150}	78.3	76.7	75.6	80.1	82.2	83.7	79.4
N_{200}	89.1	87.2	86.0	91.7	93.4	127.6	95.8
N_{250}	67.5	66.2	63.9	69.2	71.6	73.2	68.6
Mean	72.8	70.9	69.3	74.8	76.9	86.5	75.2
CD (P=0.05)	Nitrogen		Zinc+Boron		N at Zn+B		Zn+B at N
	1.72		2.07		4.13		4.13

The highest recovery efficiency (0.36 kg grain kg^{-1} N) was noticed in N_{150}+ $Zn_{10}B_1$ and the minimum (0.24 kg grain kg^{-1} N) was at N_{250}+ B_1. The levels N_{150}+ Zn_{10} B_1, N_{150}+ $B_{0.5}$ registered the recovery efficiency of 0.34, 0.33 kg grain kg^{-1} N and these two levels were statistically on par with each other. The factor productivity for applied N was maximum (44.93 kg grain kg^{-1} N) at N_{150}+ $Zn_{10}B_1$ and the minimum (18.24 kg grain kg^{-1} N) was at N_{250}+ Zn_0B_0. The levels N_{150}+ Zn_{10}, N_{150}+ Zn_5 registered the factor productivity for applied N of 42.53, 41.20 kg grain kg^{-1} N and these two levels were statistically on par with each other.

Table 4.18: Effect of nitrogen and micronutrients on N use efficiency parameters of maize

N levels (kg ha^{-1})	Agronomic Efficiency (kg grain kg^{-1} N)							Physiological Efficiency (kg grain kg^{-1} N)						
	Micronutrients level (kg ha^{-1})													
	Zn_0B_0	Zn_5	Zn_{10}	$B0_{0.5}$	B_1	$Zn_{10}B_1$	Mean	Zn_0B_0	Zn_5	Zn_{10}	$B_{0.5}$	B_0	$Zn_{10}B_1$	Mean
N_0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
N_{150}	14.7	22.7	23.5	15.6	16.7	25.4	19.8	47.7	74.6	74.2	49.4	54.2	81.9	63.7
N_{200}	12.5	18.3	18.2	13.5	14.8	21.3	16.4	45.6	61.7	61.8	45.9	52.1	72.8	56.7
N_{250}	9.6	12.1	9.9	9.4	9.8	9.7	10.1	36.9	46.1	27.7	35.6	37.3	36.1	36.6
Mean	9.2	13.3	12.9	9.6	10.3	14.1	15.4	32.6	45.6	40.9	32.7	35.9	47.7	52.3
CD (5%)	N	Zn+B	N at Zn+B		Zn+B at N		-	N	Zn+B	N at Zn+B		Zn+B at N		-
	0.18	0.39	0.73		0.77		-	0.66	1.29	2.45		2.59		-
	Recovery Efficiency for N (%)							Factor productivity for applied N						
N_0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
N_{150}	0.31	0.30	0.34	0.33	0.31	0.36	0.32	29.10	41.20	42.53	32.60	34.60	44.93	37.49
N_{200}	0.27	0.30	0.29	0.27	0.28	0.29	0.29	23.25	32.10	32.45	26.25	28.25	36.10	29.73
N_{250}	0.26	0.25	0.32	0.26	0.24	0.27	0.27	18.24	23.08	21.32	19.56	20.60	21.44	20.71
Mean	0.21	0.21	0.24	0.22	0.21	0.23	0.29	17.65	24.10	24.08	19.60	20.86	25.62	29.31
CD (5%)	N	Zn+B	N at Zn+B		Zn+B at N		-	N	Zn+B	N at Zn+B		Zn+B at N		-
	0.003	0.007	0.012		0.013		-	0.31	0.72	1.35		1.44		-

4.13 Effect of nitrogen, phosphorus and sulphur fertilization in soybean

The results of a field experiment at Devgadhbaria revealed that apart from beneficial effect of N and P effect of S on seed yield of soybean (Gujarat Soybean-I) was found significant in first and third year and in pooled also. Application of 40 kg S ha^{-1} recorded significantly the highest seed yield 893 and 757 kg ha^{-1} during first and third year, respectively. Application of S @ 40 kg ha^{-1} gave significantly higher yield (745 kg ha^{-1}) which was followed by S_1 (20 kg S ha^{-1}) in pooled. The interaction effect of N, P and S was found significant in pooled analysis (Table 4.19). The results revealed that combined application of 45 kg N ha^{-1} + 60 kg P_2O_5 ha^{-1} + 40 kg S ha^{-1} a recorded significantly the highest seed yield (855 kg ha^{-1}) and was at par with treatment combination $N_2P_2S_1$.

The results on Zn and S uptake by soybean seed revealed that N and P levels showed significant effect to increase Zn uptake by grain in individual year as well as in pooled also (Table 4.20). The Zn uptake was significantly higher at N_2 (45 kg ha^{-1}) and P_2 (60 kg ha^{-1}) level over respective lower levels. The S application did not alter Zn uptake significantly by seed The S uptake was significantly higher at higher level of N (45 kg ha^{-1}) and P (60 kg ha^{-1}) application over their respective lower levels. In case of P, its application showed non-significant effect on S uptake by soybean seed.

Table 4.19: Response of soybean to N, P and S fertilization on seed yield

Treatment	Seed Yield (kg ha^{-1})			
	2008	2009	2010	Pooled
Nitrogen Levels (N)				
N_1 (30 kg ha^{-1})	772.0	515.1	700.5	662.5
N_2 (45 kg ha^{-1})	926.7	623.4	759.1	769.7
S. Em ±	12.5	13.4	15.8	19.6
C. D. at 5 %	36.0	38.4	45.5	NS
Phosphorus Levels (P)				
P_1 (30 kg ha^{-1})	805.5	534.6	668.5	672.5
P_2 (60 kg ha^{-1})	893.2	594.9	791.1	759.7
S. Em ±	12.5	13.4	15.8	14.6
C. D. at 5 %	36.0	38.4	45.5	NS
Sulphur Levels (S)				
S_0 (00 kg ha^{-1})	809.2	552.4	687.0	628.9
S_1 (20 kg ha^{-1})	846.1	569.5	745.6	720.4
S_2 (40 kg ha^{-1})	892.8	585.9	756.7	745.1
S. Em ±	15.3	16.4	19.4	10.0
C. D. at 5 %	44.0	NS	55.7	28.0
Interaction	NS	NS	NS	Sig.
CV%	7.2	11.5	10.6	9.64

Interaction effect of N x P x S

	S_0	S_1	S_2
N_1P_1	581.0	602.4	676.8
N_1P_2	692.6	723.9	698.4
N_2P_1	701.9	723.0	750.0
N_2P_2	756.0	832.3	855.2
S. Em ±		19.9	
C.D. at 5%		56.0	

Table 4.20: Effect of nitrogen, phosphorus and sulphur on S (kg ha^{-1}) and Zn uptake (g ha^{-1}) by soybean seed

Treatments		S uptake (kg ha^{-1})			Zn uptake (g ha^{-1})		
		2008	2009	Pooled	2008	2009	Pooled
Nitrogen levels							
N_1 (30 kg ha^{-1})		31.8	42.5	37.1	3.0	2.7	2.9
N_2 (45 kg ha^{-1})		38.9	49.3	44.2	3.7	3.4	3.5
S. Em ±		0.90	1.0	0.68	0.06	0.12	0.06
CD @ 5%		2.6	2.9	1.9	0.2	0.3	0.2
Phosphorus levels							
P_1 (30 kg ha^{-1})		33.6	43.2	38.3	3.2	3.0	3.1
P_2 (60 kg ha^{-1})		37.2	48.7	42.9	3.5	3.1	3.3
S. Em ±		0.90	1.0	0.68	0.06	0.12	0.068
CD @ 5%		2.60	2.9	1.90	0.2	NS	NS
Sulphur levels							
S_0 (No S)		33.9	48.2	41.1	3.1	2.7	2.9
S_1 (20 kg ha^{-1})		35.9	45.7	40.8	3.4	3.1	3.3
S_2 (40 kg ha^{-1})		36.3	43.8	40.1	3.6	3.4	3.5
S. Em ±		1.1	1.2	1.7	0.1	0.1	0.1
CD @ 5%		NS	NS	NS	0.2	0.4	0.22
CV%		12.5	10.9	11.6	8.4	18.5	13.9
Y	S. Em ±	-	-	-	-	-	0.07
	CD @ 5%	-	-	-	-	-	0.18

4.14 Potassium and sulphur interactions and their effect on yield and quality of raya

Application of potassium and sulphur, in general, increased the seed and straw yield of raya (RH-30) at all levels of their application in an experiment at Hisar. The significant response in yield was, however, observed with sulphur application up to a level of 20 kg S ha^{-1} (5.8% in seed and 6.1%). Potassium application though resulted in yield increase at all levels but in comparison the response at successive levels was non-significant. Interaction of K and S both in seed and straw yield was also found non-significant (Table 4.21).

Table 4.21: Effect of different potassium and sulphur levels on seed and straw yields (t ha^{-1}) of raya crop

K levels (kg K_2O ha^{-1})	Seed yield	Straw yield
0	2.74	8.41
20	2.75	8.56
40	2.85	8.54
60	2.83	8.55
CD (5%)	NS	NS
S levels (kg S ha^{-1})	**Seed yield**	**Straw yield**
0	2.65	8.07
20	2.80	8.57
40	2.88	8.70
60	2.85	8.72
CD (5%)	0.13	0.29

Similarly, protein content was also found to increase significantly with each level of S and k application. However, the increase in protein content was more with S application compared to K (Table 4.22).

Table 4.22: Effect of different K and S levels on protein content (%) in raya seed

K levels (kg K_2O ha^{-1})	S levels (kg ha^{-1})			
	0	20	40	60
0	13.88	15.25	15.81	16.81
20	14.88	15.44	16.13	17.94
40	15.63	16.06	17.00	17.94
60	15.19	15.56	18.13	18.38
Mean	14.89	15.58	16.77	17.77
CD (5%)	K=0.23 S=0.23 K x S = 0.46			

4.15 Enhancement of micronutrient concentration in fodder/grass for nutritional enrichment

Micronutrients play an important role in crop-animal-human chain for their health and productivity. Though it is normal to apply micronutrients or other nutrients to augment the crop/fodder production, it is essential to supply them in adequate quantities to animals (for milch/meat) in a way that would help to enhance the their produce and thereby to humans, as long as such application is within the realm of cost-benefit ratio and without any undesirable effect on soil quality and production capabilities. In this direction, as an initiative, an experiment was planned to study the effect of micronutrient sprays on fodder jowar for their effect on enrichment of micronutrients in fodder jowar which is usually fed to milch animals.

Application of different concentration of micronutrients helped in increasing the green fodder yield of jowar significantly (Table 4.23). Highest green fodder yield of 21.67 t ha^{-1} was recorded due to combined application of micronutrients of 0.50 % Cu, Zn, Fe, Mn + 0.050 % B .This yield was 48.2% higher than that of control, 11 % higher over that of 0.25 % Cu, Zn, Fe, Mn + 0.025 % B and 25.76 % higher over that of 0.10 % Cu, Zn, Fe, Mn + 0.010 % B.

Table 4.23 Yield of green fodder jowar (t ha^{-1}) at harvest (60days)

Spray schedule	Nutrient concentrations				Mean
	Control	0.10 % Cu, Zn, Fe, Mn + 0.010 % B	0.25 % Cu, Zn, Fe, Mn + 0.025 % B	0.50 % Cu, Zn, Fe, Mn + 0.050 % B	
Single spray-10D	16.41	17.09	17.69	18.79	**17.49**
Single spray-20D	15.89	17.99	21.57	23.03	**19.62**
Single spray-30D	14.72	17.04	21.16	23.13	**19.01**
Single spray-40D	14.25	16.72	18.94	21.93	**17.96**
Mean for one spray	**15.32**	**17.21**	**19.84**	**21.72**	**18.64**
Two sprays-20,40 D	14.41	19.79	20.54	21.24	**18.99**
Three sprays-10,20,40 D	13.76	16.35	19.46	22.07	**17.91**
Four sprays-10,20,30,40 D	12.9	15.62	17.27	21.53	**16.83**
Mean for more than one spray	**13.69**	**17.25**	**19.09**	**21.61**	**15.76**
Mean for all sprays	**14.62**	**17.23**	**19.52**	**21.67**	
CD(P=0.05)	For treatments 1.97				
	For time intervals 1.73				

Among the number of sprays given at different periods, a comparison has been made between one spray made at different periods of crop growth and more than one spray given to crop. When single spray was given either at 20 or 30 days after sowing, the green fodder yield recorded was on par (19.62 at 20 DAS and 19.01 t ha^{-1} at 30 DAS). Further the single spray given at 40 days after spray recorded the lower green fodder yield (17.96 t ha^{-1}) indicating that supply of micronutrient mixture in single spray form need to be applied at much earlier stage of crop. Single spray given at 10^{th} day did not result in similar yield like that of 20 and 30^{th} day spray. Therefore, single spray to green fodder jowar either at 20 and 30^{th} day after sowing appears to be beneficial for obtaining higher forage yield (Table 4.23).

The results indicated that mean concentration of micronutrients in fodder jowar due to treatments was found to be 24.7 in case of Zn 4.38 in case of Cu, 135 in case of Fe, and 39.7 in case of Mn (Table 4.24). The increment of these micro nutrients over control (no micronutrient spray) was to an extent of 8.75 to 26.73 for Zn, 20.8 to 85.2 for Cu, 11.4 to 39.5 for Fe, 14.89 to 48.95 for Mn and 13.85 to 22.77% for B due to their application in various foliar application treatments. There was not much difference in micro nutrient concentrations by the spray schedule or due to increased number of sprays.

The experimental results revealed that a single spray of micro nutrient mixture either at 20^{th} or 30^{th} day was found to help in realizing higher green fodder yield (19.06 t ha^{-1}). Similarly the micro nutrient concentration which has a bearing on the enrichment of fodder was also found to be beneficial due to their spray. Field operations revealed that sufficient foliage at 30 days of crop growth is good for carrying out the spray. Therefore it is concluded that a single spray of multi micro nutrient mixture of 0.50 % Cu, Zn, Fe, Mn + 0.050 % B given at 20 or 30 days or in between 20 to 30 days after sowing is most beneficial for obtaining higher green fodder jowar and to enrich this fodder with Zn, Cu, Fe, Mn and B.

Table 4.24: Effect of micronutrient sprays on Zn, Cu, Fe and Mn concentration in Fodder jowar

Spray Schedule	Zn					Cu				
	Control	0.10 % Cu, Zn, Fe, Mn + 0.010 % B	0.25 % Cu, Zn, Fe, Mn + 0.025 % B	0.50 % Cu, Zn, Fe, Mn + 0.050 % B	Mean	Control	0.10 % Cu, Zn, Fe, Mn + 0.010 % B	0.25 % Cu, Zn, Fe, Mn + 0.025 % B	0.50 % Cu, Zn, Fe, Mn + 0.050 % B	Mean
Single spray-10D	21.8	23.5	25.9	26.1	24.31	2.68	3.96	4.44	5.78	4.22
Single spray-20D	21.7	23.3	24.4	25.3	23.66	2.55	3.58	4.76	5.83	4.18
Single spray-30D	21.3	23.9	25.3	26.5	24.25	3.2	3.93	4.49	5.99	4.4
Single spray-40D	21.6	23.6	25.9	27.3	24.58	2.95	3.48	4.84	6.40	4.42
Mean for one spray	21.6	23.6	25.4	26.3	24.2	2.85	3.74	4.63	6.00	4.3
2 sprays-20,40 D	21.9	23.1	25.9	26.2	24.25	3.15	3.59	4.56	5.37	4.17
3 sprays-10,20,40 D	22.1	23.9	26.6	28.5	25.27	3.26	3.96	4.55	6.36	4.53
4 sprays-10,20,30,40 D	21	23.7	25.4	27.8	24.49	3.09	3.95	4.82	5.88	4.44
Mean for more than one spray	21.6	23.6	25.8	27.2	24.55	3.09	3.81	4.64	5.9	4.36
Overall Mean	21.7	23.6	25.9	27.5	24.67	3.17	3.83	4.64	5.87	4.38
	Fe					Mn				
Single spray-10D	108	125	139	143	129	32.5	39.1	42.5	46.38	40.1
Single spray-20D	106	122	138	162	132	33.6	41.1	43.6	49.25	41.9
Single spray-30D	115	124	141	155	134	31.9	39.4	42.1	45.37	39.7
Single spray-40D	109	128	143	181	140	33.0	39.3	46.5	52.25	42.8
Mean for one spray	110	125	140	160	134	32.8	39.7	43.7	48.31	41.1
2 sprays-20,40 D	117	128	139	164	137	32.8	35.1	42.5	47.62	39.5
3 sprays-10,20,40 D	115	131	147	162	139	33.2	38.8	41	44.37	39.3
4 sprays-10,20,30,40 D	110	121	140	150	130	32.7	39.6	42.6	47.12	40.5
Mean for more than one spray	113	126	142	159	135	32.9	38.3	42.5	46.86	40.1
Overall Mean	114	127	141	159	135	32.9	37.8	42.0	46.37	39.8

CHAPTER –V

SCREENING OF CULTIVARS OF CROPS FOR MICRONUTRIENT EFFICIENCY AND BIOFORTIFICATION

The essentiality and importance for micronutrients in plants (Marschner, 1995) and animals has long been recognized (Mertz, 1987). But in India the intensification of agriculture to meet the increasing food demand of burgeoning population had accentuated soils hunger for micronutrients. On average, about 44, 15, 6 and 8%, soils of India are deficient in Zn, Fe, Mn and Cu, respectively (Shukla and Behera, 2011). Similarly, B and Mo deficiencies have been recorded in 33 and 13% of the soil samples, respectively. In recent years, increased emphasis is being given on micronutrient malnutrition in human being. The probable reason for micronutrient malnutrition especially, in vegetarian population is consumption of agricultural produce with insufficient micronutrient content produced from micronutrient deficient soils. The situation has further worsened with little use of micronutrients fertilizer coupled with little removal from the soil. Micronutrient malnutrition has been identified as a major underlying cause of numerous human health problems. According to an estimate about 3 billion people in the world are affected by Zn and Fe deficiencies (Hotz and Brown, 2004). In India, malnutrition is prevalent particularly in women, children and adolescents. It warrants immediate attention for proper growth and development of human being.

Micronutrient deficiency is referred as the hidden hunger since it is not an obvious killer or crippler, but extracts heavy human and economic cost. Nutritional disorder cannot be subsumed under infectious and non communicable diseases like cancer and cardiovascular. Nutrition is equally rather more important as neither communicable nor non-communicable diseases can be controlled without good nutrition. Therefore, it is important to ensure a balanced diet adequate in macro- and micronutrients to avoid micronutrient malnutrition.

There are three ways to address the micronutrient malnutrition, one dietary supplementation with micronutrients, second, improving the diet composition by including more pulses, fruits and animal protein and third, fortification/enrichment of cereal grains with micronutrients. In present programme, we have focused on biofortification i.e., enrichment of food grains through external supply; at different locations of India. In order to enrich the grains/feed/fodder through micronutrients application, the first step is to identify the cultivars which can respond to external application of micronutrients or self capable deriving more nutrients from soil. We have screened a large number of cultivars, widely grown by the farmers, of different crops, viz., rice, wheat, maize, chickpea, pigeon pea and green gram for Zn, Fe and Mn nutrition.

In North India, Zn enrichment study was performed at Kanpur (wheat and pigeon pea), Palampur (maize and wheat) and Pantnagar (rice and wheat) and Mn enrichment study at PAU, Ludhiana (wheat and rice). In South India, Hyderabad (rice and maize) and Coimbatore (maize) and in Eastern India, Jorhat (rice), Bhubaneswar (rice), Kalyani (rice) and Ranchi (rice), centers did Zn enrichment study. At PUSA, Bihar (rice, wheat and maize) which also belongs to eastern part and at Anand (green gram and pigeon pea), the Western part of India, study was performed for Fe enrichment. In Central India experiments were planned at Bhopal (pigeon pea and wheat) and Jabalpur (rice and wheat) for screening Zn enriched varieties.

Field experiments were conducted with 20-38 cultivars of each crop rice, wheat, maize, chickpea, pigeon pea and green gram in split plot design at three level of Zn application i.e., No-Zn control, 20 kg Zn ha^{-1} through basal application and 20kg Zn ha^{-1} soil application in combination of 0.5% foliar spray of $ZnSO_4$. Similar treatment sets were kept for Fe and Mn. At maturity total grain and straw/stover yield was recorded and concentration of respective micronutrient in straw/stover and grain was estimated using Atomic Absorption Spectrophotometer by following standard procedures. Respective micronutrient uptake was estimated by multiplying yield and concentration of micronutrient. Further, yield efficiency index and uptake efficiency index for different crop cultivars under different micronutrient study were determined using the following formula outlined by Graham *et al* (1995).

Uptake efficiency index*= (Total Uptake in control plots /Total uptake in treated plots) X 100*

Yield efficiency index*= (Total Yield in control plots /Total yield in treated plots) X 100*

Yield Efficiency Index and Uptake Efficiency Index values of each cultivar were plotted in scattered diagram to find out efficient as well as inefficient cultivars. The cultivars having high yield as well as uptake efficiency index were fall in quadrant A as depicted in scattered diagram and defined as genetically-efficient cultivars, while reverse of this fall in quadrant C and defined as genetically-inefficient cultivars. Interestingly, the genetically inefficient cultivars were agronomically highly efficient. Thus, the efficient cultivars may be utilized by breeders for QTL identification and developing high yielding micronutrient enriched cultivars (genetic biofortification) while the inefficient cultivars may be used for agronomic biofortification to dense the grains of highly responsive cultivars with micronutrients. Of Zn, Fe and Mn efficient and inefficient cultivars of different crops, the list of identified genetically efficient and inefficient cultivars along with their yield and nutrient concentration under no- Zn control and combined application of soil plus foliar application at different centers are explained below.

5.1 Biofortification with Zn in crops at different locations

A. Maize & Wheat at Palampur (Himachal Pradesh)

Zinc enrichment studies were conducted in maize crop during 2009 and 2010, at three locations of Himachal Pradesh *viz.*, Palampur, Shivalik Agricultural Research and Extension Centre (SAREC), Kangra and Hill Agricultural Research and Extension Centre (HAREC), Bajaura (Distt. Kullu), with eighteen varieties of maize at each location. The degree of increase varied with crop type and crop genotype. Location or soil type also influenced the extent of increase in micronutrient concentration in seed/grain of crops.

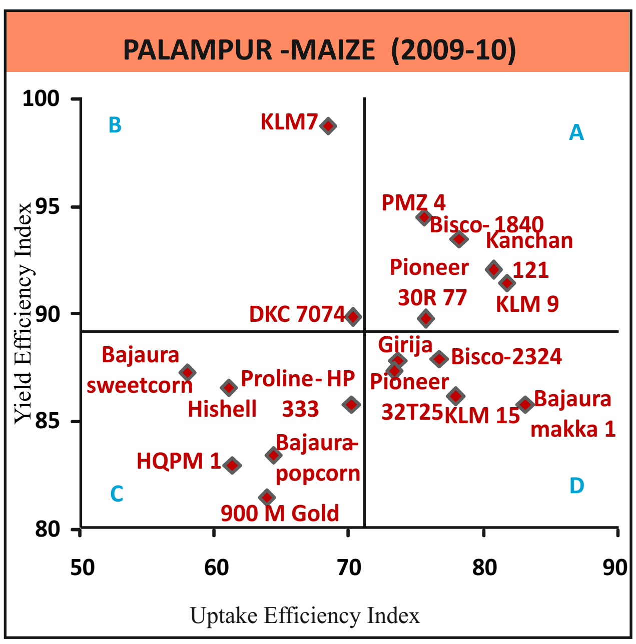
Soil and foliar application of Zn was little effective in increasing the grain yield of efficient variety of maize as compared to inefficient variety (Table 5.1). Among the efficient cultivars, the maximum increase in yield was recorded 9% (KLM-9 and Kanchan) during 2009-10 while it was 17% (Pioneer 30R 77) during 2010-11. The yield enhancement in inefficient cultivars of maize was registered 23% (900 M Gold) and 40% (Bajaura Popcorn), during 2009-10 and 2010-11, respectively. Foliar feeding of Zn along with soil application has resulted in significant increase in Zn concentration in maize grains.

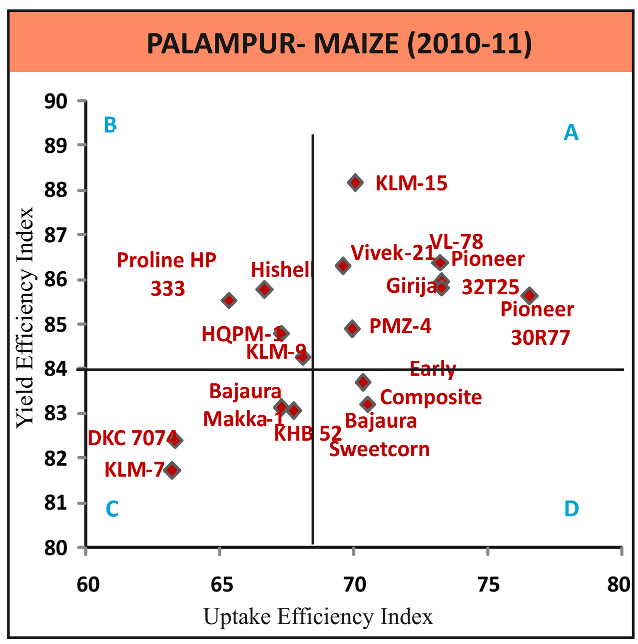
Table 5.1: Effect of Zn biofortification strategies on grain yield and zinc concentration in different cultivars of maize and wheat at Palampur, Himachal Pradesh

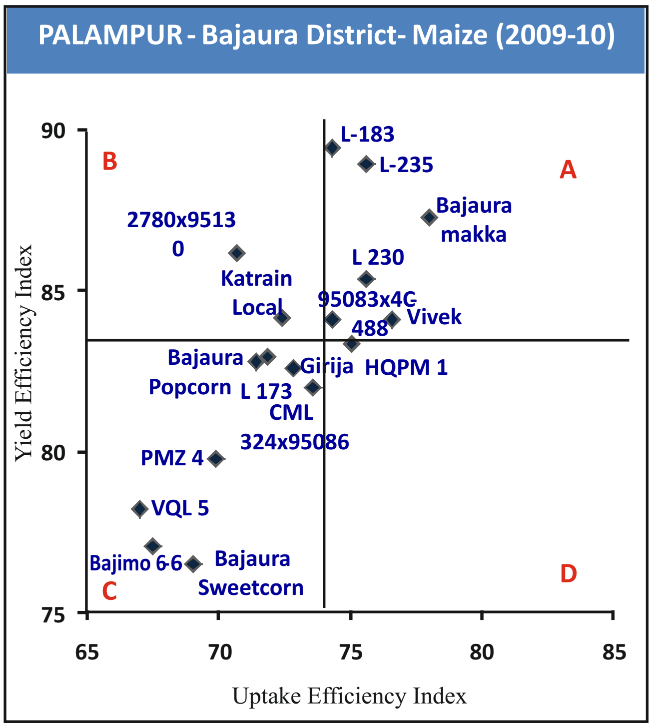
Sites	Efficient Cultivars	Yield ($t\ ha^{-1}$)		Conc. ($mg\ kg^{-1}$)		Inefficient Cultivars	Yield ($t\ ha^{-1}$)		Conc. ($mg\ kg^{-1}$)	
		-Zn	+Zn	-Zn	+Zn		-Zn	+Zn	-Zn	+Zn
					Maize					
Palampur	KLM 9	3.42	3.74	28.5	31.9	900 M Gold	4.0	4.9	29.0	37.1
	Kanchan 121	3.94	4.28	30.8	35.1	Bajaura Popcorn	2.7	3.2	26.3	34.1
	Bisco 1840	4.30	4.60	27.7	33.1	HQPM 1	3.8	4.6	32.1	43.4
	PMZ4	4.47	4.73	31.9	39.9	Hishell	4.0	4.6	26.5	37.6
Palampur	KLM -15	3.28	3.72	29.0	36.5	Bajaura Popcorn	3.1	4.3	28.7	34.2
	VL-78	3.62	4.19	32.8	38.7	KLM-7	3.0	3.7	26.7	34.5
	Pioneer 32T25	4.65	5.41	32.9	38.6	DKC 7074	4.4	5.3	31.5	41.0
	Pioneer 30R77	4.29	5.01	33.7	37.7	Bajaura-Makka1	3.5	4.2	29.3	36.2
Kangra	Bisco 1840	4.02	4.26	26.2	29.2	KLM 7	3.72	4.5	28.5	38.9
	Pioneer 30 R77	4.94	5.22	34.6	38.5	Girija	3.98	4.7	26.5	37.1
	Proline HP333	5.15	5.44	28.1	33.2	KLM 9	4.13	4.8	21.9	31.3
	Early composite	3.85	4.13	29.9	34.3	Bajaura Popcorn	2.71	3.11	24.5	31.7
						PMZ-4	4.66	5.19	32.5	41.2
Bajaura	Bajaura Makka (L-201)	4.47	5.12	37.9	42.4	Bajaura Sweet corn	2.55	3.33	46.1	51.1
	L-235	3.39	3.81	44.9	52.8	Bajimo 6-6	2.93	3.8	37.4	42.7
	L-183	3.65	4.08	33.0	39.7	VQL 5	1.87	2.39	31.7	37.0
	L-230	3.28	3.84	47.3	53.4	PMZ 4	3.72	4.66	49.5	56.5
	Vivek	3.34	3.97	52.9	58.1	CML-324x95086	3.52	4.29	48.1	53.6
Bajaura	Bajaura Makka	4.52	5.24	41.8	44.9	Bajimo 6-6	2.98	4.03	40.3	45.5
	Ghaigi Local	3.54	4.04	47.5	53.5	VQL-5	1.96	2.65	37.5	40.6
	2780x95130	4.42	4.93	29.5	35.2	Bajaura sweet corn	2.63	3.44	48.7	52.9
	L-235	3.47	3.98	47.3	54.0	PMZ 4	3.81	4.92	56.0	61.6
	L-183	3.73	4.33	36.4	42.0	CML-324x95086	3.61	4.54	50.6	56.2

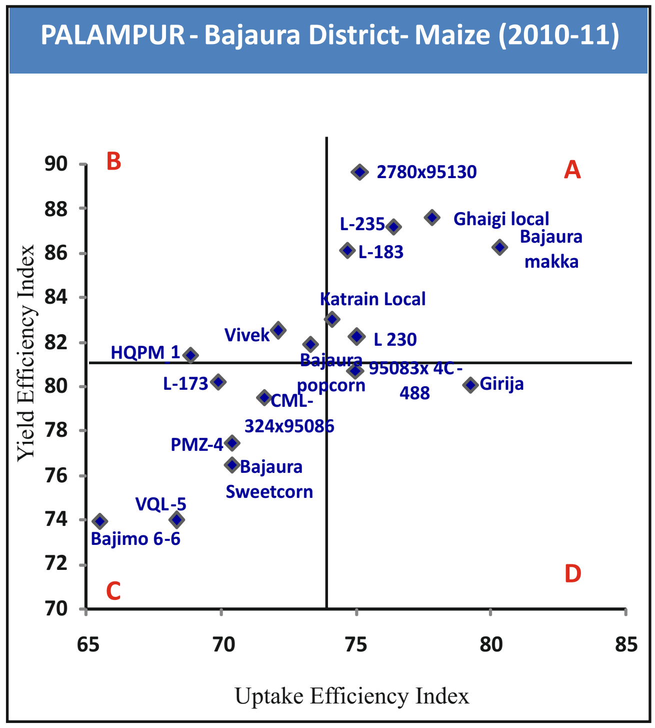
Wheat										
Palampur	VL-829	2.66	2.98	42.25	47.35	HPW-155	2.95	3.53	37.45	44.40
	VL-892	2.65	2.95	41.5	49.65	HS-295	2.96	3.40	39.00	50.55
	HPW 147	2.99	3.34	37.0	44.05	-	-	-	-	-
	HS-420	2.75	3.11	34.55	40.3	-	-	-	-	-
	HPW-89	3.08	3.45	39.0	46.65	-	-	-	-	-
Bajaura	HPW 236	3.53	4.02	55.85	61.45	HS240	2.89	3.97	67.60	73.10
	HPW313	3.45	3.98	51.1	57.85	HPW 155	2.81	3.72	41.20	48.90
	HPW 42	3.82	4.35	39.2	45.15	HPW251	2.51	3.20	29.95	37.95
	HPW 184	2.92	3.44	46.1	51.65	HS- 507	2.48	3.18	23.25	31.10
	VL-920	3.53	4.08	33.7	38.85	HS 277	2.52	3.19	26.30	32.80

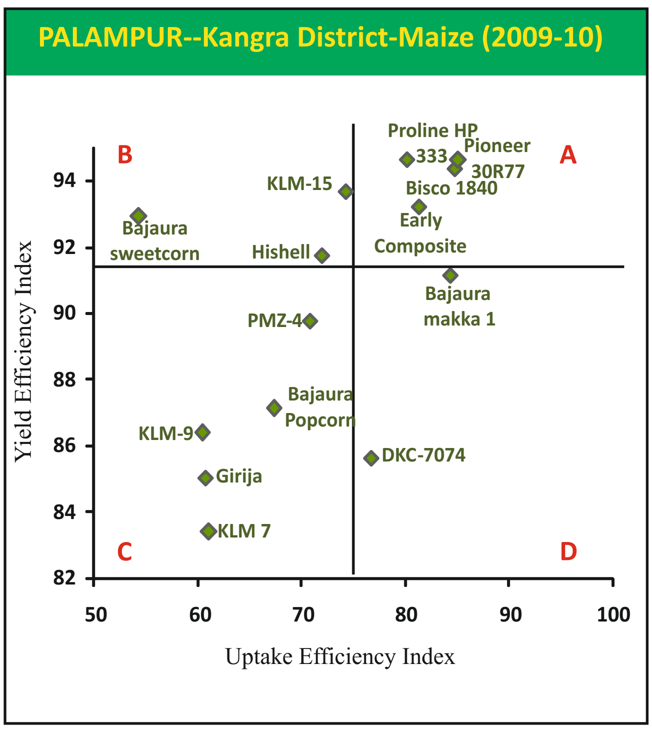
The rise in inefficient cultivar, Hishell (42%) was more than that of efficient cultivar, KLM-15 (26%) over no application of Zn. At the Kangra district, the response of maize to Zn application was less than that of Palampur district. The crop yielded 6 and 16% more with Zn application in efficient and inefficient cultivars, respectively. Application of soil+ foliar Zn increased grain yield of efficient cultivar Vivek) by 19% while in case of inefficient cultivars (Bajimo 6-6, VQL-5) of maize the increase was about 35%, at Bajaura district of Palampur. Zn concentration in efficient cultivar of maize varied from 35.2 to 58.1mg/kg while in inefficient cultivars the concentration ranged between 37 to 61.6 mg/kg.



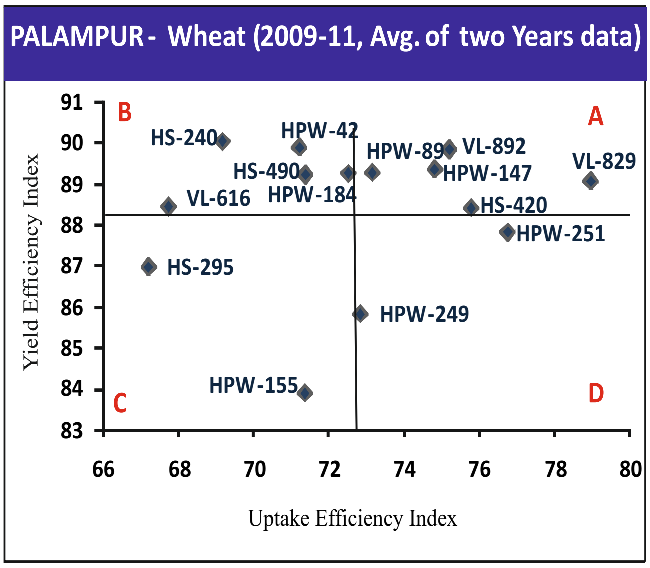


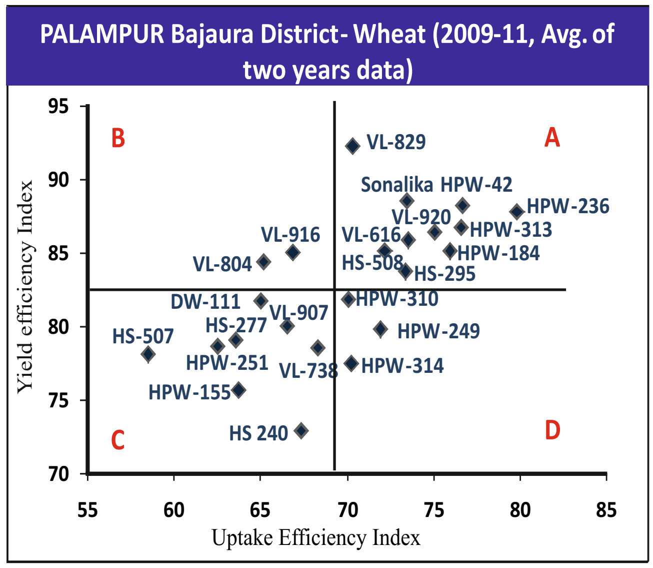






During *Rabi* 2009-10, zinc fortification trial in wheat varieties (14-23 numbers) indicated, 13 to 18% increase in yield of efficient cultivars of wheat (HS-420 and HPW-184) at Palampur and Bajaura, respectively. However, yield increase in inefficient cultivars ranged from 15% (HS-295) to 37% (HS-240) with Zn application over no- Zn control. Similarly, Soil+ foliar feeding of Zn could increase Zn concentration from 8 to 34% in inefficient cultivars and 10 to 20% in efficient cultivars. The cultivars depicted in quadrant B are non-responsive non-efficient as far as Zn concentration is concerned. However, the reverse is true for cultivars in quadrant D.



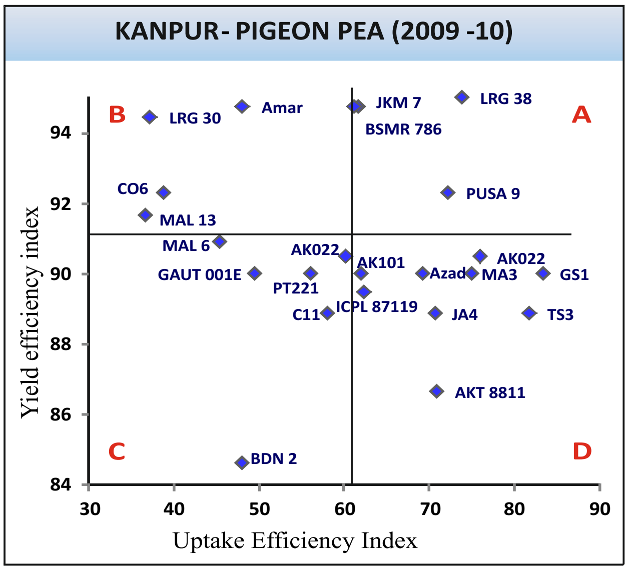


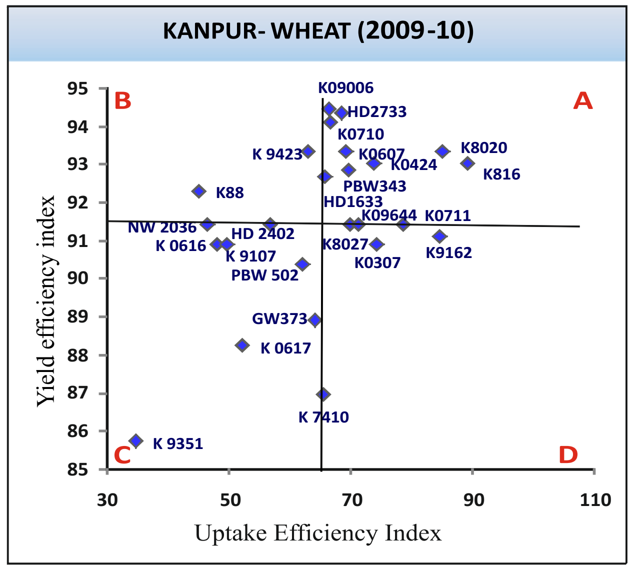
B. *Pigeon Pea and Wheat at Kanpur (Uttar Pradesh)*

Zinc Biofortification trials conducted at Kanpur on pigeon pea during *Kharif* 2009-10 revealed that application of Zn enhanced the pigeon pea grain yield by 13% over no Zn, in inefficient varieties (Table 5.2). Though the maximum yield increase in efficient cultivar (PUSA 9) and inefficient cultivar (BDN 2) was only 9 and 18% while increase in concentration was recorded up to 82% in GAUT 001 E, an inefficient cultivar, and 55% in efficient cultivars (BSMR 736) of pigeon pea. In wheat, response to Zn application was spectacularly much higher for inefficient cultivars as compared to efficient cultivars. Zn application in efficient cultivars yielded 7% more wheat whereas in inefficient cultivars it was 12%. Zn concentration in inefficient cultivars increased by 78% whereas 22% in case of efficient cultivars.

Table 5.2: Effect of Zn biofortification strategies on grain yield and zinc concentration in different cultivars of Pigeon Pea and wheat at Kanpur, Uttar Pradesh

Site	Efficient Cultivars	Yield ($t\ ha^{-1}$)		Conc. ($mg\ kg^{-1}$)		Inefficient Cultivars	Yield ($t\ ha^{-1}$)		Conc. ($mg\ kg^{-1}$)	
		-Zn	+Zn	-Zn	+Zn		-Zn	+Zn	-Zn	+Zn
Kanpur	**Pigeon Pea**									
	LRG 38	1.90	2.00	49.0	63.0	BDN 2	1.10	1.30	38.0	67.0
	JKM7	1.80	1.90	43.0	66.0	GAUT 001 E	1.80	2.00	33.0	60.0
	BSMR 736	1.80	1.90	22.0	34.0	PT 221	1.80	2.00	38.0	61.0
	Pusa 9	2.40	2.60	18.0	23.0					
	Wheat									
	K 816	4.00	4.30	70.0	73.0	K 0617	3.00	3.40	48.0	81.0
	K 8020	4.20	4.50	63.0	69.0	K 0616	4.00	4.40	44.0	83.0
	K 0424	4.00	4.30	58.0	73.0	K 9107	4.00	4.40	40.0	73.0
	K0607	4.20	4.50	55.0	74.0	K9351	3.00	3.50	30.0	74.0
	HD2733	5.10	5.40	50.0	71.0	GW373	4.00	4.50	57.0	79.0



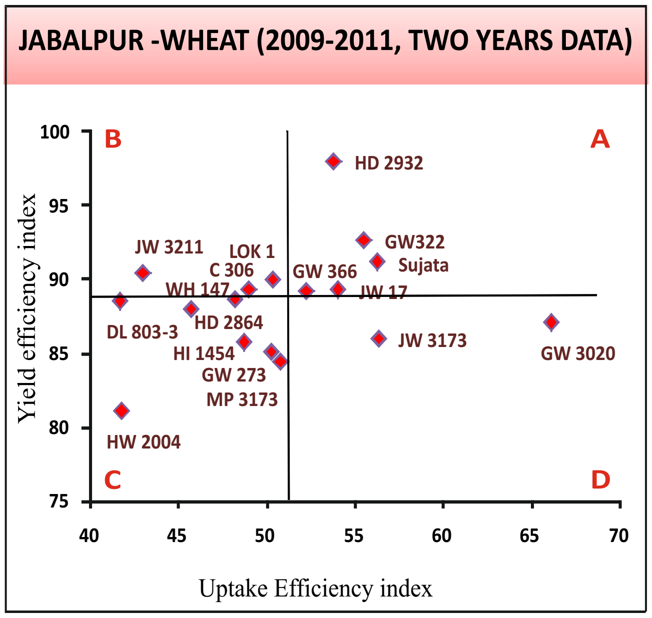


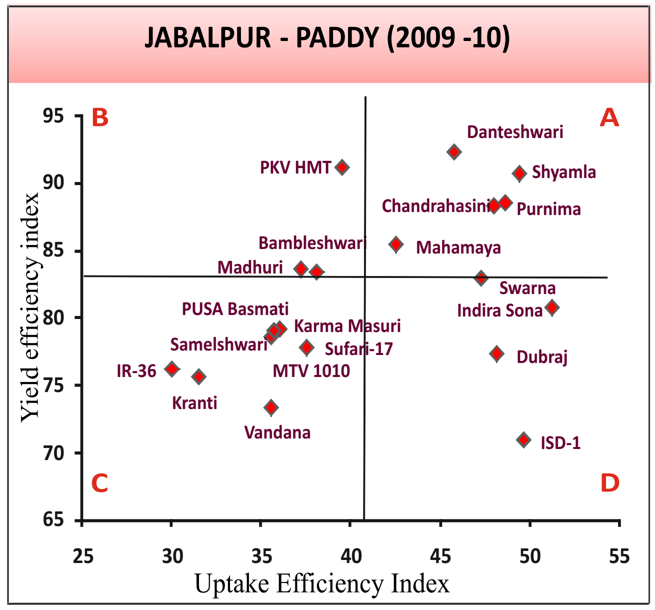
C. *Rice and Wheat at Jabalpur (Madhya Pradesh)*

Field experiment carried out at Jabalpur on wheat and rice during 2009-10 and 2010-11 revealed that increase in content of Zn was doubled in rice with application of soil+ foliar Zn feeding while in wheat it increased upto73% (Table 5.3). Zn application in rice resulted in yield increase of 17% in efficient cultivar (Mahamaya), whereas an increase of 36% in inefficient cultivar (Vandana). Similarly, efficient wheat cultivars, responded to Zn application in lesser yield increment (8%) than that of inefficient cultivars (19%).

Table 5.3: Effect of Zn biofortification strategies on grain yield and zinc concentration in different cultivars of Rice and wheat at Jabalpur, Madhya Pradesh

Site	Efficient Cultivars	Yield ($t\ ha^{-1}$)		Conc. ($mg\ kg^{-1}$)		Inefficient Cultivars	Yield ($t\ ha^{-1}$)		Conc. ($mg\ kg^{-1}$)	
		-Zn	+Zn	-Zn	+Zn		-Zn	+Zn	-Zn	+Zn
Jabalpur					Rice					
	Danteshwari	4.50	4.89	9.10	18.31	Vandana	3.81	5.20	7.42	15.27
	Chandrahasini	4.19	4.75	7.74	14.20	IR-36	4.44	5.83	7.72	19.54
	Purnima	3.90	4.41	9.97	18.10	Samleshwari	3.74	4.76	8.20	18.10
	Mahamaya	3.67	4.30	8.64	17.33	Karma Masuri	3.84	4.86	8.00	17.67
					Wheat					
	HD2932	5.19	5.49	19.53	35.71	HW 2004	3.55	4.37	20.74	40.26
	GW322	5.35	5.81	19.69	32.32	MP3173	4.21	4.99	23.01	38.12
	Sujata	3.65	4.01	25.43	41.39	GW273	5.30	6.20	21.14	35.85
						HI1454	4.37	5.16	22.49	39.68



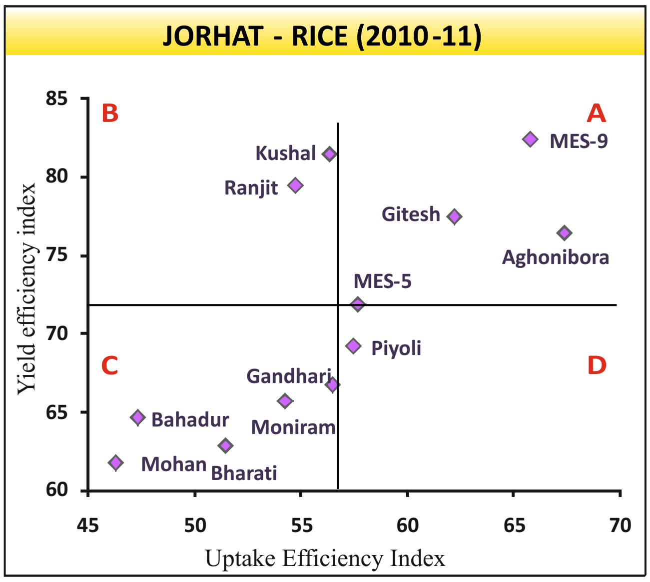


D. Rice at Jorhat (Assam)

On an average, yield increment in rice efficient cultivars was by 27% however, 21% increase was noticed in rice grain Zn content (Table 5.4). Among the efficient cultivars, maximum yield increase was recorded in Aghonibora (31%), while grain Zn content in MES-9 (25%). In inefficient cultivars, increase in yield and concentration were 56% and 28% respectively with maximum yield increase in cultivar Mohan (62%) and content increase in cultivar Bahadur (36%).

Table 5.4: Effect of Zn biofortification strategies on grain yield and zinc concentration in different cultivars of Rice at Jorhat, Assam

Site	Efficient Cultivars	Yield (t ha^{-1})		Conc. (mg kg^{-1})		Inefficient cultivars	Yield (t ha^{-1})		Conc. (mg kg^{-1})	
		-Zn	+Zn	-Zn	+Zn		-Zn	+Zn	-Zn	+Zn
					Rice					
Jorhat	MES-9	2.05	2.49	32.1	40.2	Mohan	2.1	3.4	15.2	20.1
	Gitesh	1.71	2.21	17.2	21.4	Bharati	2.2	3.5	15.8	19.3
	Aghonibora	2.52	3.30	28.4	32.2	Bahadur	3.1	4.8	26.1	35.6
						Moniram	2.8	4.2	33.2	40.2

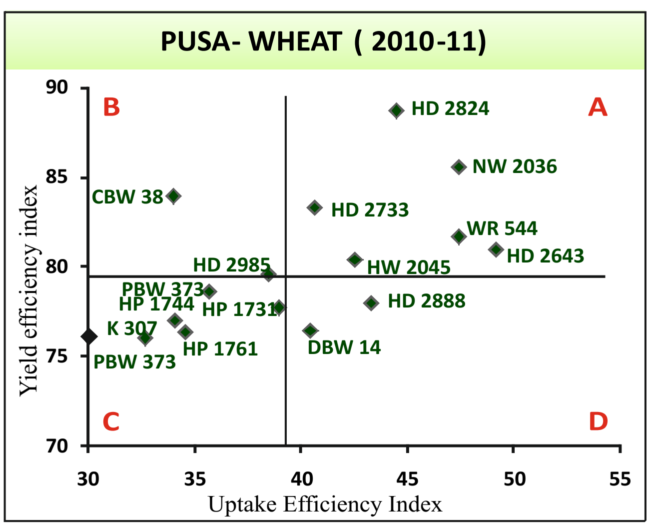


E. *Wheat at Pusa (Bihar)*

Among the wheat cultivars grown at PUSA, Bihar cultivars HD 2824, NW2036, HD2733, WR544 and HD2643 were identified as efficient and cultivars PBW343, K307, HP1761, HP1731 and HP1744 fall in inefficient group (Table 5.5). In inefficient group, cultivars PBW 343 and K307 responded extremely well to Zn application and recorded 31% increase in yield with twice increase in grain Zn content. In efficient cultivars, increase in yield was about half of the inefficient cultivars. The maximum increase in grain yield was 24 % in HD 2643, whereas maximum content increase was recorded in HD 2643 (99%).

Table 5.5: Effect of Zn biofortification strategies on grain yield and zinc concentration in different cultivars of wheat at Pusa, Bihar

Site	Efficient Cultivars	Yield (t ha^{-1})		Conc. (mg kg^{-1})		Inefficient cultivars	Yield (t ha^{-1})		Conc. (mg kg^{-1})	
		-Zn	+Zn	-Zn	+Zn		-Zn	+Zn	-Zn	+Zn
	Wheat									
Pusa	HD 2824	3.67	4.14	15.3	30.5	PBW343	3.8	5.1	13.0	32.9
	NW2036	3.67	4.29	19.9	35.9	K307	4.0	5.3	12.4	28.8
	HD2733	4.19	5.03	18.3	37.5	HP1761	4.0	5.3	15.8	34.9
	WR544	2.62	3.21	23.4	40.3	HP1731	3.2	4.2	14.3	28.5
	HD2643	3.57	4.41	19.8	32.6	HP1744	3.2	4.1	15.1	34.1

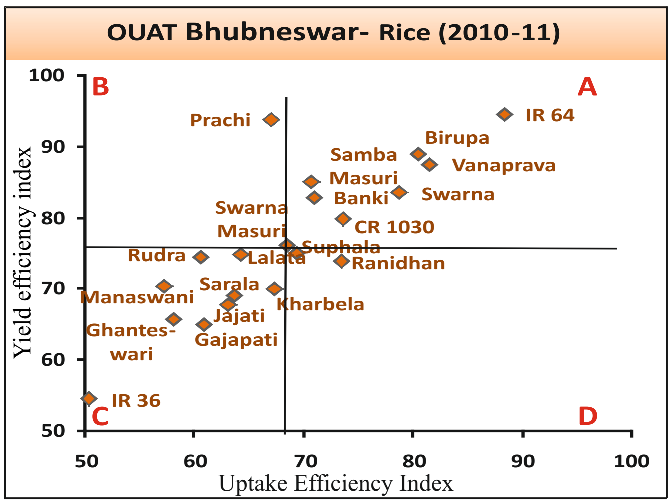


F. *Rice at Bhubaneshwar (Odisha)*

Application of Zn in rice has little less effect on grain yield than that recorded for other crops at other locations. On average, increase in the grain Zn content was 10 and 11% in efficient and inefficient rice cultivars (2010-11). The highest percentage of increase in rice yield was recorded in cultivar Swarna (20%) in the efficient group and IR 36 (84%) in the inefficient group (Table 5.6).

Table 5.6: Effect of Zn biofortification strategies on grain yield and zinc concentration in different cultivars of Rice at Bhubaneshwar, Odisha

Site	Efficient Cultivars	Yield (t ha^{-1})		Conc. (mg kg^{-1})		Inefficient cultivars	Yield (t ha^{-1})		Conc. (mg kg^{-1})	
		-Zn	+Zn	-Zn	+Zn		-Zn	+Zn	-Zn	+Zn
					Rice (2010-11)					
Bhubaneswar	IR64	2.90	3.06	27.13	29.03	IR36	2.4	4.5	31.6	34.2
	Birupa	2.67	3.00	24.90	27.50	Ghanteswari	1.5	2.2	26.8	30.3
	Vanaprava	3.03	3.46	31.20	33.47	Gajapati	2.9	4.5	27.0	28.8
	Samba Masuri	3.03	3.56	24.63	29.60	Jajati	3.5	5.2	24.9	26.7
	Swarna	3.36	4.03	36.33	38.47	Monoswani	2.8	3.9	23.5	28.9

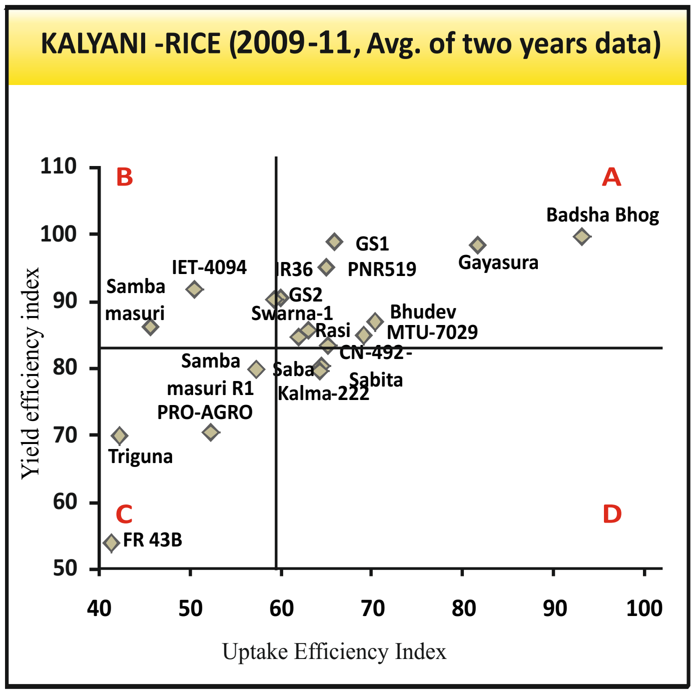


G. *Rice at Kalyani (West Bengal)*

Response of rice cultivar to zinc application was very conspicuous in case of inefficient cultivars, both in terms of yield and content. Increase in yield and grain Zn content was 41 and 43% in inefficient cultivars. Efficient varieties showed a little response to Zn application. On average, the yield rise in efficient group was only 5% with maximum response exhibited by Bhudev (15%). However, a sizeable increase of (31%) was noted in grain Zn content (Table 5.7).

Table 5.7: Effect of Zn biofortification strategies on grain yield and zinc concentration in different cultivars of Rice at Kalyani, West Bengal

Site	Efficient Cultivars	Yield (t ha^{-1})		Conc. (mg kg^{-1})		Inefficient cultivars	Yield (t ha^{-1})		Conc. (mg kg^{-1})	
		-Zn	+Zn	-Zn	+Zn		-Zn	+Zn	-Zn	+Zn
					Rice					
Kalyani	BadshaBhog	2.75	2.75	24.73	27.0	FR 43B	0.63	1.06	42.78	61.48
	Gayasura	2.25	2.31	24.73	29.6	Triguna	2.79	4.13	31.90	50.33
	GS-1	5.54	5.67	41.75	61.0	PRO-AG	2.87	4.12	42.48	55.93
	PNR-519	3.49	3.68	44.78	63.4	Samba Masuri R1	2.75	3.47	29.05	41.43
	Bhudev	3.79	4.34	33.63	42.0					

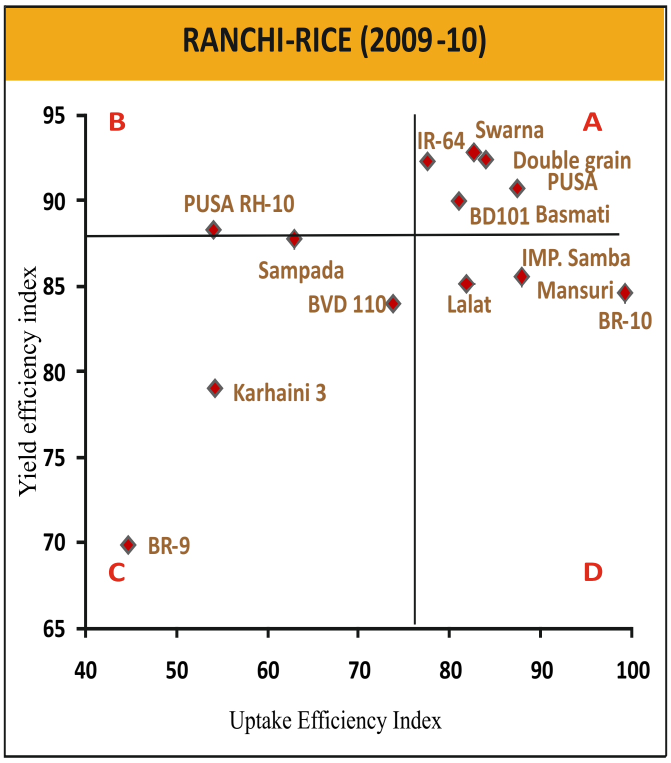


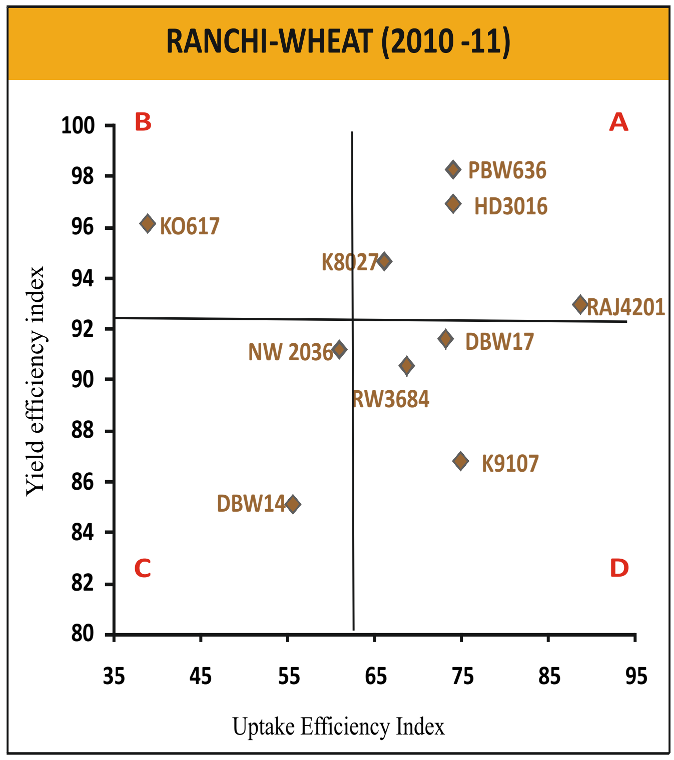
H. Rice and wheat at Ranchi (Jharkhand)

In order to enrich rice and wheat grain with Zn, an experiment carried out at Ranchi exhibited variable increase in yield. In efficient group, increase in yield varied with nature of cultivars from 2.94- 7.11 t ha^{-1} with a total increase of 9% whereas, in the inefficient group an average increase was recorded to the tune of 23% with yield range from 2.83- 8.44 t ha^{-1} (Table 5.8). Grain Zn content in inefficient variety BR-9 showed an increase of 56% (19.67 to 30.67 mg kg^{-1}) with Zn application over no Zn control whereas in the efficient group maximum increase was recorded in cv. IR64 (19%). In wheat, increase in grain Zn content was 15 and 45% in efficient and inefficient cultivars, respectively. In the inefficient group DBW 14 showed a maximum increase in yield (18%) as well as content (53%), whereas in the efficient group, maximum increase in grain Zn content was noticed in PBW636 (33%) with a little increase in yield.

Table 5.8: Effect of Zn biofortification strategies on grain yield and zinc concentration in different cultivars of rice and wheat at Ranchi, Jharkhand

Site	Efficient Cultivars	Yield (t ha^{-1})		Conc. (mg kg^{-1})		Inefficient cultivars	Yield (t ha^{-1})		Conc. (mg kg^{-1})	
		-Zn	+Zn	-Zn	+Zn		-Zn	+Zn	-Zn	+Zn
	Rice									
	Double Grain	5.06	5.47	29.67	32.67	BR-9	3.73	5.34	19.67	30.67
	Swarna	3.86	4.16	33.00	37.00	KARHAI NI-3	2.29	2.90	27.00	39.33
Ranchi	IR64	6.56	7.11	19.33	23.00	BVD-110	2.38	2.83	26.67	30.33
	BD101	2.65	2.94	33.00	36.67	Sampada	7.40	8.44	17.00	23.67
	PUSA Basmati	3.61	3.98	26.33	27.33					
	Wheat									
	RAJ 4201	4.54	4.88	43.00	45.00	DBW 14	4.40	5.17	28.67	43.75
	PBW 636	4.11	4.18	34.33	45.50	RW 3684	4.13	4.56	32.67	43.00
	HD 3016	5.16	5.33	37.33	48.75	NW 2036	3.85	4.22	42.00	62.75





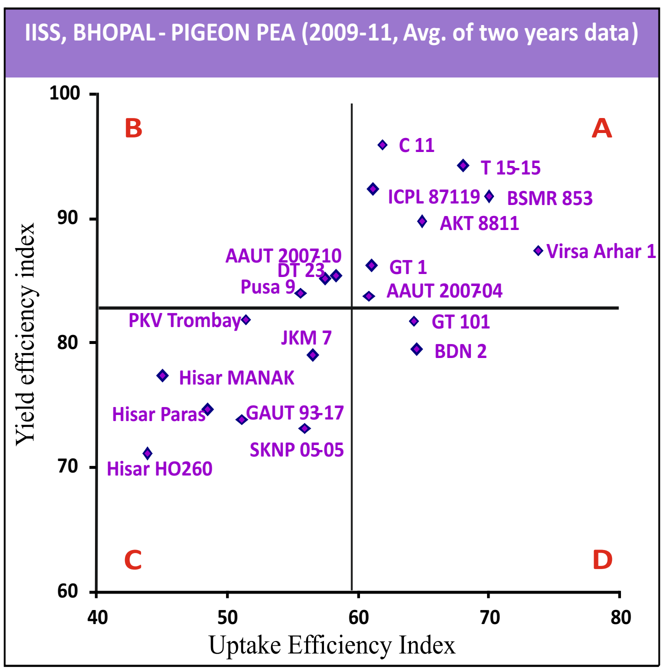
I. *Pigeon pea and wheat at Bhopal (Madhya Pradesh)*

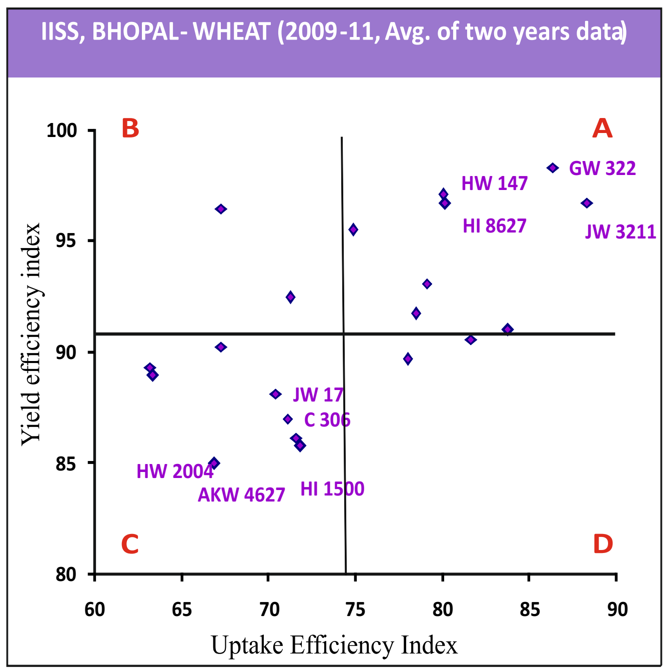
From the biofortification trials conducted at Bhopal, in pigeon pea ICPL 87119, T 15-15 and Virsa Arhar 1 were identified as the efficient cultivars and Hisar HO2-60, Hisar Paras and Hisar Manak as the ineffcient cultivars, whereas in wheat, varieties selected from the efficient group were GW 322, JW 3211 and HI 8627 and varieties selected from the inefficient group were HW 2004, JW 17 and C 306 (Table 5.9). After soil+ foliar application of Zn, the increment in Zn content over control was less in case of wheat (27%) than that of pigeon pea (64%). The increased Zn concentration in pigeon pea varied from 38.7 - 55.7 mg kg^{-1}. In the efficient cultivar of pigeon pea, utmost increase in content was 50% (ICPL 87119) whereas in inefficient cultivar increase was 75% (Hisar Manak).

In wheat increase in content was 15% in efficient cultivars and 27% in inefficient cultivars. Grain Zn content of inefficient wheat variety, HW 2004 showed an increase of 29% whereas in efficient group maximum increase was recorded in cv. HI 8627 (21%). Increase in yield after Zn application was 22% in pigeon pea whereas 8% in wheat. Efficient cultivars of pigeon pea yielded 10% more whereas increase in inefficient cultivars was 35%. In wheat yield increase was only 3% in efficient cultivars and 13% in inefficient cultivars.

Table 5.9: Effect of Zn biofortification strategies on grain yield and zinc concentration in different cultivars of pigeon pea and wheat at Bhopal, Madhya Pradesh

Site	Efficient Cultivars	Yield ($t\ ha^{-1}$)		Conc. ($mg\ kg^{-1}$)		Inefficient cultivars	Yield ($t\ ha^{-1}$)		Conc. ($mg\ kg^{-1}$)	
		-Zn	+Zn	-Zn	+Zn		-Zn	+Zn	-Zn	+Zn
	Pigeon pea									
Bhopal	ICPL 87119	1.84	1.99	27.8	41.8	Hisar HO2-60	0.91	1.28	34.3	56.3
	T 15-15	1.46	1.55	32.3	44.6	Hisar Paras	0.94	1.26	33.1	51.3
	Virsa Arhar 1	1.53	1.76	32.8	38.7	Hisar Manak	0.96	1.24	31.9	55.7
	Wheat									
	GW 322	3.86	3.92	39.0	44.3	HW 2004	2.67	3.13	42.8	55.3
	JW 3211	3.72	3.84	38.6	42.2	JW 17	3.51	3.85	39.4	49.9
	HI 8627	4.09	4.23	39.9	48.1	C 306	2.92	3.34	41.4	51.5





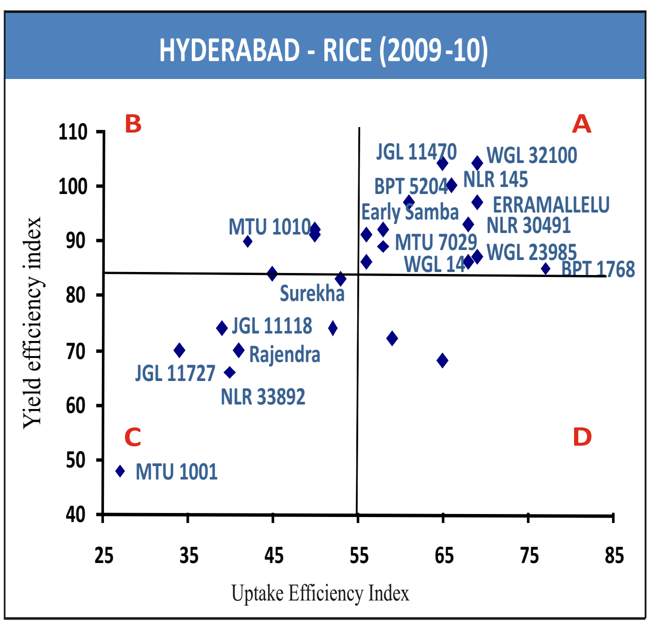
J. *Rice and Maize at Hyderabad (Andhra Pradesh)*

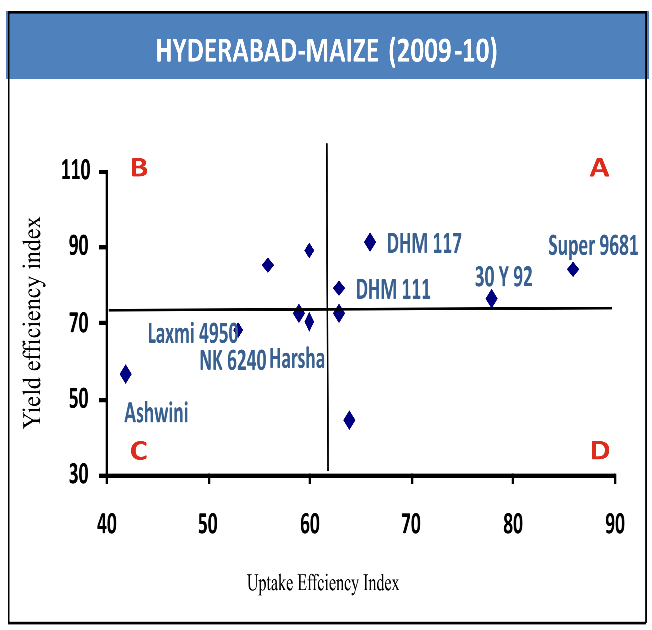
Zn enrichment studies in rice at Hyderabad showed that Zn application could increase 41% Zn concentration in rice grain, varied from 14.2- 20.8 $mg\ kg^{-1}$ (Table 5.10). Inefficient rice cultivars showed 63% increase in yield and 80% increase in Zn concentration. Application of Zn doubled the yield and Zn concentration in inefficient cultivars (MTU 1001 and JGL11727).

Table 5.10: Effect of Zn biofortification strategies on grain yield and zinc concentration in different cultivars of rice and maize at ANGRAU, Hyderabad, Andhra Pradesh

Site	Efficient Cultivars	Yield ($t\ ha^{-1}$)		Conc. ($mg\ kg^{-1}$)		Inefficient cultivars	Yield ($t\ ha^{-1}$)		Conc. ($mg\ kg^{-1}$)	
		-Zn	+Zn	-Zn	+Zn		-Zn	+Zn	-Zn	+Zn
	Rice									
Hyderabad	Erramallelu	5.28	5.44	12.8	17.9	MTU 1001	3.94	8.19	11.7	20.8
	WGL 32100	6.25	6.02	13.2	19.8	NLR 33892	5.23	7.96	8.7	14.2
	NLR 30491	5.83	6.29	12.3	16.7	JGL 11727	6.20	8.80	7.4	15.3
	Maize									
	Super 9681	4.25	4.92	27.2	26.7	Ashwini	3.23	5.74	23.8	31.6
	DHM 117	5.76	6.35	20.6	28.4	Lakshmi 4950	5.20	7.23	22.6	27.4
	DHM 111	4.92	6.19	24.1	30.6	NK6240	5.32	7.73	23.7	30.5

In efficient cultivars of rice, very little increase in grain yield was noticed however, grain Zn content enhanced (41%) significantly. In inefficient cultivars of maize, increment in Zn concentration was 27% whereas it was 19% in efficient cultivars. Total yield enhancement in inefficient cultivars was 50% while in efficient cultivars yield increase was 16%. In the inefficient group, cv. Ashwini showed the maximum increase of 78% (3.23 to 5.74 tha^{-1}) in yield and 33% in concentration (23.8 to 31.6 $mg\ kg^{-1}$). In the efficient group the concentration raised to the tune of 38% in cv. DHM 117.



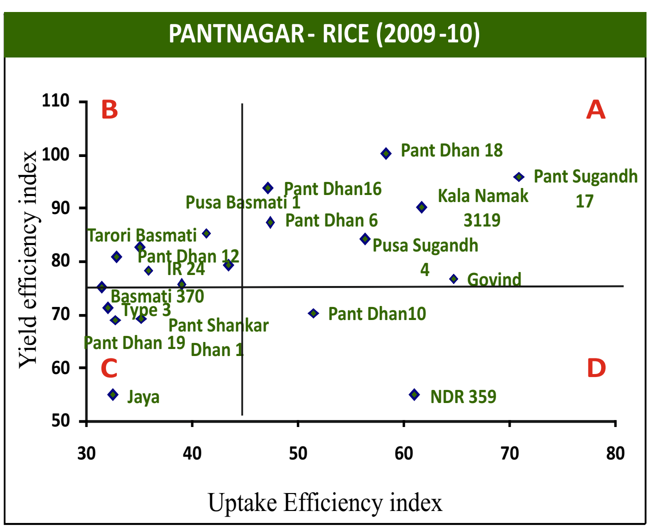


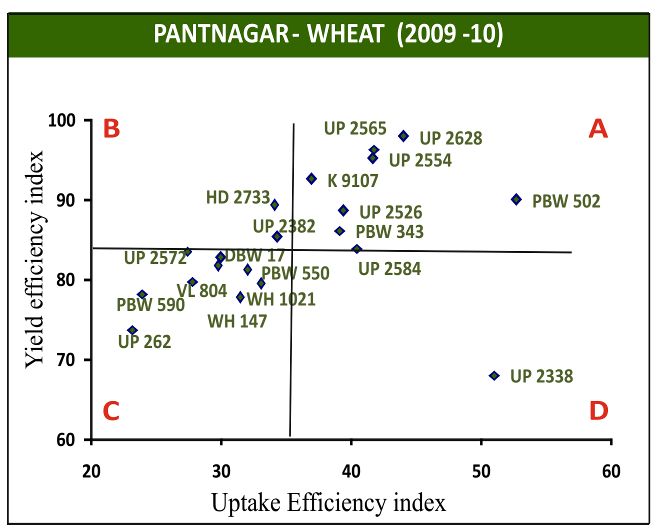
K. *Rice and Wheat at* **Pantnagar** *(Uttarakhand)*

Among the 20 cultivars of rice grown at Pantnagar the inefficient group recorded 55% increase in yield and 87% in Zn concentration. In Pant Dhan 19, Zn application has enhanced the grain Zn content twice (7 to 14.8 mg kg^{-1}) over the control whereas in efficient cultivars maximum rise in content was 68% (Pant Dhan 18). There was the highest increase in yield in efficient cultivars Pusa Sugandh 4 (19%) whereas; increase was 83% in inefficient cultivar, Jaya. In wheat, application of Zn increased the content of Zn many folds both in efficient as well as inefficient group. Rise in concentration was twice than that of the control in efficient group (UP 2565, UP 2628) whereas in inefficient group (UP 262, PBW 590 & VL 804) it was thrice to no-Zn control. Increment in yield was 4% in efficient cultivars whereas 29% in inefficient cultivars.

Table 5.11: Effect of Zn biofortification strategies on grain yield and zinc concentration in different cultivars of rice and wheat at GBPUAT, Pantnagar Uttarakhand

Site	Efficient Cultivars	Yield (t ha^{-1})		Conc. (mg kg^{-1})		Inefficient cultivars	Yield (t ha^{-1})		Conc. (mg kg^{-1})	
		-Zn	+Zn	-Zn	+Zn		-Zn	+Zn	-Zn	+Zn
Pantnagar	**Rice**									
	Pant Dhan 18	5.3	5.3	13.2	22.2	Jaya	4.0	7.3	8.9	14.6
	Pant Sugandh Dhan 17	4.5	4.7	19.1	26.3	Pant Dhan 19	5.3	7.7	7.0	14.8
	Pusa Sugandh 4	4.7	5.6	14.7	23.1	Pant Sankar Dhan 1	4.7	6.8	14.3	27.3
	Wheat									
	UP 2565	4.4	4.6	16.4	37.3	UP 262	3.4	4.6	13.0	41.3
	UP 2628	3.8	3.9	19.6	43.4	PBW 590	3.8	4.9	14.4	46.5
	PBW 502	4.1	4.5	24.1	40.8	VL 804	3.0	3.8	14.7	42.4





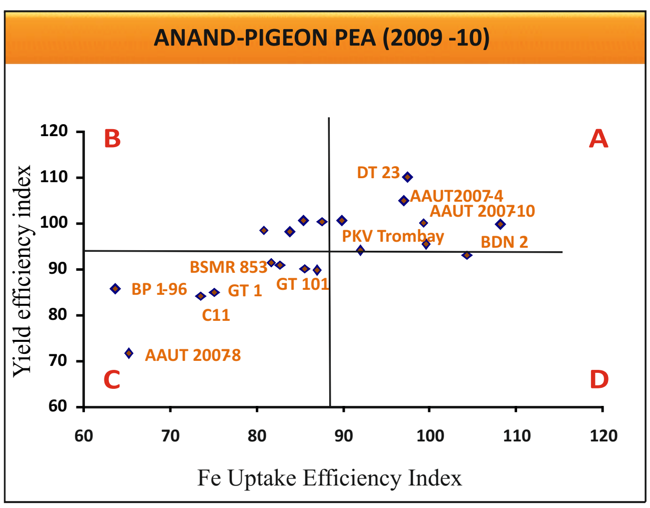
5.2 Biofortification with Fe in crops at different locations

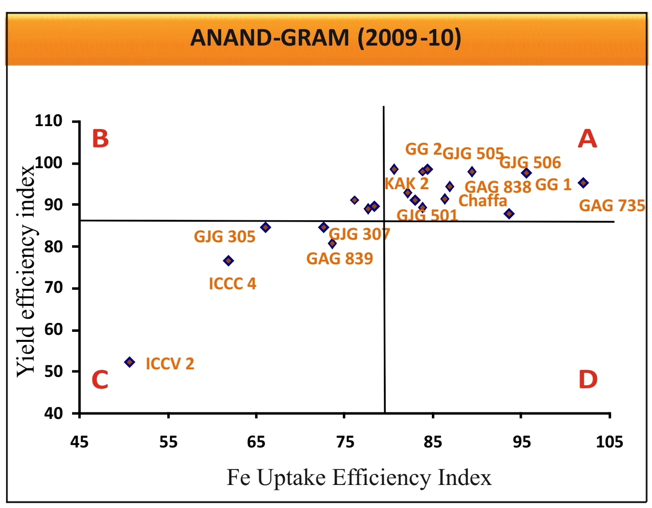
A. Pigeon pea and gram at Anand (Gujarat)

Effect of Fe application on grain yield and Fe concentration in grain was studied in pigeon pea and gram at Anand, Gujarat. Similar to Zn application, Fe could hardly influence the yield of efficient cultivars but it had significant effect on Fe concentration in grain. Efficient cultivars of pigeon pea, exhibited 10% increase in Fe concentration, while in case of inefficient cultivars, increase was 19% (Table 5.12). Among the inefficient cultivars maximum increase in content was 33% (BP-1-96), whereas in efficient cultivars maximum rise was of 11% only (PKV Trombay and DT 23). In the efficient cultivars there was hardly any increase in the yield after Fe application whereas in inefficient cultivars that rise was up to 15%. Similarly, yield and Fe concentration in the efficient cultivars of green gram was less than that recorded in inefficient cultivars which exhibited an increase of 24% in yield and 20% in concentration after Fe treatment.

Table 5.12: Effect of Fe biofortification strategies on grain yield and Fe concentration in different cultivars of pigeon pea and gram at Anand, Gujarat

Site	Efficient Cultivars	Yield (t ha^{-1})		Conc. (mg kg^{-1})		Inefficient cultivars	Yield (t ha^{-1})		Conc. (mg kg^{-1})	
		-Fe	+Fe	-Fe	+Fe		-Fe	+Fe	-Fe	+Fe
	Pigeon pea									
Anand	DT 23	2.63	2.40	33.4	37.0	BP 1 -96	2.32	2.71	29.9	39.8
	AAUT 2007-8	1.82	1.74	37.6	40.6	C 11	2.37	2.82	34.8	39.6
	PKV Trombay	2.78	2.77	32.7	36.4	BSMR 853	2.79	3.06	34.5	38.6
	Gram									
	GJG 506	2.60	2.66	50.3	55.2	ICCC 4	1.99	2.61	59.3	73.7
	GG 1	3.77	3.87	63.8	64.8	GAG 839	1.82	2.26	53.2	58.0
	GAG 838	3.09	3.28	62.8	68.3	GJG 305	3.25	3.85	55.5	70.7



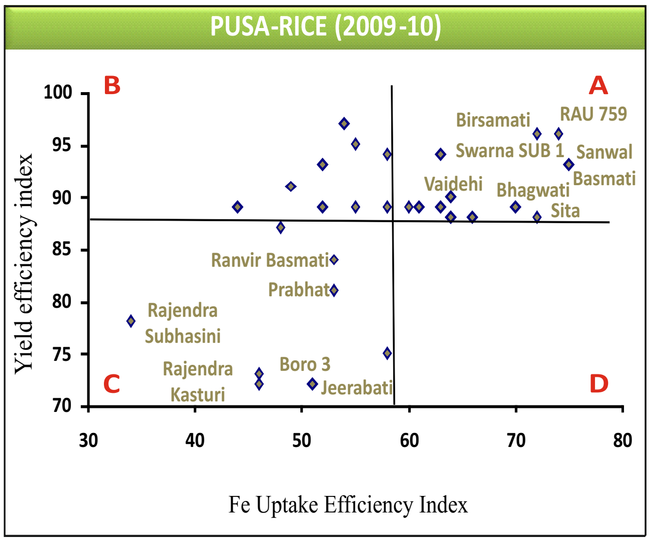


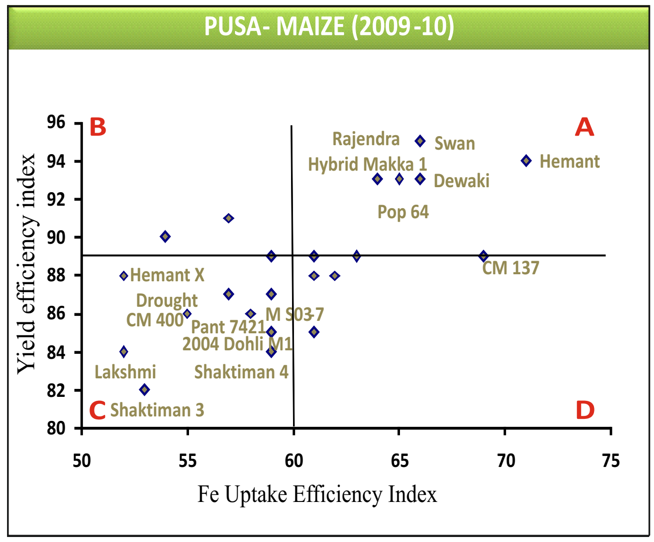
B. Rice, maize and wheat at Pusa (Bihar)

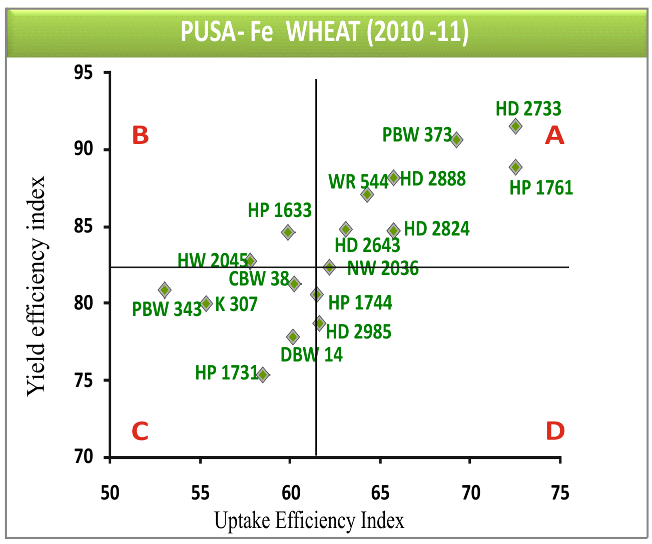
At Pusa, seed loading with Fe enhanced by 33% in efficient cultivars and 73% in inefficient cultivars of rice, with soil plus foliar feeding of Fe. Maximum increase was found in Rajendra Subhashni, in which the Fe content in grain was doubled with Fe application (Table 5.13). There was also a yield increase of 35% in inefficient cultivars. In the inefficient varieties of maize there was an increase of 51% and in efficient varieties the increase was 40% after Fe application. The maximum increase of 57% was there in CM 400. In wheat, application of Fe increase the Fe content up to 52% in inefficient cultivar (PBW343) and 34% in efficient cultivar (HD 2888). Increase in yield was 12% in efficient cultivars and 26% in inefficient cultivars.

Table 5.13: Effect of Fe biofortification strategies on grain yield and Fe concentration in different cultivars of Rice, Maize and Wheat RAU, Pusa (Bihar)

Site	Efficient Cultivars	Yield (t ha^{-1})		Conc. (mg kg^{-1})		Inefficient cultivars	Yield (t ha^{-1})		Conc. (mg kg^{-1})	
		-Fe	+Fe	-Fe	+Fe		-Fe	+Fe	-Fe	+Fe
Pusa	**Rice**									
	RAU 759	6.33	6.58	71.1	93.0	Boro 3	3.29	4.50	38.0	60.1
	Sanwal Basmati	4.58	4.93	74.3	92.1	Rajendra Kasturi	3.17	4.42	46.3	72.0
	Swarna Sub-1	5.10	5.40	47.8	70.9	Rajendra Subhashni	2.92	3.75	25.0	56.8
	Maize									
	Debaki	5.64	6.06	40.1	56.5	Shaktiman 3	5.74	6.97	44.1	69.0
	Hemant	5.10	5.40	46.5	62.2	CM 400	4.52	5.27	37.7	59.3
	Rajendra hyb. Makka1	5.76	6.19	53.1	77.4	Shaktiman 4	5.85	6.95	52.7	75.3
	Wheat									
	HD 2733	3.44	3.76	37.8	47.7	HP 1731	2.68	3.56	42.6	54.8
	HP 1761	3.65	4.11	35.6	43.6	DBW14	3.08	3.96	42.7	55.2
	PBW373	3.37	3.72	36.6	47.9	PBW343	4.16	5.15	30.8	46.9
	HD2888	3.56	4.04	36.8	49.3	K 307	3.55	4.44	29.9	43.2







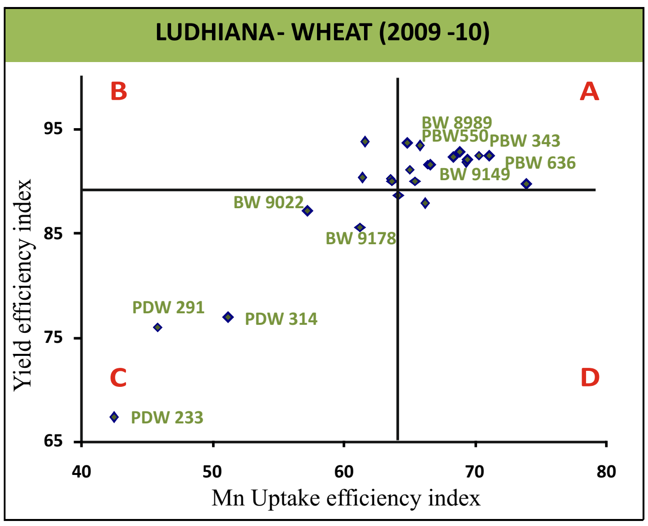
5.3 Biofortification with Mn in crops at different locations

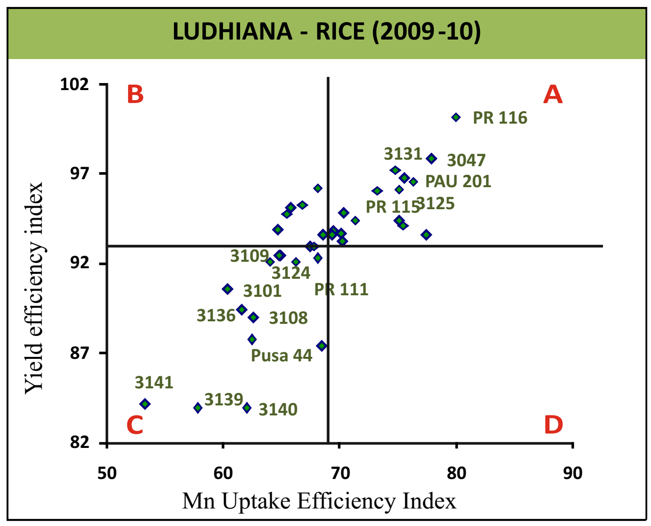
Rice and Wheat at Ludhiana (Punjab)

The Mn enrichment studies in rice and wheat were undertaken at PAU, Ludhiana revealed that increase in rice grain yield was 27% in efficient cultivars whereas 44% increase in inefficient cultivars. Maximum increase in Mn content was noticed in cultivar 3141 with an increase of 55% (26.4 to 40.9 mg kg^{-1}). The maximum increase in inefficient cultivar was 29% (4.5 to 53.4 mg kg^{-1}) in cultivar3047. In wheat, Mn application has resulted in more increase of grain Mn content than that in rice. In inefficient cultivars, increment in Mn content was 56%, whereas, in efficient cultivars it was 34%. In terms of yield, efficient cultivars showed an enhancement of 8% (5.03 to 5.45mg kg^{-1}) and inefficient cultivars by 25% (4.15 to 5.18 mg kg^{-1}). Maximum effect of Mn application was observed on PDW 291 with a content increase of 69% (18.8 to 31.7 mg kg^{-1}) and 33% (from 3.78 to 4.98 t ha^{-1}) in yield increase.

Table 5.14: Effect of Mn biofortification strategies on grain yield and Mn concentration in different cultivars of Rice and Wheat at PAU, Ludhiana (Punjab)

Site	Efficient Cultivars	Yield(t ha^{-1})		Conc. (mg kg^{-1})		Inefficient cultivars	Yield(t ha^{-1})		Conc. (mg kg^{-1})	
		-Mn	+Mn	-Mn	+Mn		-Mn	+Mn	-Mn	+Mn
					Rice					
Ludhiana	PAU 201	6.98	7.23	40.6	51.9	3140	4.17	4.97	28.9	38.8
	3047	6.70	6.85	41.5	53.4	3141	3.92	4.66	26.4	40.9
	PR 116	6.95	6.94	41.2	51.5	Pusa 44	5.35	6.10	31.1	44.4
					Wheat					
	PBW 636	5.17	5.60	26.2	35.5	PDW 291	3.78	4.98	18.8	31.7
	BW 8989	4.95	5.38	23.1	30.8	PDW 314	4.02	5.23	19.9	29.5
	PBW 550	4.97	5.39	28.4	38.2	BW 9022	4.65	5.34	20.3	30.6





From the present investigation it is evident that agronomic manipulation like application of micronutrients to soil and foliar can enhance micronutrient density in edible plant parts which can lead to better human health. The most effective fertilization could be via soil plus foliar feeding (for Zn and, to some extent, Mn) and foliar application (for Fe). While deciding the strategy, care should be taken not to over fertilize crops with micronutrients because of consequent toxicity and losses in quality and quantity of grain yield. Effectiveness of various agricultural measures in increasing micronutrient density depends on soil type, crop, cultivar, rotation, and environmental and other factors, thus necessitating development of a specific set of measures for specific crop and region. Agricultural measures would need to be supplemented with appropriate changes in the milling technology to ascertain that increased micronutrient concentrations in some grain parts are passed into the food chain

CHAPTER –VI

HEAVY METAL POLLUTION AND REMEDIATION

Although urban and industrial wastes are being used widely on agricultural lands as sources of plant nutrient, their indiscriminate disposal and/or use has increased the risks of health hazards arising out of simultaneous addition of heavy metal pollutants like Ni, B, Cd, Cr, Pb, Zn etc. in the soil-plant-animal-human chain. The results of various centres are summarized below:

6.1 Uptake and distribution of heavy metals at excess supply in different plant parts of maize

Maize (*Zea mays* L.) var. GB 636 was grown in purified sand with complete nutrient solution (with 0.0001 mM Co and Ni) for 27 days. On 28th day, pots were divided in to six lots, one lot was maintained as such to serve as control. The other five lots were supplied cadmium ($CdSO_4$), chromium ($CrSO_4$), cobalt ($CoSO_4$), nickel ($NiSO_4$) and lead ($Pb(NO_3)_3$) at excess i.e. 0.25mM. The intensity of visible symptoms of toxicity of these elements in maize was in the order: Cr > Cd > Co > Ni > Pb. However, at 56 DAS the depression in biomass as compared to control was Cr > Co > Cd > Ni > Pb. In maize plants, a major fraction of almost all heavy metals (Cd, Cr, Co, Ni and Pb), taken up by the plant was accumulated in roots and little was translocated variably to the upper plant parts. The accumulation of the elements in roots was as follows: Co (82%) > Pb (65%) >Cd (57%) > Ni (41%) > Cr (17%).

Growth and Visible toxicity symptoms

In maize, the characteristic effects of excess Cd, Cr, Co, Ni and Pb were discernable as growth depression at 38 DAS i.e. 10 days after treatment when the plants were subjected to excess levels of these metals (0.25 mM) in purified sand. The visible symptoms of Cd toxicity appeared as chlorosis in middle and old leaves. After another 4-5 days, the growth depression became more marked on leaves which became golden yellow in colour. Later the affected leaves turned dry and shed. Chromium toxicity appeared as growth depression in maize plants followed by wilting of lamina (8 days after treatment) of old leaves which hang down. Plants showed condensation of internodes. Later, growth was markedly depressed and with persistent toxicity the plant collapsed (Fig. 6.1 to 6.4).

Initially, Cobalt toxicity appeared as chlorosis of young leaves from apex to base. Later on the upper portion of the stem and young leaves turned purple in colour and necrotic spots developed on the interveinal areas of the leaf lamina. These chlorotic spots enlarged in size, coalesced and a major portion of lamina turned necrotic. Further growth of plants was checked due to death of the growing point. Nickel toxicity appeared as chlorosis of young leaves along with slight growth depression. Later the affected chlorotic leaves turned necrotic. Application of 0.25 mM Pb did not show any visible symptom of Pb toxicity except for a slight growth depression. The intensity of the visible symptoms in maize was in the following order: Cr > Cd > Co > Ni > Pb

Biomass, tissue heavy metal concentration and translocation index

The biomass of maize decreased at the excess supply of each metal. After 41 days of metal supply, at the excess supply of each metal, the decrease in biomass of maize as compared to control plants was in the order of Cr (56%) >Cd (51%)> Co(25%) > Ni (17%) > Pb (10%). At 56 DAS, as compared to control plants the depression in the biomass was in the following order: Cr (83%) > Co (78%) > Cd (60 %) > Ni (36%) > Pb (28 %).

Cadmium (Cd) concentration in maize plants grown at excess Cd ranged between 94 to 1066 µg g^{-1} dry matter. The Cd concentration was comparatively higher in old leaf sheath and stem and was maximum in roots (Table 6.1). Out of the total 4147µg Cd taken up by each plant, 57.1% remained in root and 18-18.4% distributed to leaves and stem, while 5.4% was translocated to leaf sheath and only 1.1% to inflorescence. In leaves, leaf sheath and stem a major fraction of Cd was distributed into the middle part. Owing to excess Cr supply, the Cr concentration in maize ranged between 84 to 99 µg g^{-1} dry matter but there was not much variation in the concentration of Cr in different plant parts (Table 6.1). Total uptake of Cr was 522µg in each part, a major proportion of which was translocated into leaves followed by stem, root and leaf sheath. In leaves and stem the distribution of Cr was maximum in young parts and minimum in old parts while in leaf sheath it was minimum in the middle part.

Compared to the control at 0.0001 mM Co, the concentration of Co in different plant parts increased at excess Co supply (Table 6.1). Co concentration was higher in roots as compared to other plant parts. At 56 DAS, concentration of Co was 773 µg g^{-1} dry matter in root at excess Co as compared to 14 µg g^{-1} in roots of control plants. At normal Co (0.0001 mM) the translocation of Co was maximum in leaves and stem and only 18.2% was retained in roots. At excess (0.25 mM) Co maximum amount (82.1%) was retained in roots and rest is translocated to shoots, comparatively higher in leaves than stem. In all three above ground parts maximum Co was distributed to the older plant parts. In control plants of maize Ni concentration ranged between 0.4 to 16 µg g^{-1} dry matter whereas at excess Ni supply Ni concentration ranged between 101 to 622 µg g^{-1}(Table 6.1). As compared to other plant parts maximum nickel concentration was observed in roots. In control plants (at 0.0001 mM Ni) only 25.4% of the total Ni taken up was retained in roots and much of it was translocated to leaves followed by stem, leaf sheath and inflorescence. At excess Ni about 40.9% of the total Ni taken up was retained in roots, 20-25% translocated to leaves and stem and rest to inflorescence and leaf sheath. In leaves and stem a major fraction of Ni is distributed to younger plant parts.

Compared to control where Pb concentration was nil in all plant parts, lead concentration at excess Pb ranged from 35 to 1161 µg g^{-1} dry matter with maximum concentration in roots (Table 6.1). Out of total 6295 µg Pb taken up by plants approximately 16.6% was translocated to leaves and 9.2-9.3% in leaf sheath and stem and 64.9% retained in roots. The distribution of Pb was higher in older leaf and leaf sheath and middle stem.

In maize plants, almost all heavy metals (Cd, Cr, Co, Ni and Pb) were accumulated in roots and rest of the element translocated to the upper plant part. Accumulation of elements in roots was as follows: Co (82%) > Pb (65%) Cd (57%) > Ni (41%) > Cr (17%)

Table 6.1-A: Effect of heavy metal supply on dry weight of different plant parts of maize.

	Parts	Inflorescence	Leaf	Leaf sheath	Stem	Roots	Total
Dry weight (g plant^{-1}) at 32 DAMS (56 DAS)							
Control	Whole plant	2.90	9.47	8.54	8.94	5.38	34.78
+Cd	Whole plant	0.44	6.33	1.41	2.37	2.22	13.77 (-60)
Control	Whole plant	2.90	9.47	8.54	8.94	5.38	34.78
+Cr	Whole plant	--	2.98	0.64	1.12	1.02	5.76 (-83)
Control	Whole plant	--	5.93	1.03	3.04	1.75	11.75
+Co	Whole plant	--	3.87	0.70	2.37	1.90	8.84 (-25)
Control	Whole plant	2.90	9.47	8.54	8.94	5.38	34.78
+Ni	Whole plant	2.93	1.03	3.04	2.75	9.75 (-17)	
Control	Whole plant	2.90	9.47	8.54	8.94	5.38	34.78
+Pb	Whole plant	2.25	7.53	2.88	9.27	3.52	25.16 (-28)
BDL, Below detection limit							

Table 6.1-B : Effect of heavy metal supply on tissue concentration of Cd, Co, Cr, Ni, and Pb on different plant parts of maize.

	Parts	Inflorescence	Leaf	Leaf sheath	Stem	Roots	Whole Plant
Tissue concentration of heavy metals plant parts of maize at 32 DAMS (56 DAS)							
Cr concentration: (µg g^{-1} Dry matter)							
Control	Young		BDL	BDL	BDL		
	Middle		BDL	BDL	BDL		
	Old	BDL	BDL	BDL	BDL	BDL	
+Cr	Young		91	93	93		
	Middle		96	85	85		
	Old	--	84	99	99	85	
Cd concentration: (µg g^{-1} Dry matter)							
Control	Young		BDL	BDL	BDL	BDL	BDL
	Middle		BDL	BDL	BDL	BDL	BDL
	Old	BDL	BDL	BDL	BDL	BDL	BDL

	Parts	Inflorescence	Leaf	Leaf sheath	Stem	Roots	Whole Plant
+Cd	Young	--	288	37	141	--	--
	Middle	--	351	96	384	--	--
	Old	47	126	90	220	--	--
Tissue concentration of Co in plant parts of maize at 32 DAMS (56 DAS)							
Co concentration: µg g^{-1} Dry matter							
Control	Young	--	16	15	9	--	--
	Middle	--	17	15	16	--	--
	Old	2	12	0.32	9	14	--
+Co	Young	--	53	40	37	--	--
	Middle	--	56	52	34	--	--
	Old	--	126	52	85	773	--
Tissue concentration of Ni in plant parts of maize (µg g^{-1} Dry matter) at 32 DAMS (56 DAS)							
Control	Young	--	10	11	8	--	--
	Middle	--	10	4	10	--	--
	Old	0.4	14	6	10	16	--
+Ni	Young	--	113	101	155	--	--
	Middle	--	163	141	150	--	--
	Old	248	155	160	144	622	--
Tissue concentration of Pb in plant parts of maize (µg g^{-1} Dry matter) at 32 DAMS (56 DAS)							
Control	Young	--	BDL	BDL	BDL	--	--
	Middle	--	BDL	BDL	BDL	--	--
	Old	BDL	BDL	BDL	BDL	BDL	--
+Pb	Young	--	71	90	178	--	--
	Middle		230	154	238		
	Old		743	343	161		
BDL, Below detection limit							

Fig 6.1: Excess Ni in maize

Fig 6.2: Excess Co in maize

Fig 6.3: Excess Cd in maize

Fig 6.4: Excess Cr in maize

6.2 Uptake and distribution of heavy metals at excess supply in different plant parts of tomato

Growth and Visible toxicity symptoms

Tomato (*Lycopersicon esculentum* L.), var. US4545 plants were grown in purified sand with complete nutrient solution (with 0.0001 mM Co and Ni) for 30 days. On 31st day, pots were divided in to six lots one lot was maintained as such to serve as control. The other five lots were supplied cadmium ($CdSO_4$), chromium ($CrSO_4$), cobalt ($CoSO_4$), nickel ($NiSO_4$) and lead ($Pb(NO_3)_3$) at excess i.e. 0.25mM.

In tomato, the characteristic effects of excess Co, Ni, Cd, Cr, and Pb were discernable as growth depression at d 40 (10 days after metal supply) when the plants were subjected to excess levels of these metals (0.25 mM) in purified sand (Fig. 6.5 to 6.10). Cobalt toxicity appeared as chlorosis of young leaves from apex to base. In severe toxicity, the upper portion of the stem and young leaves turned reddish brown in colour and necrotic spots developed on the interveinal areas of the leaf lamina. Later these chlorotic spots enlarged in size, coalesced and a major portion of lamina turned necrotic. Further growth of plants was checked due to death of the growing point.

Nickel toxicity appeared as chlorosis of young leaves along with slight growth depression. Later the affected chlorotic leaves turned necrotic and dry. The visible symptoms of Cd toxicity appeared as chlorosis in old leaves. After another 4-5 days, the growth depression became more marked and old leaves which became golden yellow in colour. Later the affected leaves turned dry and shed. Chromium toxicity appeared as growth depression in tomato plants followed by wilting of lamina (10 days after treatment) of old leaves which hang down. Later, growth was markedly depressed and with persistent toxicity the plant collapsed. No visible symptom of Pb toxicity was observed except for a slight growth depression. The intensity of the visible symptoms in tomato was in the following order: Cr > Ni > Cd > Co > Pb. The biomass of tomato decreased at the excess supply of each metal. After 20 days of metal supply, as compared to control plants, at the excess supply of each metal, the decrease in biomass of tomato was in the order of Cr (88%) >Ni (81%)> Cd(67%) > Co (61%) > Pb (18%). At 110 DAS, order of biomass depression was: Cr (94%) >Ni (86%) > Cd (84 %) > Co (76%) > Pb (44 %) (Table 6.2).

Distribution of heavy metal in different plant parts

In tomato plants, a major fraction of almost all heavy metals (Cd, Cr, Co, Ni and Pb) taken up by the plant was accumulated in roots and rest of it translocated variably to the upper plant parts. The accumulation of the elements in roots was as follows: Cd (40%) > Cr (39%) >Pb (37%) > Co (35%) > Ni (30%). The concentration of Co in different plant parts increased at excess Co supply. The distribution of Co concentration in young leaves, old leaves, young stem, old stem and root was 30.9, 27.7, 13.8, 18% and 9.6%, respectively in control while in Co-excess plants, the distribution was in the order of roots (35%), old stem (29.2%), young leaves (14.8%), old leaves (11.0%) and young stem (10%), respectively. In control plants the distribution of Ni was highest in young stem (28.6%) followed by roots (26.11%), old leaves (22.7%), young stem (13.5%), after excess Ni supply, maximum accumulation was recorded in old stem (38.5%) followed by root (30.5%), young stem (15.6%), young leaves (9.2%) and lowest in old stem (6.2%), respectively. Uptake of Cadmium, Chromium and Lead under control condition was not detected. After excess all the metals (*i.e.* Cd, Cr, Pb) the highest accumulation was recorded in root. The distribution of Cd and Cr followed the same trend and lowest accumulation was noticed in young leaves (Table 6.3).

Table 6.2: Effect of heavy metal supply on dry matter of different plant parts of Tomato

Plant part	Treatments					
	Control	0.25mM Co	0.25 mM Ni	0.25mM Cd	0.25 mM Cr	0.25mM Pb
	Dry Matter (g plant^{-1})					
Young leaves	6.97	1.37	0.49	0.67	0.21	4.66
Old leaves	6.35	1.15	0.36	0.8	0.22	3.7
Young stem	4.27	1.24	0.88	0.86	0.42	2.27
Old stem	5.11	1.98	1.37	1.34	0.45	3.16
Root	1.44	0.71	0.49	0.59	0.26	1.56
Whole plant	27.54	6.45	3.59	4.26	1.56	15.35

Table 6.3: Effect of heavy metal supply on their concentrations and uptake by different plant parts of Tomato

Plant part	Co		Ni		Cd	
	Control	0.25mM	Control	0.25mM	Control	0.25mM
Heavy metal concentration in plant parts of tomato						
Young leaves	4.22	51.79	4.85	111.84	BDL	96.32
Old leaves	4.09	46.07	4.24	101.66	BDL	119.71
Young stem	3.07	38.49	3.81	105.55	BDL	110.56
Old stem	3.41	70.5	6.04	168.05	BDL	136.3
Root	5.85	236.9	7.81	370.7	BDL	470.18
Whole plant	---	---	---	---	BDL	---
Heavy metal uptake by different plant parts of tomato						
Young leaves	29	71	34	55	BDL	65
Old leaves	26	53	27	37	BDL	96
Young stem	13	48	16	93	BDL	95
Old stem	17	48	31	230	BDL	183
Root	9	168	11	182	---	277
Whole plant	94	480	119	597	BDL	716

Fig. 6.5: Excess Cd (0.25 mM) in tomato

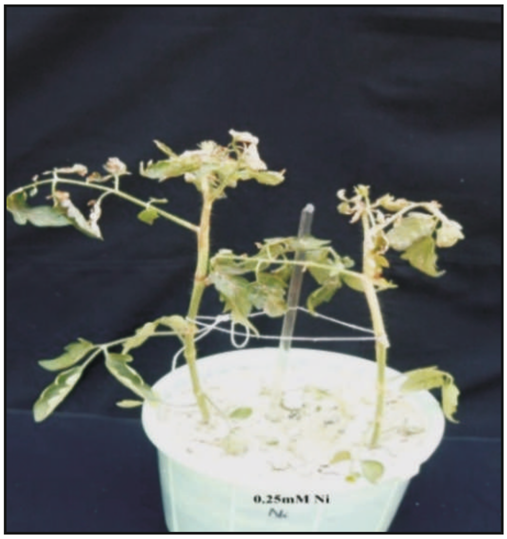


Fig. 6.6: Excess Ni (0.25 mM) in tomato

Fig. 6.7: Excess Co (0.25 mM) in tomato

Fig. 6.8: Excess Cr (0.25 mM) in tomato

Fig. 6.9: Excess Pb (0.25 mM) in tomato

Fig. 6.10: Effect of heavy metals at 0.25 mM Co, Ni, Cr, Cd and Pb (L to R) in tomato

6.3 Monitoring health hazards from heavy metals and trace elements in soils and plants and developing techniques for in situ management

A survey was carried out to identify the farmers who are using city sewage effluent for irrigating the field for growing the field as well as vegetable crops in the peri-urban area of Aurangabad and Nagpur districts. The sites were selected which are using the sewage effluent from 40-50 years near Nagpur and 35 - 40 years near Aurangabad. The fields were also selected which are using only well water for irrigating crops for comparison. From the survey, it was observed that the sewage effluents flowing towards the down streams in the city in the vicinity area of both the cities the farmers are using the sewage water for irrigating crops. The sewage effluent samples were collected from the city *nalas*/river flowing out of the city in the nearby villages.

The GPS readings (latitude, longitude, altitude) of each sampling sites were recorded. The water samples from nearby wells were also collected and analyzed for heavy metal and micronutrient content. The pH of the sewage effluent collected from open drain ranged from 6.98 to 7.22 and electrical conductivity varied from 0.96 to 1.10 dSm^{-1}. The turbidity of sewage effluent at both the location ranged from 39.3 to 49.2 while total dissolved solids varied from 498 to 603 mg L^{-1}. The pH, electrical conductivity, $CaCO_3$ and organic carbon of the soil irrigated with sewage effluent near Nagpur varied from 5.98 to 7.65, 1.25 to 1.41 dSm^{-1}, 2.5 to 8.5 % and 9.1 to 13.5 g kg^{-1} respectively. While near Aurangabad it ranged from 6.58 to 7.20, 1.07 to 1.59 dSm^{-1}, 4.3 to 10.6 % and 12.1 to 18.0 g kg^{-1}, respectively (Table 6.4).

Table 6.4: Characteristics of soil irrigated with sewage effluent and well water in peri-urban area of major cities in Maharashtra

Location of sampling sites	Soil properties			
	pH	EC (dSm^{-1})	$CaCO_3$ (%)	O.C. (g kg^{-1})
Soils irrigated with sewage effluent				
Nagpur (6)	6.96	1.30	5.08	11.98
Aurangabad (4)	6.98	1.26	6.62	14.14
Soils irrigated with well water				
Nagpur (2)	7.79	0.27	7.12	4.95
Aurangabad (2)	8.09	0.40	5.44	4.00

The pH, Electrical conductivity, $CaCO_3$ and organic carbon of soil irrigated with well water near Nagpur ranged from 7.56 to 8.01, 0.24 to 0.29 dSm^{-1}, 4.87 to 9.37 % and 4.7 to 5.2 g kg^{-1} respectively. At Aurangabad pH, Electrical conductivity, $CaCO_3$ and organic carbon of soil irrigated with well water ranged from 8.08 to 8.10, 0.36 to 0.44 dSm^{-1}, 3.25 to 7.62 % and 3.1 to 4.9 g kg^{-1} respectively. The pH was recorded lower in soil irrigated with sewage effluent (6.97) as compared to soil irrigated with well water (7.94) which showed reduction in pH. The mean electrical conductivity of soil irrigated with sewage effluent water was found higher (1.28 dSm^{-1}) as compared to soil irrigated with well water (0.33 dSm^{-1}) indicating the increase in salinity due to irrigation with sewage effluent water (Table 6.4).

The organic carbon content in the soils was found to be higher (13.18 g kg^{-1}) in the soils where it was continuously irrigated with sewage water as compared to soil irrigated with well water (4.48 g kg^{-1}) which indicated the build-up of organic carbon. The soils irrigated with sewage water recorded low pH, higher salinity and improvement in organic carbon content as compared to well irrigated water sites.

Heavy metals, micronutrient and sulphur content in soil

The soils in the peri-urban areas of Nagpur and Aurangabad districts continuously irrigated with sewage water showed higher average available sulphur (29.8 mg kg^{-1}) as compared to well water irrigated soil (17.4 mg kg^{-1}) . Average DTPA-extractable micronutrients and heavy metals (Table 6.5) were also found higher in the soils irrigated with sewage effluent. The mean Zn, Fe, Mn, Cu, Co, Cd, Pb and Cr were found to be 3.12, 21.46, 26.43, 3.67, 0.769, 0.144, 1.85 and 0.595 mg kg^{-1}, respectively, while in well water irrigated areas it was found to be 0.63, 9.91, 15.50, 1.81, 0.050, 0.026, 0.32 and 0.238 mg kg^{-1}, respectively.

Table 6.5: Micro and secondary nutrient and heavy metal status of soil irrigated with sewage effluent and well-water in peri-urban area of major cities in Maharashtra

Sampling sites/ locations	Avail. S (mg kg^{-1})	DTPA micro nutrients and heavy metals (mg kg^{-1})							
		Zn	Fe	Mn	Cu	Co	Cd	Pb	Cr
Soils irrigated with sewage effluent									
Nagpur (4)	20.85	4.75	10.88	19.36	4.67	0.68	0.14	1.32	0.42
Aurangabad (6)	38.73	1.50	32.05	33.52	2.69	0.85	0.14	2.39	0.77
Soils irrigated with well water									
Nagpur(2)	15.15	0.51	5.88	10.1	1.54	0.020	0.01	0.04	0.14
Aurangabad (2)	19.75	0.755	13.96	20.9	2.1	0.08	0.042	0.61	0.34

Heavy metals and micronutrient content in crop plants

The crops grown on the sewage effluent irrigated soils showed slightly higher content of micronutrients (Zn, Fe, Cu and Mn) and heavy metals (Cd, Co, Cr and Pb) in plants *viz.,* wheat, chilli, chickpea and cowpea near Nagpur (Table 6.6).

Table 6.6: Micronutrients and heavy metals concentration in different crop plants (Nagpur)

Elements	Crops irrigated with sewage water		Crops irrigated with well water	
	Wheat	Chilli	Wheat	Chilli
	Range (mg kg^{-1})		Range (mg kg^{-1})	
Zn	14.1 - 30.9	18.51 - 32.1	8.44 - 18.9	4.78 - 12.30
Fe	110.8 - 135.6	74.7 - 190.0	77.9 - 120.0	40.20 - 90.40
Cu	48.6 - 61.8	44.1 - 63.8	39.1 - 51.6	36.20- 47.50
Mn	84.6 - 124.0	93.1 - 190.0	33.6 – 92.0	63.8 - 118.20
Cd	0.66 - 3.10	0.36 - 1.7	0.09 - 0.20	0.06 - 0.24
Co	0.88 - 2.66	0.96 - 1.97	0.03 - 0.90	0.05 - 1.12
Cr	1.52 - 5.60	1.28 - 4.83	0.45 - 0.76	0.52 - 0.98
Pb	4.20 - 8.27	4.47 - 7.91	0.85 - 1.06	0.68 - 0.92

Micro and secondary nutrients and heavy metal status of profile soil samples

The pH of the soil irrigated with sewage water was lower as compared to the soils irrigated with well water which indicates the sewage water irrigation reduces the soil pH. The electrical conductivity of the surface soil was found higher in sewage water irrigated soil indicating salt accumulation. The organic carbon content of the sewage water irrigated soil was higher as compared to well water irrigated soil, which was decreased with the soil depth which shows that sewage effluent irrigated soil accumulates high amount of organic carbon. The data indicates that the pH and $CaCO_3$ was found to increase with the depth of the soil.

The data presented in Table 6.7 indicated that the available sulphur in the soils irrigated with sewage water varied from 14.24 to 41.7 mg kg^{-1} and 9.46 to 17.6 mg kg^{-1} in well water irrigated soil. In surface horizon, mean DTPA extractable micronutrients Zn (3.20 mg kg^{-1}), Fe (27.23 mg kg^{-1}), Mn (20.22 mg kg^{-1}), Cu (3.16 mg kg^{-1}) and heavy metals Co (0.892 mg kg^{-1}), Cd (0.186 mg kg^{-1}), Pb (1.975 mg kg^{-1}) and Cr (0.545 mg kg^{-1}) were recorded higher in the soil irrigated with sewage effluent water as compared to soils irrigated with well water Zn (0.55 mg kg^{-1}), Fe (11.17 mg kg^{-1}), Mn (15.11 mg kg^{-1}) Cu (1.38 mg kg^{-1}) and heavy metals Co (0.055 mg kg^{-1}), Cd (0.009 mg kg^{-1}), Pb (0.390 mg kg^{-1}) and Cr (0.210 mg kg^{-1}). In general, the content of S, micronutrients (Zn, Fe, Mn, Cu) and heavy metals (Co, Cd, Pb and Cr) was more concentrated in the upper soil horizon and their concentration was recorded to be reduced with the depth of soil.

Table 6.7: Micro and secondary nutrients and heavy metal status of profile soil samples collected from area irrigated with sewage effluent and well water in peri-urban areas Nagpur and Aurangabad districts

Location	Avail. S	DTPA-Micronutrients & heavy metals (mg kg^{-1})							
	(mg kg^{-1})	Zn	Fe	Mn	Cu	Co	Cd	Pb	Cr
Sewage water irrigated soil									
Nagpur									
0 – 20 cm	22.64	4.24	12.27	17.24	2.86	0.574	0.174	1.52	0.46
20 – 40 cm	20.52	2.10	10.95	15.68	1.60	0.452	0.066	0.60	0.32
40 – 60 cm	14.24	0.97	6.23	10.06	0.93	0.218	0.004	0.12	0.19
Aurangabad									
0 – 20 cm	41.7	2.17	42.20	23.20	3.47	1.21	0.198	2.43	0.63
20 – 40 cm	30.50	1.47	40.60	19.50	2.74	1.05	0.172	2.04	0.38
40 – 60 cm	19.30	1.15	14.20	18.4	2.45	0.07	0.144	1.36	0.18
Well-water irrigated soil									
Nagpur									
0 – 20 cm	14.67	0.58	6.95	12.73	0.72	0.02	0.006	0.05	0.13
20 – 40 cm	13.38	0.38	4.12	10.05	0.63	0.016	0.002	0.01	0.09
40 – 60 cm	9.46	0.16	2.58	4.91	0.31	0.004	ND	ND	0.03
Aurangabad									
0 – 20 cm	17.60	0.52	15.40	17.50	2.05	0.09	0.012	0.73	0.29
20 – 40 cm	13.70	0.44	10.90	16.70	2.17	0.074	0.01	0.46	0.16
40 – 60 cm	12.90	0.41	9.80	14.22	1.53	0.022	0.008	0.10	0.09

6.4 Effect of cadmium application on dry matter yield, its concentration and uptake by different plant parts of fenugreek in the presence and absence of EDTA

Dry matter, concentration and uptake of Cd

A screen house experiment was conducted at Ludhiana centre on loamy sand soil having DTPA extractable Cd 0.18 mg kg $^{-1}$ soil to assess the effect of six levels of Cd (0, 5, 10, 20, 40 and 80 mg kg^{-1} soil) and two levels of EDTA (0 and 1 g kg^{-1} soil) in a factorial complete randomized design on dry matter yield and to find out its critical limit. Five kg of this processed soil (having DAPA extractable Cd, Zn, Fe, Mn and Cu 0.18, 0.98, 12.65, 5.40 and 0.60 mg kg^{-1} soil) was taken in each pot, lined inside by polythene sheet to avoid contamination from the surface of the wall of earthen pots. The required amounts of cadmium and EDTA were applied as cadmium chloride and sodium ethylene diamine tetra acetic acid at the above rates in solution form. The pots were then kept for one month to attain equilibrium for cadmium. The recommended doses of N, P_2O_5 and K_2O at the rate of 100, 30 and 30 mg kg^{-1} soil to fenugreek were applied, respectively.

The dry matter yield of the crop recorded grand growth stages with increasing level of Cd application increased from 0 to 80 mg kg^{-1} soil. This attributed to reduction in uptake of micronutrients, particularly Zn due to excess Cd loading. The mean dry matter yields of shoots of fenugreek at grand growth decreased from 6.96 g pot^{-1} to 6.26, 4.60, 3.96, 3.72 and 1.40 g pot^{-1} with the application of 5, 10, 20, 40, 80 mg Cd kg^{-1} soil. The reduction in dry matter yield further increased with the application of EDTA irrespective of EDTA Maximum adverse effect of added Cd was observed with 80 mg Cd kg^{-1} soil application. The reduction in dry matter was significantly influenced at/ beyond 10 mg Cd kg^{-1} soil.

Table 6.8: Effect of Cd and EDTA levels on dry matter, concentration and uptake of Cd by shoot and roots of Fenugreek

Cd levels (mg kg^{-1} soil)	Dry Wt. g pot^{-1}		Cd content (µg g^{-1} dry matter)		Cd uptake (µg pot^{-1})	
	without EDTA (0)	with EDTA	without EDTA	with EDTA	without EDTA	with EDTA
			Shoot			
0	7.30	6.62	0.30	1.00	2.16	6.63
5	7.06	5.46	3.73	5.13	26.49	27.96
10	5.16	4.04	5.47	9.63	27.71	38.8
20	4.57	3.45	12.30	19.33	56.36	64.29
40	3.90	2.53	23.33	39.80	89.94	100.31
80	1.60	1.2	36.13	63.50	57.96	76.73
CD (5%)	EDTA levels	0.40	EDTA levels	1.37	EDTA levels	6.60
	Cd levels	0.80	Cd levels	2.30	Cd levels	10.50
	EDTA X Cd	NS	EDTA X Cd	3.0	EDTA X Cd	NS

Root						
0	2.04	1.97	0.37	0.79	0.76	1.57
5	1.91	1.80	5.37	7.17	10.3	12.97
10	1.65	1.51	9.90	13.68	16.37	20.64
20	1.58	1.20	19.99	31.42	31.42	37.84
40	1.17	0.85	31.89	48.59	37.09	41.29
80	0.61	0.46	58.95	94	35.6	42.84
Mean	1.49	1.30	21.0	32.61	21.92	21.19
CD (5%)	EDTA levels	0.12	EDTA levels	1.62	EDTA levels	2.96
	Cd levels	0.20	Cd levels	2.81	Cd levels	5.13
	EDTA X Cd	NS	EDTA X Cd	3.98	EDTA X Cd	NS

Similarly to shoot the dry matter yield of root started declining even with the lowest rate of 5 mg Cd kg^{-1} soil application, however, a significant decrease in root dry matter yield was obtained with the application of 10 mg Cd kg^{-1}soil (Table 6.8). Mean dry weight of roots of the fenugreek declined from 2.01 to 1.85, 1.58, 1.39, 1.01 and 0.52 g pot^{-1} at 5, 10, 20, 40 and 80 mg Cd kg^{-1} soil application. In contrast to dry matter yield the Cd concentration in fenugreek shoots increased with increasing rates of Cd supply. The mean Cd concentration increased from 0.65 µg g^{-1} dry matter in control to 49.81 µg g^{-1} dry matter at 80 mg Cd kg^{-1} soil application. This may be ascribed to increased supply of Cd metal being absorbed by the plants. Compared to its value in shoot, cadmium contents in roots were invariably higher at all levels of added cadmium. Further, the application of EDTA enhanced the Cd concentration in the shoots significantly irrespective of Cd levels. It increased from 13.54, 2306 µg g^{-1} dry matter where EDTA was added @ 1g kg^{-1} soil. The effect of EDTA application in increasing Cd concentration in the roots followed the same trend as that of shoot.

The Cd uptake in fenugreek increased from 4.40 µg pot^{-1} in control to 27.22, 33.26, 60.32, 95.1 and 67.34 µg pot^{-1} in shoot with 5, 10, 20, 40 and 80 mg Cd kg^{-1} in soil respectively, which was 4.4, 7.5, 13.7, 21.6 fold more than the control. While in root it increased from 1.16 µg pot^{-1} to 11.64, 18.51, 34.63, 39.19 39.22 µg pot^{-1} respectively, which were 9.6, 15.9, 29.9, 33.8 and 33.9 times more than the control. It suggested that applied Cd was readily absorbed by crop and was easily translocated from roots to above ground plant parts. Cd uptake decreased where Cd supply increasing from 40 to 80 mg kg^{-1}soil due to sever reduction in dry matter yield (Table 6.8).

DTPA extractable Cd in soil

The extractable Cd increased markedly and significantly with increasing rates of Cd application irrespective of EDTA levels at both stages, i.e.at equilibrium before sowing of crop but after one month of Cd application and after harvest of the crop (Table 6.9). The content of DTPA–Cd in soil after crop harvest was lower than that recorded at equilibrium. This might be due to removal of Cd by the crops as well as transformations in to relatively insoluble forms. It was also evident that the amount of DTPA left in soil after the crop harvest with the application of EDTA was significantly lower as compared to without EDTA. This may be attributed to increased in solubility of Cd with EDTA and subsequently higher absorption by plants, subsequently resulting in lower amount of Cd in soil after crop harvest.

Table 6.9 Effect of Cd and EDTA levels on DTPA Cd (at equilibrium)

	Cd levels (mg kg^{-1}soil)						
EDTA levels ($g\ kg^{-1}$ soil)	**0**	**5**	**10**	**20**	**40**	**80**	**Mean**
At equilibrium							
0	0.17	2.55	4.84	8.18	16.45	31.09	10.55
1	0.22	3.20	5.89	10.57	21.34	38.40	13.27
Mean	0.19	2.88	5.37	9.37	18.90	34.75	
CD (5%)	EDTA	1.17	Cd	2.02	EDTA X Cd	2.86	
Post harvest							
0	0.14	2.30	4.34	7.90	15.20	29.40	9.88
1	0.09	2.14	4.04	7.54	14.98	26.42	9.20
Mean	0.12	2.22	4.19	7.72	15.09	27.91	
CD (5%)	EDTA	0.39	Cd	0.67	EDTA X Cd	0.95	

Upper Critical level of Cadmium in Soil and shoot

The toxic or upper critical level of Cd is defined as its lowest concentration in tissue or soil at which its presence led to reduction in yield. The critical concentration can also be calculated by interpolating the concentration at which yield is reduced by some arbitrary amount usually 10 to 30 percent. For finding the upper critical level, the regression equation was worked out where the value of percent reduction in dry matter yield was regressed with corresponding DTPA- Cd in soil From this equation, the toxic level of DTPA – Cd at which 20 percent reduction in dry matter yield occurred, was then estimated. The toxic level of DTPA – Cd was found to be 4.90 mg kg^{-1} soil for fenugreek. The toxic level of Cd in shoots of fenugreek at grand growth stage was found to 7.97µg g^{-1} dry matter.

6.5 Monitoring of quality of sewage sludge obtained after treatment in sewage treatment plants for its use in agriculture

Punjab state has installed sewage treatment plants (STP) at Bhattian, Balloke, Jamalpur (Dist Ludhiana) to treat 111, 152, 48, 25, 100 and 20 million litres sewage per day, respectively. These treatments carry out secondary treatment of the sewage water by employing up flow anaerobic sewage blanket (UASB) technique. Sewage sludge obtained after treatment may contain contaminants above the permissible limit and needs testing before its disposal. Therefore, regular monitoring of treated sewage sludge is required before its use for agriculture. Sewage sludge production is expected to increase substantially so its agriculture use in the near future as more and more treatment plants will be installed. A total of 23 samples of sludge were analyzed from different Sewage Treatment Plants (STPs). Twelve samples of sludge from STP Bhattian, 6 from STP Jamalpur, 5 from STP Balloke, were dried and analyzed for different elements such as Nitrogen (N), Sulphur (S), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), Zinc (Zn), Copper (Cu), Iron (Fe), Manganese (Mn), Arsenic (As), Cadmium (Cd), Chromium (Cr), Nickel (Ni), Lead (Pb) Samples were also analyzed for pH and electrical conductance (EC) in sludge: water ratio of 1:8.

The pH values ranged between 6.18 - 8.63, 5.10 -7.71 and 3.58 -5.84 with a mean value of 7.42, 6.85 and 4.26 in sludge samples from STP Bhattian, Jamalpur and Balloke, respectively. Similarly EC ranged between 1.25-3.00, 4.00 -5.80 and 1.04 -5.20 dSm^{-1} with a mean value of 2.07, 4.78 and 3.11 dSm^{-1} sludge samples from STP Bhattian, Jamalpur and Balloke. Mean N content of 1.86% was found to be highest in sewage sludge of Bhattian followed by mean N content of 1.47 (range 1.01-2.46 %) and 0.96% (range 0.83-1.14 %) in sewage sludge of Balloke and Jamalpur. The mean phosphorus content was 0.37 % in STP Balloke, 0.27 % in STP Bhattian and 0.23% in STP Jamalpur. Mean K content varied from 0.08 to 0.48 % being highest in sludge sample from STP Bhattian and lowest in STP Jamalpur whereas sludge from STP Balloke contained intermediate values of 0.16% K (Table 6.10).

Mean values of Cd varied from 0.55 mg kg^{-1} to 2.9 mg kg^{-1} in Ludhiana city sludge with minimum content in sludge from STP Bhattian and maximum in Jamalpur. The mean chromium content among sludge varied considerably. Minimum values of chromium (85 mg kg^{-1}) was observed in sludge samples drawn from STP Bhattian while sludge from Jamalpur and Balloke contained chromium 612 mg kg^{-1} and 394 mg kg^{-1}, respectively. Nickel content varied from 35 mg kg^{-1} in sludge of STP Bhattian to 1817 mg kg^{-1} in sludge of STP Jamalpur and Pb varied from 132.9 mg kg^{-1} in STP Bhattian to 238 mg kg^{-1} in STP Jamalpur. The contents of these pollutant elements sometimes surpassed permissible limits.

Table 6.10: Characterization of sewage sludge obtained after treatment in sewage treatment plants

Location	Bhattian		Jamalpur		Balloke	
	Range	Mean ±SD	Range	Mean ±SD	Range	Mean ±SD
pH	6.18-8.63	7.42±0.83	5.10-7.71	9.85±0.98	3.58-5.84	4.26±0.94
EC	1.25-3.00	2.07±0.53	4.00-5.80	4.78±0.80	3.11-5.20	±1.86
Per cent composition of sewage sludge with respect to secondary nutrients (mg kg^{-1} sludge)						
Avail. S	0.48-2.87	1.85±0.84	1.80-9.88	7.47±2.91	1.60-6.49	4.15±2.02
Composition of sewage sludge with respect to micronutrients and heavy metals (mg kg^{-1} sludge)						
DTPA-Zn	6-1287	477±507	1755-7737	4541±2457	668-2175	1594±728
DTPA-Cu	0-412	133±155	288-561	381±124	183-419	301±103
DTPA-Fe	1-29740	11741±10623	10050±79560	44828±29050	17452±5780	38371±23735
DTPA-Mn	1-511	171±151	104-647	346±225	135-156	149±10
As	0.12-8.54	3.15±2.90	0.0-5.2	2.9±2.7	1.92-7.58	4.94±2.11
DTPA-Cd	0.00-2.26	0.55±0.85	0.2-6.4	2.6±2.9	0.00-3.94	1.94±1.70
DTPA-Cr	0.0-251.00	85.02±89.01	152-996	612±394	114.6-438.0	242.48±135.09
DTPA-Ni	0.78-170.8	35.3±48.5	718-3250	1817±1055	33.0-795.4	425.81±360.50
DTPA-Pb	1.4-588.0	132.9±179.7	25-469	238±206	6.24-583.0	172.65±236.40

Rovira *et al* (1996) have defined the respective critical limits of Cd, Cr, Cu, Pb, Ni and Zn to be 3, 150, 210, 300, 112 and 460 mg kg^{-1} in soils. Based on these limits and the average content of these metals in the sludge samples, it was calculated and observed that addition of 5t sludge per hectare annually adds much less amount of these toxic elements than the prescribed safe limits for them. Guidelines designed to limit the application of sludge to agriculture land exhibit considerable variations Bastian (1997) proposed the safe limits for disposal of bio-solids on land for Cd 39 mg kg^{-1}, Ni 420 mg kg^{-1}, Pb 300 mg kg^{-1}, Cu 1500 mg kg^{-1} and Zn 2800 mg kg^{-1}, whereas Elliot (1990) proposed the safe limits for Cd as 25 mg kg^{-1}, Ni 200 mg kg^{-1}, Pb 1000 mg kg^{-1}, Zn 2500 mg kg^{-1} and Cu 1000 mg kg^{-1}. With respect to these limits, the sludge samples from all these STPs tested were safe for Cd, Cr, Pb on the basis of mean values .In general, the maximum amount of pollutant elements were found in sludge samples from STP Jamalpur. The contents of these pollutant elements sometimes surpassed permissible limits. Nickel was not in safe limits in the sludge samples from STP Jamalpur and Balloke. In all other samples it was in safe limits. Therefore, regular monitoring of the sludge is desirable before its safe disposal. However, the build-up of toxic elements in the soil and in the produce needs to be investigated further as there is a large concentration of toxic elements in the sludge produced by some STPs.

6.6 Threshold toxic limits of Ni and Cd in Buckwheat grown in Mollisol with and without FYM

(A) Nickel

Dry matter yield and Ni concentration

In order to determine the critical toxic limits of Ni and Cd in Buckwheat (*Kuttu*), a leafy vegetable grown in a Mollisol receiving varying levels of FYM, pot experiments were conducted during the year 2010 – 11 in the green house. Bulk surface (0-15 cm) samples of Mollisol with general properties of soil, sandy loam texture, 6.86 pH, 0.118 dSm^{-1} E.C., 1.38% O.C., 0.1 mg DTPA extractable Ni kg^{-1} soil while soil sample used for Cd had sandy loam texture, 7.05 pH, 0.128 dSm^{-1} E.C., 1.11% O.C., 0.16 mg DTPA extractable Ni kg^{-1} soil.

The toxicity of Ni in buckwheat caused reduction in the size of lamina with basal part of the lamina becoming more tapering. The application of Ni significantly influenced the dry matter yield of buckwheat. Addition of 2.5 and 5 mg Ni kg^{-1} soil increased the dry matter yield of buckwheat significantly by 13.51 and 36.82 percent in comparison to control (0 mg Ni kg^{-1} soil), respectively. Further, increasing the Ni 10, 20, 40, 80 and 120 mg Ni kg^{-1} soil showed reduction of 5 mg kg^{-1} soil but it was comparable to control (Table 6.11).

As regards the main effects of FYM levels on dry matter yield of buckwheat, application of 2.23 g FYM kg^{-1} soil did not show significant effect on dry matter yield of buckwheat over no FYM (0 g FYM kg^{-1} soil). However, further, addition of 4.46 g FYM kg^{-1} soil has decreased the dry matter yield of buckwheat by 14.6 percent over no FYM (0 g FYM kg^{-1} soil). The interaction effect of Ni and FYM levels did not influenced the dry matter yield of buckwheat significantly.

Table 6.11: Effect of nickel and FYM application on dry matter yield and Ni concentration in buckwheat

Ni levels (mg kg^{-1} soil)	FYM levels (g. kg^{-1} soil)			
	0	2.23	4.46	**Mean**
		Dry matter yield (g Pot^{-i})		
0	2.96	3.03	2.90	2.96
2.5	3.60	3.50	3.00	3.36
5.0	3.90	4.80	3.46	4.06
10	3.60	3.60	2.92	3.37
20	3.56	3.90	2.73	3.39
40	3.20	3.76	2.53	3.16
80	2.95	3.20	2.43	2.86
120	2.60	3.03	2.50	2.71
Mean	3.29	3.60	2.81	3.23
Effect	FYM level	Ni level	FYM X Ni	
S. Em.±	0.13	0.21	0.37	
CD (P=0.05)	0.38	0.62	NS	
		Ni concentration (mg kg^{-1} dry weight)		
0	0.46	3.45	3.60	2.36
2.5	4.10	6.93	4.80	5.27
5.0	7.43	9.06	5.44	7.31
10	9.80	8.79	6.66	8.42
20	11.83	10.13	9.04	1.33
40	13.63	13.10	13.6	13.44
80	17.4	15.75	17.2	16.78
120	26.50	23.73	20.20	23.47
Mean	11.34	11.37	10.07	10.92
Effect	FYM level	Ni level	FYM X Ni	
S. Em.±	0.17	0.29	0.5	
CD (P=0.05)	0.50	0.82	1.43	

That the main effects of both Ni and FYM levels significantly influenced the Ni concentration in buckwheat. Addition of 2.5, 5, 10, 20, 40, 80 and 120 mg Ni kg^{-1} soil increased the Ni concentration in buckwheat significantly by 123.30, 209.74, 256.77, 337.71, 469.49, 611.01, and 894.49 percent in comparison of control (0 mg Ni kg^{-1} soil), respectively (Table 6.11). The application of 2.23 g FYM kg^{-1} soil could not change the Ni concentration significantly over no application of FYM (0 g FYM kg^{-1} soil). However, application of 4.46 g FYM kg^{-1} soil decreased Ni concentration significantly by 17.2 percent over no FYM. With application of 2.23 g FYM kg^{-1} and addition of Ni i.e. 2.5, 5, 10, 20, 40, 80 and 120 mg Ni kg^{-1} soil increased the nickel concentration in buckwheat significantly by 100.9, 162.6, 154.8, 193.6, 279.7, 356.5 and 587.8 percent over no Ni Addition of 2.5, 5, 10, 20, 40, 80 and 120 mg Ni kg^{-1} soil increased Ni concentration of buckwheat significantly by 33.3, 51.2, 85, 151.1, 277.8, 377.8 and 461.1 percent over 0 mg Ni kg^{-1} soil level, respectively.

Threshold values of Ni toxicity in plants and soil

In order to estimate the threshold toxic limits of Ni in buckwheat grown in soil treated with varying levels of FYM, percent relative yields were plotted against Ni concentrations in plant and extractable soil Ni content. The threshold toxic limits of Ni in buckwheat for 10 percent reduction in relative yields were 25.4, 29.0 and 11.5 mg Ni kg^{-1} dry matter for soil which received 0, 2.23 and 4.46 g FYM kg^{-1} soil respectively (Fig. 6.11). Percent relative yields of buckwheat had significant negative correlation with extractable soil Ni; the values of simple correlation coefficients (r) varied from -0.441** to 0.503**. The threshold toxic limits of 0.1 N HCl extractable Ni in soil for buckwheat were 41.0, 58.0 and 17.5 mg Ni kg^{-1} soil for 10 percent reduction in relative yield at 0, 2.23 and 4.46 g FYM kg^{-1} soil levels, respectively (Fig. 6.12). The threshold toxic limits of DTPA extractable Ni in soil were 10.3, 14.8 and 3.7 mg Ni kg^{-1} soil for 10 percent reduction in relative yield of buckwheat at 0, 2.23 and 4.46 g FYM kg^{-1} soil levels, respectively (Fig. 6.12).

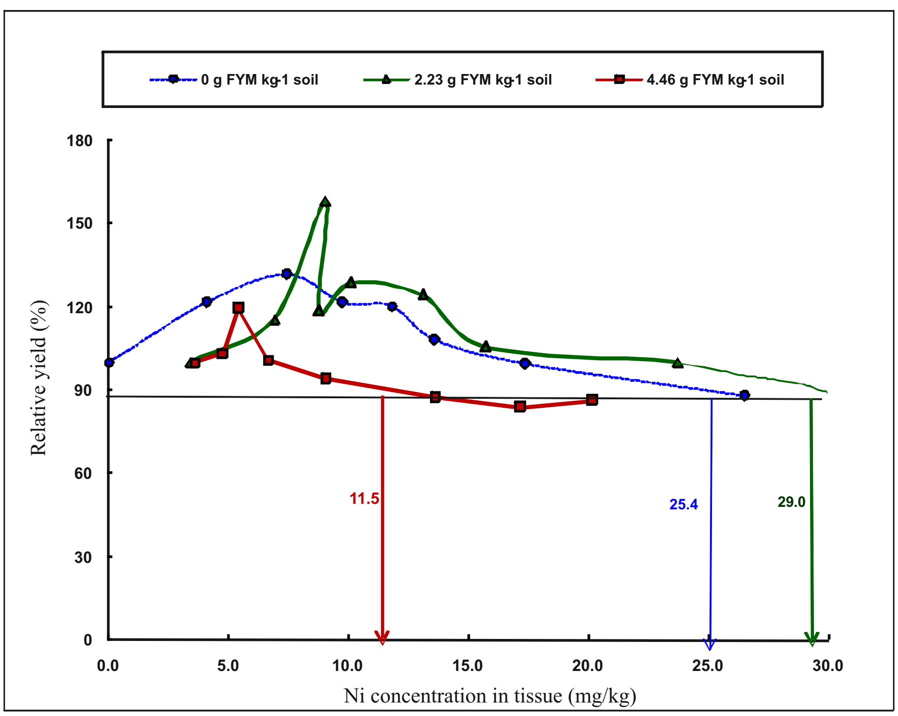


Fig.6.11: Plot between Ni concentration in buckwheat and relative yields of Buckwheat grown at the varying levels of FYM

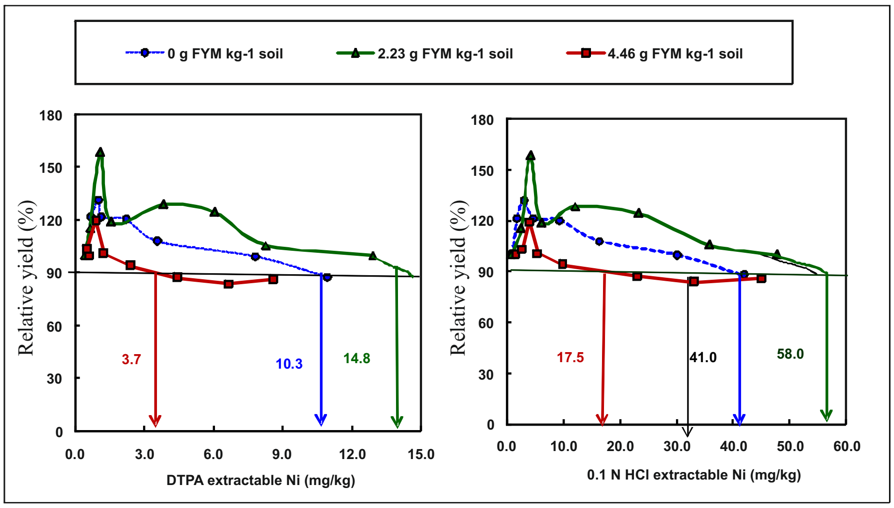


Fig.6.12: Relationship between DTPA and 0.1 N HCl extractable Ni in soil and relative yields of Buckwheat grown at the varying levels of FYM

(B) Cadmium

Dry matter yield and Cd concentration

The toxicity symptoms of Cd on buckwheat appeared a severe reduction in the size of lamina. The upper leaves also showed chlorosis. Similar to Ni the cadmium level 5 and 10 mg Cd kg^{-1} soil had no significant effect on dry matter yield of buckwheat. However, addition of 25, 50, 100, 150 mg Cd kg^{-1} soil decreased the dry matter yield of buckwheat significantly by 22.78, 37.55, 49.79 and 67.09 percent in comparison to control (0 mg Cd kg^{-1} soil), respectively (Table 6.12).

The cadmium concentration in buckwheat significantly increased by 176.4, 373.3, 530.1, 767.5, 1251.4 and 1979.5 percent in comparison of control (0 mg Cd kg^{-1} soil), respectively with addition of 5,10,25,50,100 and 150 mg Cd kg^{-1} soil (Fig. 6.13).

Table 6.12: Effect of cadmium and FYM application on dry matter yield (g Pot^{-1}) of buckwheat

Cd levels	FYM levels (g. kg^{-1} soil)			Mean
(mg kg^{-1} soil)	0	2.23	4.46	
0	2.70	2.30	2.10	2.37
5	2.30	2.83	1.94	2.35
10	2.20	2.25	1.95	2.13
25	1.90	2.10	1.50	1.83
50	1.60	1.53	1.33	1.48
10	1.13	1.35	1.10	1.19
150	0.93	0.75	0.66	0.78
Mean	1.82	1.87	1.51	1.78
Effect	FYM level	Cd level	FYM X Cd	
S. Em.±	0.83	0.12	0.22	
CD (P=0.05)	0.23	0.36	NS	

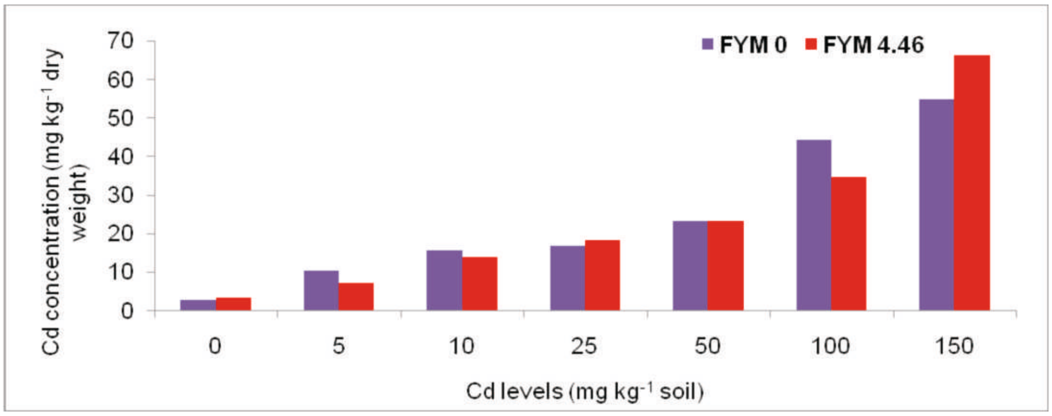


Fig.6.13: Effect of cadmium and FYM application on Cd concentration (mg kg^{-1} dry weight) in buckwheat

Threshold values of Cd toxicity in buckwheat and soil

In order to estimate the threshold toxic limits of Cd in leafy vegetables grown in soil treated with varying levels of FYM, percent relative yields of plants were plotted against concentrations in plant. As shown in Fig. 6.14, percent relative yields of buckwheat were closely and inversely associated with Cd concentrations in plant; (r, -0.891 to -0.965, significant at p=0.01). The threshold toxic limits of Cd for 10 percent reduction in relative yields of buckwheat were 6.0, 21.0 and 15.25 mg Cd kg^{-1} dry matter grown in soil which received 0, 2.23 and 4.46 g FYM kg^{-1}, soil respectively (Fig. 6.14).

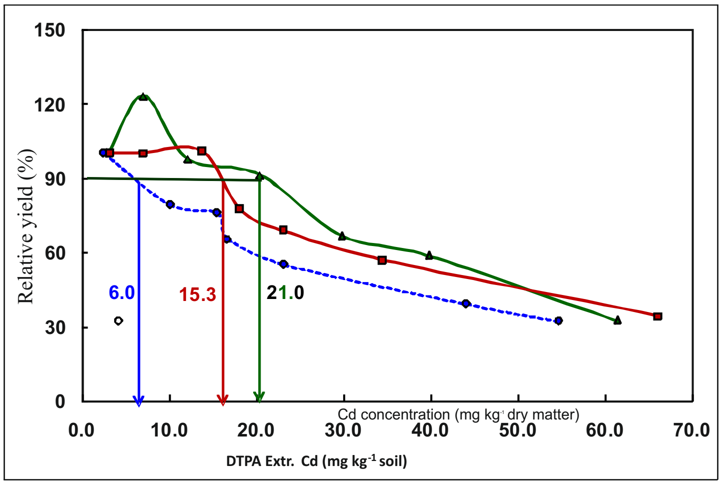


Fig.6.14: Relative yield versus Cd concentration in Buckwheat grown in soil recieving varying levels of FYM. The arrows indicate critical toxicity levels for 10 percent reduction in dry matter yields

The threshold toxic limits of 0.1 N HCl extractable Cd in soil for 10 percent reduction in relative yield of buckwheat were 2.8, 14.5 and 14.6 mg Cd kg^{-1} soil at 0, 2.23 and 4.46 g FYM kg^{-1} soil levels, respectively The threshold toxic limits of DTPA extractable Cd in soil were 1.6, 11.5 and 7.9 mg Cd kg^{-1} soil for 10 percent reduction in relative yield of buckwheat at 0, 2.23 and 4.46 g FYM kg^{-1} soil levels, respectively.

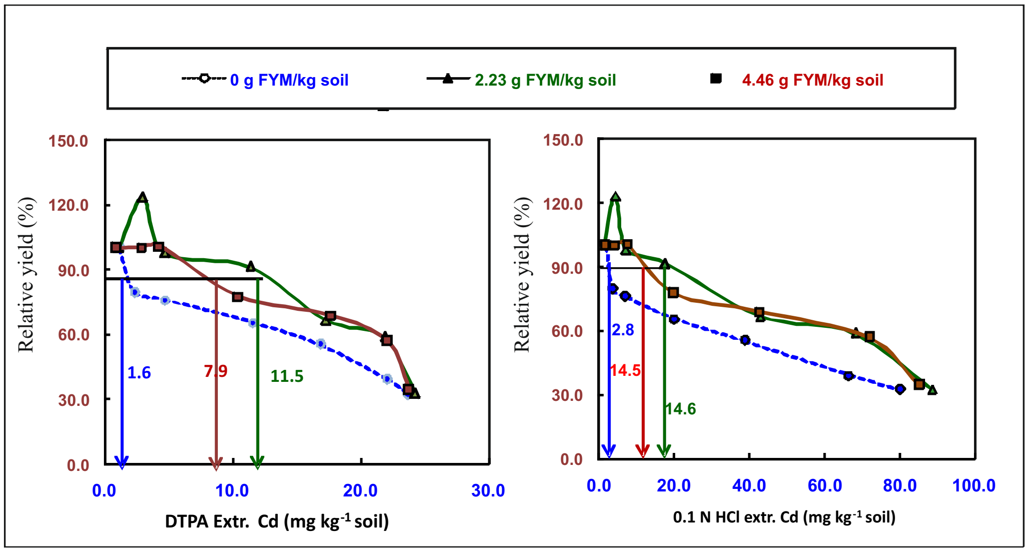


Fig.6.15: Relative yield of Buckwheat versus DTPA and 0.1 N HCl extractable Cd in soil recieving varying levels of FYM. The arrows indicate critical toxicity levels for 10 percent reduction in dry matter yields

6.7 Monitoring of Heavy Metal Pollutants and Trace Element Toxicities in Bhubaneswar

Sewage effluents from different outlets of Bhubaneswar municipality were collected and analyzed for various pollutants and heavy metal elements revealed that pH and EC of effluents varied from 4.0 to 6.3 and 0.04 to 0.14 dSm^{-1}, respectively. The BOD of sewage waters ranged from 0.2 to 1.6 ppm, low in BOD. The soluble solid contained 0.002 to 0.005 percent. The Cd, Pb and Cr levels varied from 0.005 to 0.026 ppm, trace to 2.766 ppm and 0.004 to 0.021 ppm, respectively. Except As, the content of Cd, Pb and Cr were below the toxic limit (Table 6.13).

Table 6.13: Pollution load of different sewage water of Bhubaneswar municipal area

S. No.	Discharge points	pH	EC (dSm^{-1})	BOD (ppm)	Soluble Solids (%)	Cd (mg/L)	As (mg/L)	Pb (mg/L)	Cr (mg/L)
1.	Jayadev Vihar	6.0	0.14	0.2	0.0025	0.006	0.624	0.009	0.009
2.	Mancheswar	5.8	0.05	0.9	0.005	0.006	2.128	trace	0.010
3.	Badagada	6.1	0.05	0.3	0.005	0.026	1.118	trace	0.017
4.	VSS Nagar	6.0	0.09	0.3	0.005	0.007	1.104	trace	0.009
5.	Palasuni	6.1	0.04	1.6	0.004	0.009	2.766	2.766	0.004
6.	Sainik School	5.9	0.06	0.8	0.002	0.006	1.233	0.016	0.016
7.	Gangua Drain	6.0	0.06	1.0	0.005	0.004	1.334	0.013	0.021
8.	Chakaaisiani	4.0	0.09	0.7	0.0035	0.005	1.776	trace	0.018
9.	Manchswar Indust. area	5.8	0.08	0.9	0.005	0.005	0.65	0.023	0.018
10.	Saptaswati	6.3	0.04	1.7	0.017	0.005	2.447	trace	0.002

In another study, vegetable salads which are consumed directly like tomato, cucumber, onion, carrot, radish, cabbage, spinach etc were collected from near industrial area NALCO and analyzed for heavy metal accumulation(Zn, Cu, Pb. Cd, Ni) , showed that cucumber accumulated all the pollutant elements i.e. 33.5,1.9, 2.0, 0.9, and 2.9 mg kg^{-1} vegetable of Zn, Cu, Pb, Cd and Ni. The maximum Cu, Pb and Ni accumulation was recorded in spinach, Zn content of different vegetables varied from 14.1 (cabbage) to 33.5 (cucumber) mg kg^{-1} whereas Cu content varied from trace to 10.3 mg kg^{-1}, Pb content varied from 0.9 to 6.4 mg kg^{-1} and Ni content varied from trace to 18.1 mg kg. The content of Zn, Cu, Pb and Cd were safe limit whereas Ni content in spinach, cabbage, tomato and cucumber was not in safe limit. A continuous monitoring of heavy metal is required in crops grown municipal water.

Table 6.14: Pollution load of different vegetables (mg kg^{-1})

Vegetables	Zn	Cu	Pb	Cd	Ni
Onion	21.2	Tr.	1.7	Tr.	0.8
Carrot	15.1	1.0	0.9	Tr.	1.4
Cabbage	14.1	Tr.	2.1	Tr.	7.8
Tomato	22.0	5.2	3.5	Tr.	10.9
Cucumber	33.5	1.9	2.0	0.9	2.9
Radish	18.2	Tr.	1.8	Tr.	Tr.
Spinach	31.6	10.3	6.4	Tr.	18.1

Tr.= traces

6.8 *In situ demonstration of phytoremediation technologies in contaminated soils by various crops*

Two field experiments were carried out with Amaranthus and Marigold in the contaminated sites at Ukkadam and Nanjundapuram villages of Coimbatore district in order to verifying the strategies devalued through pot culture experiments. The soils of both the farmers' holdings were contaminated with Pb due to continuous irrigation with sewage water. The initial soil analysis showed that, both soils were having higher DTPA-extractable (9.80 and 15.2 mg kg^{-1}) and total Pb status (635 and 968 mg kg^{-1}). The soil reaction was neutral with low salt and high organic carbon content. The crops grown were twelve treatments comprising of three levels of EDTA (0, 50 and 100 mg kg^{-1}) and four sources of organic manures (No organics, FYM at 5 t, Green leaf manure at 5 t and microbial inoculums at 2 kg ha^{-1}).

Yield and growth

As indicated in Table 6.15, increasing levels of EDTA increased the fresh green matter yield of amaranthus up to 50 mg kg^{-1} and showed a decline in yield at 100 mg EDTA kg^{-1} of soil (from 7.17 to 12 t ha^{-1}). Addition of organics significantly improved the fresh green mater yield and the highest mean yield was noted with the addition of 5 t FYM (11.3 t ha^{-1}) followed by green leaf manure incorporation (10.43 t ha^{-1}). The interaction effect was found non-significant. In marigold, total dry matter production was reduced with increasing level of the highest dry matter was recorded with the application of 50 mg EDTA kg^{-1} along with 5 t GLM ha^{-1} which was comparable with EDTA with 5 t FYM ha^{-1}.

Table 6.15: Effect of EDTA and organics on the fresh green matter yield and growth attributes of Amaranthus and Marigold

EDTA levels (mg kg^{-1})	Fresh yield (t ha^{-1}) Amaranthus				
	No organics	FYM	GLM	Microbial inoculum	Mean
0	7.17	10.9	9.8	8.57	9.11
50	7.83	12.0	11.1	8.83	9.93
100	7.53	10.9	10.4	8.33	9.3
Mean	7.51	11.27	10.43	8.58	9.45
	Total dry matter yield (t ha^{-1}) Marigold				
0	20.5	27.7	30.7	24.4	25.8
50	21.2	30.4	32.8	28.1	28.1
100	21.4	28.9	31.0	27.7	27.3
Mean	21.1	29.0	31.5	26.7	27.1

DTPA and bio-available fractions of Pb

In amaranthus, The DTPA Pb extracted at harvest stage was ranged from 9.9 to 20.3 mg kg^{-1} and increasing levels of EDTA increased the extractability of Pb (Table 6.16). The highest DTPA Pb was noted with 100 mg kg^{-1} (16.9 mg kg^{-1}). Increasing levels of EDTA increased the bio available pool of Pb and the order of higher extractability was: Organically bound (14.2 to 22.0 mg kg^{-1})> Exchangeable + adsorbed (4.06 to 8.18 mg kg^{-1}) > Water soluble Pb (1.90 to 4.22 mg kg^{-1}). Addition of 5 t FYM along with 100 mg EDTA kg^{-1} recorded higher bio-available fractions followed by Green leaf manure. The lowest values were noted with control plots.

Table 6.16: Effect of EDTA and organics in amaranthus and marigold on bio-available fractions of Pb and DTPA-Pb (mg kg^{-1})

EDTA levels mg kg^{-1})	Water soluble Pb		Exchangeable + Adsorbed Pb		Organically bound Pb		DTPA-Pb	
	No organics	Organics	No Organics	organics	No organics	organics	No organics	Organics
				Amaranthus				
0	1.90	2.70	4.06	5.74	14.20	17.50	9.90	14.30
50	2.60	3.58	4.85	6.36	16.30	20.45	12.30	17.65
100	2.84	4.10	5.38	7.78	17.40	23.20	13.30	20.05
Mean	2.45	3.46	4.77	6.62	16.00	20.40	11.90	17.30
				Marigold				
0	2.86	3.61	4.99	6.91	19	23.55	13.00	17.05
50	2.98	4.40	6.43	7.96	19.5	26.05	14.20	19.95
100	3.23	5.15	6.20	8.99	19.7	32.05	15.00	22.95
Mean	3.03	4.38	5.88	7.96	19.4	27.20	14.10	20.00

While in amaranthus, DTPA Pb content in soil also followed recorded highest values with 100 mg EDTA kg^{-1} (19.5 mg kg^{-1}). Both FYM and GLM had comparable effect on Pb availability (14.1 to 20.6 mg kg^{-1}). However, microbial inoculation could not prove to be beneficial. The bio available fractions were increased with increasing EDTA application and higher values were recorded with 100 mg EDTA kg^{-1}. The three fractions were in the order of availability, organically bound (19 to 32.6 mg kg^{-1}) > Exchangeable + adsorbed (4.99 to 9.27mg kg^{-1}) > water soluble Pb. (2.86 to 5.40 mg kg^{-1}). Addition of either FYM or GLM was not significant in influencing the water soluble and organically bound Pb however higher exchangeable + adsorbed Pb fraction was associated with 5 t FYM addition.

Pb content and uptake

Similar to Pb availability, Pb absorption by amaranthus was also increased due the addition of EDTA and organics. The distribution of Pb in various plant parts of Amaranthus indicated that shoot accumulated more of Pb than root. The highest Pb content in shoot and root was noted with the addition of 100 mg EDTA kg^{-1} + 5 t FYM in shoot (323 mg kg^{-1}) and root (182 mg kg^{-1}) (Table 6.17). This was closely followed by the addition of 5 t GLM. The effect of microbial inoculum was not marked in increasing the Pb content in plant. The interaction of EDTA and Organics were significant with shoot Pb content while it was not significant with root Pb content. Increasing levels of EDTA increased the Pb uptake by amaranthus and the values varied from 171 to 876 g ha^{-1} in shoot, 26.8 to 102.6 g ha^{-1} in root and 198 to 974 g ha^{-1} in total uptake. Although the addition of 100 mg kg^{-1} EDTA + 5 t FYM enhanced the uptake of Pb and recorded higher values, it was on par with 50 mg kg^{-1} EDTA + 5 t GLM. Hence, application of 50 mg kg^{-1} EDTA + 5 t FYM to Amaranthus was the best and economical in removing higher Pb from the contaminated soils.

Table 6.17: Effect of EDTA and organics on the Pb uptake by amaranthus and marigold (g ha^{-1})

EDTA levels (mg kg^{-1})	Amaranthus (g ha^{-1})				Marigold (g ha^{-1})			
	Pb uptake - Shoot		Pb uptake - Root		Pb uptake - Shoot		Pb uptake - Root	
	No organics	Organics	No Organics	organics	No organics	organics	No organics	Organics
0	171	462.5	26.8	64.6	3.6	13.4	0.58	1.055
50	222	757.0	32.1	94.8	3.1	16.1	0.62	1.265
100	216	803.5	36.0	92.3	3.3	16.9	0.67	1.29
Mean	203	674.33	31.63	83.9	3.3	15.4	0.62	1.20

Similar to Pb availability the Pb content and uptake was also significantly influenced by EDTA levels and organics in marigold. The highest Pb content in shoot (682 mg kg^{-1}), root (268 mg kg^{-1}) and total (950 mg kg^{-1}) were recorded with the application of 100 mg EDTA kg^{-1} along with 5 t GLM. Next to GLM, inclusion of FYM registered higher Pb content various plant parts of Marigold (Table 6.18).

Table 6.18: Effect of EDTA and organics on the Pb content in Marigold (mg kg^{-1})

EDTA levels (mg kg)	No	FYM organics	GLM	Microbial Inoculum	Mean
			Pb content - Shoot		
0	213	501	593	337	411
50	256	601	622	455	484
100	256	669	682	573	545
Mean	242	590	632	455	480
			Pb content - Root		
0	169	200	231	177	194
50	177	235	246	192	212
100	187	250	268	202	227
Mean	178	228	248	190	211

Although increasing levels of EDTA increased the Pb uptake of both the levels of organics, however, they were comparable with each other and the total Pb uptake was varied from 10.1 to 12.6 kg ha^{-1}. Among the organics application of 5 t GLM recorded the higher Pb uptake in shoot (16.6 kg ha^{-1}) and root (1.30 kg ha^{-1}). This was closely followed by the addition of FYM and the microbial inoculum did not have significant impact on the Pb uptake though registered little higher values than control plots.

Phyto extraction efficiency

The phyto remediation efficiency of the crop was assessed based on the translocation co efficient (TCF) and bio concentration factors (BCF). The increasing levels of EDTA increased the translocation coefficient (>1.00) and BCF and higher values were noted with 100 mg EDTA kg^{-1} (1.39 to 1.57 and 8.28 to 8.44, respectively) (Table 6.19). Among the organics, higher TCF and BCF (1.64 and 9.68) values were noted with 5 t FYM followed by GLM and the microbial inoculum was not found as a good source to enhance translocation of Pb. Hence application of 50 mg EDTA kg^{-1} along with 5 t FYM ha^{-1} was the best and economical in increasing Pb removal by Amaranthus thus can be recommended to remediate the Pb contaminated soils.

Table 6.19: Effect of EDTA and organics on DTPA Pb, TCF and BCF in amaranthus and marigold

EDTA levels (mg kg^{-1})	Translocation coefficient		Bio concentration factor	
	No organics	Organics	No organics	Organics
		Amaranthus		
0	1.28	1.45	7.74	8.85
50	1.37	1.60	6.78	9.36
100	1.20	1.76	7.18	9.20
Mean	**1.28**	1.61	**7.23**	9.13
		Marigold		
0	1.31	2.55	10.6	12.65
50	1.02	2.63	12.7	13.35
100	1.00	2.96	12.5	14.90
Mean	**1.11**	2.71	**11.9**	13.65

The TCF and BCF values worked out for assessing the phyto remediation efficiency of marigold crop revealed that, application of 100 mg EDTA kg^{-1} along with either 5 t FYM or GLM was found to increase the Pb absorption, translocation and removal by the crop. However the effect of both 50 and 100 mg EDTA kg^{-1} was comparable hence addition of 50 mg EDTA kg^{-1} can be economical and thus recommended to remediate the Pb contaminated soils.

Effect of EDTA and Organics on phytoextraction of Pb by different crops

The biomass yield, Pb availability, its absorption and removal by all the crops were significantly influenced by the levels of EDTA (Table 6.20) and organic manure addition (Table 6.21). The effect of EDTA levels on the biomass production of crops showed that, increasing levels of EDTA decreased the biomass production of crops such as Amaranthus, Fodder cowpea and Cluster bean. However, no such effect was noticed on Marigold and Castor sp.

The order of higher biomass production was: Marigold > Castor wild > Castor hybrid > Fodder cowpea > Cluster bean > Amaranthus. Among the organics, higher biomass yield was recorded with 5 t FYM ha^{-1} in Amaranthus and Cluster bean while with Fodder cowpea, Marigold, Castor wild and hybrid, addition of green leaf manure at 5 t ha^{-1} registered the highest biomass yield. The interaction effect was found non-significant.

Increasing levels of EDTA increased the Pb extractability in soil irrespective of crops and higher DTPA Pb status was noted at 100 mg EDTA kg^{-1} addition. Among the crops, the order of higher Pb extractability was noticed with Castor wild > Castor hybrid > Amaranthus > Fodder cowpea > Marigold = Cluster bean. Addition of Green leaf manure at 5 t ha^{-1} significantly increased the DTPA Pb status in soils grown with Amaranthus and fodder cowpea while with other crops; FYM addition registered higher Pb extractability. However both the sources were comparable with each other. Marked variations in total Pb content of plants were noticed for EDTA levels and organics. Increasing addition of EDTA increased the total Pb content in plants which was reflected in increased translocation co efficient values. The magnitude of increase in total Pb absorption was high in Amaranthus (42.5 %) followed by Marigold (33 %) > Fodder cowpea (29.6%) > Cluster bean (28.5 %) > Castor wild and hybrid (15 %). Higher Pb content was recorded in shoot than in root. Except Castor crop, higher total Pb content in plant was recorded with 5 t FYM ha^{-1} followed by Green leaf manure addition. The lowest total Pb content was observed in pots received no organics.

Phyto remediation potential of the crops based on the biomass yield and translocation co efficient (TCF) indicted that, application of 100 mg EDTA kg^{-1} along with either 5 t FYM or green leaf manure ha^{-1} enhanced the phyto extraction efficiency of crops by increasing the translocation co efficient values and bio concentration factors. Considering the importance of crops in food chain, Marigold and Castor can be recommended for remediating the Pb contaminated soils.

Table 6.20: Effect of levels of EDTA on the fresh biomass yield, DTPA Pb, its content and uptake and Phyto extraction efficiency by various crops

EDTA levels (mg kg)	Amaranthus	Fodder cowpea	Cluster bean	Mari gold	Castor wild	Castor hybrid	Amaranthus	Fodder cowpea	Cluster bean	Mari gold	Castor wild	Castor hybrid
	Fresh biomass (g pot^{-1})						DTPA Pb (mg kg^{-1})					
0	34.7	68.0	55.0	217	112	105	14.7	14.8	9.7	10.2	20.3	17.8
50	49.0	64.8	63.3	249	123	113	18.7	16.5	11.0	11.3	22.1	19.5
100	38.9	56.6	54.1	269	133	117	21.8	18.7	11.8	12.2	23.7	21.1
Mean	**40.8**	**63.1**	**57.5**	**245**	**123**	**112**	**18.4**	**16.7**	**10.8**	**11.2**	**22.0**	**19.5**
CD (5%)	7.70	NS	7.40	48.0	9.8	15.8	4.10	1.50	NS	NS	1.88	2.42
	Total Pb content (mg kg^{-1})						Total Pb uptake (mg kg^{-1})					
0	285	324	217	166	362	311	0.51	1.31	1.45	4.05	7.80	8.00
50	352	376	249	196	382	332	1.01	1.44	1.54	5.62	9.10	9.28
100	406	420	279	221	416	360	0.91	1.40	1.76	7.11	10.8	10.5
Mean	**348**	**373**	**249**	**194**	**389**	**334**	**0.82**	**1.38**	**1.58**	**5.59**	**9.2**	**9.26**
CD (5%)	42.2	51.0	40.6	21.9	40.4	37.5	0.51	NS	NS	NS	1.87	2.01
	TCF						BCF					
0	1.72	2.02	4.29	2.61	2.48	2.44	7.20	7.28	3.77	3.95	4.34	4.50
50	1.96	2.07	4.39	2.66	2.52	2.56	7.51	7.36	3.79	4.19	4.68	5.00
100	1.92	2.11	4.43	2.74	2.54	2.58	7.77	7.34	3.92	4.36	4.99	5.40
Mean	**1.87**	**2.07**	**4.37**	**2.67**	**2.51**	**2.53**	**7.66**	**7.33**	**3.83**	**4.15**	**4.67**	**4.97**

Table 6.21: Effect of organics on the fresh biomass yield, DTPA Pb its content and uptake and Phyto extraction efficiency by various crops

EDTA levels	Amaranthus	Fodder cowpea	Cluster bean	Marigold	Castor wild	Castor hybrid	Amaranthus	Fodder cowpea	Cluster bean	Marigold	Castor wild	Castor hybrid
	Fresh biomass (g pot^{-1})						DTPA Pb (mg kg^{-1})					
No organics	40.6	49.5	55.9	170	94.6	87.7	18.5	12.4	7.82	9.0	18.8	16.2
FYM 5 t ha^{-1}	51.5	69.7	58.0	293	139	122	17.0	18.1	13.7	13.4	25.6	21.6
GLM 5 t ha^{-1}	37.0	72.8	58.6	304	143	130	20.8	20.6	12.1	12.2	24.2	21.9
Micr.Inno. 2 kg ha^{-1}	34.3	60.5	57.8	212	114	107	17.2	15.6	9.67	10.3	19.4	18.1
Mean	**40.8**	**63.1**	**57.6**	**245**	**123**	**112**	**18.4**	**16.7**	**10.8**	**11.2**	**22.0**	**19.5**
CD (5%)	15.3	14.1	NS	32.0	15.7	30.6	2.80	1.40	1.47	1.12	3.26	3.17
EDTA levels	**Total Pb content (mg kg^{-1})**						**Total Pb uptake (mg kg^{-1})**					
No organics	229	228	135	120	311	238	0.50	0.62	0.90	2.15	5.50	5.00
FYM 5 t ha^{-1}	469	534	344	275	431	395	1.40	2.12	2.59	9.16	11.4	11.6
GLM 5 t ha^{-1}	392	413	300	215	456	416	0.80	1.72	1.71	7.22	12.4	13.1
Micr.Inno. 2 kg ha^{-1}	301	319	216	167	354	289	0.57	1.08	1.13	3.85	7.60	7.43
Mean	**348**	**373**	**249**	**194**	**388**	**335**	**0.82**	**1.38**	**1.58**	**5.89**	**9.20**	**9.26**
CD (5%)	38.1	42.3	44.4	35.2	58.7	62.5	0.301	0.479	0.86	2.20	0.89	1.18
EDTA levels	**TCF**						**BCF**					
No organics	1.57	1.62	3.57	2.30	2.33	2.22	5.13	6.20	3.43	3.68	4.40	4.50
FYM 5 t ha^{-1}	1.97	2.37	4.87	2.87	2.75	2.67	9.22	9.01	3.93	4.79	5.00	5.84
GLM 5 t ha^{-1}	1.95	2.31	4.83	2.77	2.59	2.74	6.73	7.13	3.96	4.24	5.60	5.73
Micr.Inno. 2 kg ha^{-1}	1.68	1.97	4.20	2.72	2.57	2.48	6.69	6.98	3.98	3.89	4.80	4.26
Mean	**1.87**	**2.07**	**4.37**	**2.67**	**2.56**	**2.53**	**7.66**	**7.33**	**3.83**	**4.15**	**4.95**	**5.07**

Proceedings of the 26th Biennial Workshop of AICRP on Micro and Secondary Nutrients and Pollutant Elements in Soils and Plants held at BCKV, Kalyani from 10 to 12th February 2012

The 26th Biennial Workshop of All India Coordinated Research Project on Micro and Secondary Nutrients and Pollutant Elements in Soils and Plants (MSPE) was organized from 10 to 12 February 2012 at BCKV, Kalyani. The workshop was inaugurated by eminent soil scientist and ex-Vice Chancellor, BCKV, Kalyani, Prof. L. N. Mandal. The inaugural function was presided over by Prof. S. K. Sanyal, Vice Chancellor, BCKV, Kalyani. Dr. A. K. Singh, DDG (NRM), ICAR, New Delhi graced the workshop. Dr P. N. Takkar, Ex-Director, IISS, Bhopal and Dr K. N. Tiwari, Ex-Director, IPNI India Office participated in the workshop as expert members appointed by the Council. Besides, Dr A. Subba Rao, Director, IISS, Bhopal, Dr. Pradip K. Sharma, Dean College of Agriculture, CSKHPKV, Palampur, Dr. V. Velu, Director, Natural Resource Management, TNAU, Coimbatore, Dr. A. Mitra, Director of Research, BCKV, Kalyani, Dr. Kaushik Majumdar, Director IPNI India Programme, Dr. Soumitra Das, Director, IZA India office, Dr. M. L. Jat, Senior Agronomist, CIMMYT, India, Dr. V. K. Singh, Principal Scientist, PDFSR, Modipuram, Meerut, Dr. P. Suresh Kumar, Professor and Head, RTL, KAU, Kerala, Dr. N.K.S. Gowda, Principal Scientist (Animal Nutrition) NIANP, Bangalore, Dr. C. A. Srinivasamurthy, Professor & Head, Soil Science, GKVK, Bangalore, Dr. I. M. Inge, Professor and Head Soil Science, PDKV, Akola, Dr Arvind K. Shukla, Project Coordinator Micronutrient, scientists of the project from different centers and scientists from different ICAR institutes and personnel from more than 15 Industries participated in the workshop. A brain storming session on "Micro and secondary nutrients and pollutant elements- from soil-plant to soil-plant-animal/human continuum was also organized during the workshop in which ten learned speakers/panelists presented their views under the chairmanship of Dr. A. K. Singh, DDG (NRM). The session-wise proceedings have been described below.

Inaugural session

At the outset, the Director of Research, BCKV, Kalyani Dr. A. Mitra welcomed the delegates. The project Coordinator Dr. Arvind K. Shukla welcomed the dignitaries and delegates and briefed about the project. Prof. L. N. Mandal, the chief guest of the session highlighted the declined trend in factor productivity of the country due to several factors including emergence of micronutrient deficiencies in different parts of the country. He also urged upon the scientist to work for amelioration of such deficiencies in soil for higher crop production as well as increased micronutrient concentration in agricultural produce. He also expressed his concern for strengthening research on heavy metal pollution in India, increasing micronutrient use efficiency and developing simple and suitable extractants for extraction of micronutrients and heavy metals in different soil types. Dr. S. K. Sanyal, Vice-Chancellor BCKV, Kalyani and president of the function welcomed the delegates and expressed his thankfulness to DDG (NRM), ICAR for holding the workshop at BCKV, Kalyani. In his remark, he focused on the issues and importance of micronutrient and pollutant elements especially arsenic in soil-plant-animal/human health. He also showed his concern on nutritional security of the people of India and also emphasized to work more on secondary nutrients like S, Ca and Mg in


26th BIENNIAL WORKSHOP
AICRP on "Micro-and Secondary Nutrients and Pollutant Elements in Soils and Plants"
February 10-12, 2012
Venue: Farmers' Training Centre, BCKV
Kalyani, West Bengal


26th BIENNIAL WORKSHOP
AICRP on "Micro-and Secondary Nutrients and Pollutant Elements in Soils and Plants"
February 10-12, 2012
Venue: Farmers' Training Centre, BCKV
Kalyani, West Bengal


Brain Storming Session
on
Micro- and Secondary Nutrients and Pollutan
from Soil-Plant to Soil-Plant-Animal/Human
Sponsored by

addition to micronutrients. He stressed upon remediation of heavy metal pollution in soil-plant system and to control movement of heavy metals to grain. The session was concluded with formal vote of thanks presented by Dr. Biswapati Mandal, Professor Soil Science, BCKV, Kalyani.

Technical Session I

The first technical session of the workshop was chaired by Dr. P.N.Takkar in which four presentations were made. In the first presentation, Dr. A. K. Shukla, Project Coordinator lucidly highlighted research findings of AICRP (MSPE). Starting with the brief history of the project, he accounted the various work done by the different centers of the project such as status of micro and secondary nutrient deficiencies in the country, nutrient indexing for forecasting, micro and secondary nutrient management for higher crop production, evaluation of some new products and some case studies of heavy metal pollution in the country. He emphasized the importance of micronutrient in reversing the trends of declining factor productivity of some important cropping systems. He also presented some findings of the biofortification work carried out in the project.

During discussion on the presentation made by Dr. Shukla, Dr. A. Subba Rao, Director, IISS, Bhopal pointed out that there is a need to work on long term effect of repeated micronutrient especially Zn and B application to soil as its use efficiency is low. He also urged to develop management options for Fe deficiency as it is coming up in different parts of the country. It was also felt that there is a need to re-visit the critical limits and develop suitable methods for Fe and Mn estimation. Dr. Ramkala presented the progress of the work of the Haryana centre. He showed that crops are responding to boron and sulphur application. In her presentation, Dr. Anjali Basumataray from AAU, Jorhat centre showed widespread zinc and boron deficiencies in seven districts of Assam. Work on agronomic biofortification of rice revealed that application of Zn through soil+foliar application was more effective in enhancing Zn concentration in grain and straw as compared to soil application alone. Dr. Kulhare presented the achievements of the Jablapur center in last two years. He reported that the deficiency of Fe and S are increasing in some districts of Madhya Pradesh whereas Zn deficiency remains unchanged over the years. Nutrient indexing programme showed that continuous cropping without Zn application reduced the available Zn status in soil to a great extent. He also showed that application of sewage sludge @ 10t ha^{-1} in rice-wheat cropping sequence every year is safe as far as heavy metal accumulation is concerned. The session was concluded with chairman's remarks that there is need to take cognizance of gaps pointed out by Project Coordinator in his presentation and accordingly the appropriate technical programmes could be developed for all the centres at the end of the workshop.

Technical Session II

In this technical session, presentations of four centers were scheduled, i.e. ANGRAU, Hyderabad; TNAU, Coimbatore; OUAT, Bhubaneswar and Lucknow University, Lucknow, but nobody from Lucknow centre turned up for the presentation. The session was chaired by Dr. A. Subba Rao, Director, IISS, Bhopal. While presenting the research achievements of ANGRAU, Hyderabad for the last years Dr. Surendra Babu indicated extensive emergence of B and Cu deficiencies in samples collected from orchard, rice-rice cropping system and other cropping systems in four districts of Andhra Pradesh. The chairman of the session, Dr. A. Subba Rao suggested for classifying the data cropping system wise and orchard data separately. During presentation of response of chilly and fodder crops to micronutrient especially Zn application he informed that Zn efficiency increased when it was incubated with FYM and subsequently applied to crops. Foliar spray of multi micronutrient mixture was found to enhance fodder yield by 18 – 48% along with increase in their concentration in fodder crops. He was advised to analyze response data of individual farmers instead of pooling the data for all locations for better understanding. His proposal to study the changes in micronutrients status after 10 years of experimentation under nutrient indexing programme was not accepted.

Dr. P. Stalin from TNAU, Coimbatore presented the micro and secondary nutrients delineation results of 6 districts and explained that Zn deficiency was predominant in all the districts followed by Cu and B. He was advised by the chairman to look into critical limits of micronutrients, particularly Cu. He also suggested revisiting the critical limits for all the micronutrients in next plan. In nutrient indexing programme a negative balance of N, K and Zn was noticed in rice-rice systems, while in sugarcane –sugarcane system the negative balance of Fe, Cu and Zn was evidenced. He also showed the data pertaining to enhanced use efficiency of N and P in several crops due to application of micronutrients, particularly Zn. He was suggested to check the data of seed Zn content in green gram before drawing any conclusion. In elaborating nutrient biofortification study he indicated that addition of lime in foliar formulation is not required. Soil application of 100 kg zinc sulphate along with three foliar sprays increased the seed Zn content in green gram and maize crops. For iron, soil application of ferrous sulphate was superior to foliar spray.

The progress of Bhubaneswar centre was presented by Dr. A. K. Pal. Analysis of samples collected from four district of Odisha showed that about 5-47% deficient are deficient in Zn, 38–62% are deficient in B and 2-65% are in Sulphur. Reassessment study in the same district revealed that B and Zn deficiency has increased whereas S deficiency decreased in 2010 as compared to 2001. Vegetable growing areas showed greater B deficiency than area under cereals crops. He also elaborated that Zn application along with either plant residue or FYM had similar effect on both yield and Zn uptake. Soil application along with spray of Zn was better than only soil application in enriching seed of rice with Zn. Under INM programme, integrated application of Zn @ 2.5 kg/ha + FYM @ 5 t/ha boosted rice yield.

Technical Session III

There were four presentations by PAU, Ludhiana, CSKHPKV, Palampur, PDKV, Akola and RAU, Pusa in technical session III. Dr. K. N. Tiwari, Ex Director, IPNI, Gurgaon chaired the session. The highlights of presentation furnished as under:

In Punjab, during 2009-11 total of seven districts surveyed under reassessment programme showed ubiquitous Mn deficiency while Zn deficiency has decreased from 40% (before 2002) to about 20% (2010). Cu deficiencies are also coming up in some pockets. In response study trials, potato responded to 45 kg S ha^{-1} supplied through Bentonite S and wheat responded to application of 5 kg Cu ha^{-1} in a deficient soil (0.18 ppm). Response to 1 kg ha^{-1} B application was also recorded in Onion and garlic. Critical limit of B in soil for toria was optimized 0.55 mg kg^{-1} in soil while for Toria crop it was 29 mg kg^{-1}. Critical limit of DTPA Cu for wheat was estimated 0.21 t 0.24 mg kg^{-1} under pot culture study and 0.25- 0.27 mg kg^{-1} under field condition. In Phytoremediation studies, it was reported that raya could be grown more efficiently in Cd contaminated soil than spinach.

In Himachal Pradesh, B and Zn deficiency was prevalent in all the five districts delineated for micro and secondary nutrients. Boron deficiency ranged from 26-51 % while Zn deficiency varied from2-14%. Of the five districts, Fe (21%), Mn

(6%) and Cu (29%) deficiency was reported only in Sirmaur district. Experiments on screening genotypes for zinc fortification in maize and wheat revealed that soil application of 100 kg $ZnSO_4$ + 0.5% $ZnSO_4$ foliar spray enhanced the Zn content in grain in both the crops. Genotypes having high response to Zn and productivity were identified.

Results of PDKV Akola centre showed prevalence of Zn deficiency in all the four districts viz. Nagpur, Gondia, Wardha and Hingoli. Fe deficiency (14 to 31 %) is also coming up in a big way. Sulphur deficiency ranged from 5 to 55 percent. In the nutrient indexing programme, the deficiency of S, Zn, Fe and B was recorded at 10, 41, 3 and 20%, respectively in rice based cropping systems after six years continuous cropping without addition of the said nutrients. Analysis of soil samples collected from sewage as well as tube well water irrigated areas showed Cu, Cd, Pb and Cr content 3 to 4 times higher in sewage irrigated areas than well water irrigated areas. In response study trials, higher grain yield and root nodulation in soybean was recorded when seed was treated with Zn (2 g) + Mo (1g) + Co (0.5g) per kg seed. Soybean grain yield increased significantly with the application of S @ 30 kg ha^{-1} + Zn @ 2.5 kg ha^{-1}. Application of 100 kg $ZnSO_4$ + two foliar sprays in rice could increase the Zn content in grains.

Delineation work carried out for seven districts during two years under report in Bihar exhibited the pronounced deficiency of Zn, B and S. The deficiency of Fe and Mn was also observed in some pockets. The DTPA Zn decreased from 6.0 mg kg^{-1} to 0.7-1.0 mg kg^{-1} in 23 crop cycles of rice-wheat-sorghum (F) and rice-mustard-moong cropping systems under control condition in long term experiment. The cumulative yield response was higher in rice-wheat-sorghum as compared to rice-mustard-moong rotation with the application of 10 kg Zn (initial) + 5 t FYM every year. Screening of rice and wheat genotype to Zn stress was carried out and it was observed that Sugandha, Janki and Kishori were efficient while Birsamati, Sita and Rajendra Subhashni were insufficient rice cultivars. For wheat HD 2733, NW2036 and WRS44 were efficient while HP 1731, HP1744 and HP2888 were inefficient cultivars.

Technical Session IV

The session was chaired by Dr. P.K. Sharma, Dean, College of Agriculture (CSKHPKV, Palampur. Four presentations made by the centres, *viz*. CSAUA&T, Kanpur, AAU, Anand, BAU, Ranchi and BCKV, Kalyani centers. The research progress of Kanpur centre pertaining to delineation and biofortification programme was presented by Dr. D. D. Tiwari. Among the six districts delineated for micro and secondary nutrients, in general, Zn was the most deficient element ranging from 15 to 36% deficiency except in Etawaha district where S was the most limiting element (39%). The deficiency of other elements like, Cu, Fe, Mn, and B was much scattered to draw any conclusion. In agronomic biofortification the centre has taken pigeon pea and wheat crop for Zn fortification. Though the application of zinc sulphate @ 100 kg ha^{-1} along with three foliar spray of zinc sulphate resulted in higher yields and enhanced zinc and manganese contents in grain whereas Cu content decreased. The iron contents both in wheat and pigeon pea were reduced when foliar feeding of Zn was made along with basal application of zinc sulphate.

Dr. V.P. Ramani presented the results of AAU, Anand centre. Reassessment and delineation of micro and secondary nutrients, nutrient indexing, role of organic manures in maintenance of micro nutrient status under continuous cropping and evaluation of micro and secondary nutrient in different cropping systems are the major programmes at AAU, Anand centre. The deficiency of Zn, Fe, B and S are the most common in six districts delineated during last two years (2009-

2011). Based on the front line demonstrations in deficient areas, it was observed that soil properties like pH, EC and OC are highly correlated the micro-nutrients content in soils. On the basis of nutrient indexing in Mahi Kadana command area, it was reported that soils of the area were sufficient in micronutrient contents as farmers are applying micronutrients fertilizer in this area after the deficiency was reported. Among the different nutrients, S showed the clear periodical reduction in its content. In the cropping system based experiments, over the years DTPA-extractable micronutrients decreased and reached close to critical limit under continuous cropping without micronutrient application, however, the rate of decrease was slow in treatment received FYM along with recommended NPK. In S fraction study, continuous application of N and P fertilizers caused more depletion in different S fractions i. e. organic-S, SO_4^- S and total S as compared to NP + FYM treatment. Application of Fe @ 20 mg kg^{-1} on Fe-deficient soils is sufficient for better growth and development of iron in inefficient pigeon pea varieties besides better Fe-content in plant. For soybean the S requirement is worked out as 40 kg S ha^{-1}. Four flower crops viz marigold, Gaillaride, Balsam and Bataniya was grown on pollutant contaminated soils under frontline demonstration and observed that speedy bioremediation was possible with marigold.

The study at BAU, Ranchi the centre on zinc bio-fortification in rice and wheat revealed that grains of rice and wheat were densed under 100 kg ha $ZnSO_4$ + foliar spray treatment. Rice cultivars like Vandana, Birsa Dhan-108, BVD-203, Pusa RH 10, Bharidhan, Improved Sambha Mansuri and wheat cultivars like KO 811, BIRSA GEHUN-2, MP-3304 & HUW-620, HD 2888, K-8027 were selected for further study on Zn enrichment. Dr. G. C. Hazra presented research achievement of BCKV, Kalyani centre and reported that among the micronutrients Boron is the most deficient micronutrients in all the districts and its deficiency ranged from 28.8 to 79.5%. Very high Cu deficiency (63-78%) was also reported in two districts, Hoogly and Naida. In zinc-biofortification in rice programme, it was noted that application of zinc @ 20kg ha-1 could increase additional rice yield upto 4-20% in most of the cultivars. HYV and hybrids were more responsive than locals and aromatics cultivars. At the end of the session, chairman suggested that crop response studies should be on different nutrient status level (low/medium/high) of the soil and uniform methodology should be used for analyzing nutrients content in plants. The nutrient management studies should be avoided in nutrient rich soils.

Technical Session V

This session was chaired by Dr S. K. Sanyal, Vice Chancellor, BCKV, Kalyani. Out of the three presentations made in this session, two were invited speakers, namely, Dr. Suresh Kumar, KAU, Kerala and Dr. G. C. Satish, Micronutrient Laboratory, IIHR, Bangalore. The research achievements of regular centre GBPUA&T, Pantnagar was presented Dr S. P. Pachauri, Pantnagar who informed that Zn deficiency in two districts of Uttarakhand ranged from 7.5 to 10 %. The Fe (9.5%) and S (11%) deficiencies were also reported in Haridwar district. Foliar application of Zn helped in increasing the P utilization efficiency. Application of 12.5 kg $ZnSO_4$ + 40 kg P_2O_5 ha^{-1} for Basmati rice and 25 kg $ZnSO_4$ + 60 kg P_2O_5 ha^{-1} for wheat were found suitable combination for enhancing grain yields. Application of potassium appeared to have synergistic effect on Zn nutrition for both rice and wheat crops. The thresh hold limit of Ni in fenugreek and buckwheat increased at lower FYM level (2.23 g kg^{-1} soil) but decline at higher FYM level; may be due to more uptake of Ni with high FYM. Similarly, for Cd it also increased at lower FYM level. In on farm front line demonstrations trials foliar spray of 0.15% B through solubor in tomato at 30 and 45 days after planting, while in maize basal application of DAP containing 0.30% B was superior in increasing the yields.

Dr Suresh Kumar from KAU, Kerala presented over view of research work done on secondary and micronutrients in the state. In the state, about 43, 86 and 19 percent samples were reported deficient in Ca, Mg and S, respectively. Among micronutrients, the deficiency of B and Zn was reported 59 and 30 per cent, respectively. This deficiency might be due to excessive leaching. He also presented Fe, Mn and Al toxicity problems in many crops grown on acid sulphate soils. Banana and coconut crops are severely suffering due to deficiency of B and Ca, hence management of these nutrients needs attention. He emphasized for establishment of a new centre of AICRP on MSPE as explained that soils of Kerala are altogether different than other parts of the country and needs specific management options. In addition systematic study on micronutrient/pollutant deficiency/toxicity delineation would be helpful in planning and management of soil-crop production system in the state. Dr G. C. Satish, IIHR, Bangalore explained micronutrient research on fruit crops carried out by the institute. He discussed about Ca Zn and B deficiency in different fruit crops. In general, crop specific micronutrients special fertilizers package for fruit crops have been developed by IIHR researcher for managing the micro and secondary nutrients problem in fruit crops, however, it was stressed upon for further collaboration with AICRP MSPE for solving the problems of secondary and micronutrients and developing location specific management options of micro and secondary nutrients for different crops.

During discussion the chairman Dr S. K. Sanyal, VC, BCKV, Kalyani suggested Pantnagar centre should work out step wise regression to find out concrete output and specific dose of Zn and P. Mr. G. P. Shetty, Ex President, IMMA, Pune submitted his opinion that there is a need to create awareness among the farmers and extension workers for use of micronutrients in agriculture for quality higher production in Kerala state. Dr P. N. Takkar suggested that there should be straight forward recommendation for farmers use on fruit crops in Karnataka. At the end, Chairman extended thanks to the speakers, rapporteears and participants.

Brain storming session

A brain storming session on Micro- and secondary nutrients and pollutant elements in soil-plant system to soil plant animal human continuum was held on 11th February, 2012 under the Chairmanship of Dr A. K. Singh, DDG (NRM) with panelists as Dr. P. N. Takkar, Ex Director, IISS, Bhopal, Dr. K. N. Tiwari, Ex Director, IPNI, Gurgaon, Dr. S. K. Sanyal, Vice Chancellor, BCKV, Kalyani, Dr. K. Mazumdar, Director, IPNI, India Programme, Dr. Biswapati Mandal, Prof, Soil Science, BCKV, Dr. N.K.S. Gowda, Principal Scientist, Animal Physiology, NIANP, Bangalore, Dr. K. S. Subramanian, Professor, Nano technology, TNAU, Coimbatore , Dr. Soumitra Das, Director, International Zinc Association, India programme, Dr. S. P. Datta, Sr. Scientist, IARI (on behalf of Dr. B. S. Dwivedi) and Dr. Arvind K. Shukla, Project Coordinator (MSPE). First of all, DDG (NRM) welcomed all the panel members and highlighted the increasing importance of micro and secondary nutrients from soil-plant system to soil-plant-animal continuum. He elaborated that there are many common elements essential and/or beneficial for crop production as well as for maintaining good animal and human health. He told that widespread micronutrient deficiencies are not only limiting the crop production but also affecting micronutrients concentration, particularly, Zn and Fe in grains and fodder. Hence, it is not surprising that the well documented micronutrients deficiency problems in humans occur predominantly in many parts of India where soils are low in available micronutrients and cereals are the major source of calorie intake. Before presentation by the panelists and discussion, he asked the Coordinator of the Project to brief about the progress made in the project and issues to be addressed in future.

Dr. A.K. Shukla, Project Coordinator (MSPE) briefed about the progress made by the project and raised several issue pertaining to future research on micro and secondary nutrients and pollutant elements in soil-plant-animal/human continuum. Dr. Shukla informed the panelist and house about wide spread micronutrients deficiency. Analysis of more than 3 lakhs soils samples revealed that about half of the soils are deficient in Zn while 1/3rd in B. Periodical distribution of analyses data from 1967 to 1988, 1989 to 2000 and from 2001 to 2010 showed that deficiency of Fe (particularly in Bihar, Maharashtra, Punjab, Haryana, Gujarat, Tamilnadu), Mn (in rice-wheat growing areas of Punjab and Hrayana and some parts of Bihar, Gujarat and Tamilnadu) and Cu (Bihar, Punjab and Tamilnadu) are also coming up in big way during 2001 to 2010 as compared to previous years. While, the extent of Zn deficiency is decreasing in north India and increasing in central and south India. He highlighted the picture of the status of multiple micronutrients deficiencies in intensively cultivated areas of the country. Among the secondary nutrients Sulphur deficiency (41%) are very extensive across the country. He informed the house that micronutrients soil fertility maps for eleven states of the country have been developed, however, there is need to open some new centers in states like, Rajasthan, Karnataka, Chhatisgarh, Kerala and CAU, Manipur (or Barapani, Meghalaya?) to cover the major part of the country for micronutrient studies. He also raised the issue of soil and plant sampling techniques and requested the peers to suggest the proper methodology including no. of samples and periodicity of sampling.

At present methods used for estimation of micronutrients, particularly for B and Mo are cumbersome and estimation of Fe with DTPA is questioned sometime. Therefore, he emphasized for developing/testing new methods to resolve this issue. While presenting the information regarding response of crops to micronutrient application, he showed the changing response of Zn over the years. During 1967 to 1984, about 42 per cent trials responded less than 200 kg ha^{-1}, 32 percent 200-500 kg ha^{-1}, 17 percent 500 to 1000 kg ha^{-1} and 9 percent more than 1000 kg ha^{-1} while during 2001 to 2010 about 28, 39, 25 and 8 percent trials falls in the category of < 200 kg ha^{-1} 200-500 kg ha^{-1}, 500 to 1000 kg ha^{-1} and more than 1000 kg ha^{-1}, respectively. In explaining the response behaviour he told that there were many soils having micronutrient slightly above the critical limit also responded to micronutrients application. Moreover, there is difference of opinion regarding existing critical limits and there is need to revisit the critical limit by conducting trials under field conditions rather than green house study. While demonstrating the response results of many crops to micronutrients fertilization, he explained that micronutrient use efficiencies are very poor. He raised the issue for use of nano technology and testing of new products for enhancing the micronutrients use efficiency. He informed that a separate presentation will be made by Dr. Subramaniam regarding use of nanotechnology for enhancing micronutrients use efficiency and possibilities of collaboration. Micronutrients research on fruits and vegetable crops is scattered and scanty; however, there is ample scope for micronutrients use in these crops for enhancing quality and yield. Thus, he proposed some collaborative centers, like, IIHR, Bangalore, CITH, Jammu & Kashmir, NRC, Citrus, Nagpur, CISH, Lucknow, DOPR, Pedavegi and NRC on Banana for micronutrient research in 12th plan. He raised the concern of time, energy and human resource consumed in evaluating new products from different companies at the cost of regular project work. He requested the chair that such project should be approved only if sufficient man power and funds are provided by the firm at least for 2 years. He also raised the issue of animal and human health related to micronutrient deficiency in soil and heavy metal toxicity. He told that existing modern cultivars contains less nutrients concentration as compared to traditional cultivars. He elaborated the strategies of micronutrients enrichment of seed and fodder and suggested for biofortification of Rice, wheat, maize, pulses, potato and fodder crops in collaboration with CRRI, Cuttack, DWR, Karnal, DMR, New Delhi, IIPR, Kanpur, CPRI, Shimla and IGFRI, Jhansi. He also acquainted the house with heavy metal studies carried out in the project. The Chairman showed his concern for taking more systematic studies on heavy metal pollution particularly in peri-urban areas of the country. He emphasized that heavy metal study should be carried out under soil/water-plant-animal/human continuum and also suggested for collaboration with NIN, Hyderabad, NIANP, Bangalore and IARI, New Delhi for such study.

Dr. S. K. Sanyal, Vice Chancellor, BCKV, Kalyani gave a brief account of work carried out on heavy metals and other pollutants in the country. He enlightened the house with two important issues pertaining to soil and pollutants. The first, Soil -A major Sink of the toxins – may also act as a source when its carrying capacity is exceeded, and second, Soil as a Source may also lead to the entry of the toxins in the human food-web accompanied with possible biomagnifications up in the food-chain. Pollution in water-soil-crop-animal continuum due to anthropogenic activities have been reported from Peri-Urban, Urban, Semi-rural and Rural areas. The industrialization, excess use of fertilizers and sewage sludge are major sources of deteriorating soil and water quality. He presented the impact of As, Cd Cr and F on human health and suggested researchable issues such as speciation of contaminants in soils and other heterogeneous systems for ascertaining release mechanism, spatial resolution, chemical transformations (conversion of toxic species to less toxic forms or production of volatile species of toxins) and hence its toxicity, bioavailability and impact on human health, effective remediation and waste management strategies, development of models for predicting the rate, fate and transport of contaminants in the sub-surface environment, elucidation of mechanism for microbial transformations of contaminants on soil components and understanding plant/soil interfacial reactions for rhizosphere chemistry characterization and soil remediation to address the problems..

Dr. N K S Gowda, principal scientist, animal physiology, NIANP, Bangalore presented the scope of micronutrients research in Soil-Plant-Animal continuum. He gave an account of mineral deficiency in animal body and emphasized that decline in soil fertility is one of the major reason of such deficiencies. He told that soil, plant and animal are interrelated to each other but not always linear because a large no of plant and animal factors affect the mineral nutrients utilization. However, it is proved that feeding of animals with produce obtained from mineral deficient soil lead to deficiency of those elements in animal body too. He suggested that mineral supplementation by feeding enriched fodder is one of the effective way to reduce animal malnutrition. At the same time he cautioned that feeding dry fodder is not effective because of high amount of silicates, phytate, oxalates and lignin etc, hence, green fodder is the option. Since mineral content in soil vary with region, hence, different strategies should be adopted for different regions. He emphasized collaboration of NIANP with AICRP-MSPE for study on impact of micronutrients and soil pollutants (heavy metals and nitrate) on mineral uptake by plants and subsequent effect on animals.

The topic entitled "Micronutrients malnutrition affecting animal and human health-Research Need in India" was presented by Dr P. N. Takkar, INSA honorary Scientist and Ex Director, IISS, Bhopal. Micronutrients essential for plants (Zn, Fe, Mn, Cu, B, Mo and Co) including iodine (I), selenium (Se) and chromium (Cr) are essential for animal and human. Because of beneficial effect of F in dental caries it is recognized as essential for human beings. Micronutrients flow in soil-plant-animal/human chain decreased due to its depletion from soil due intensive cultivation and use of high analysis NPK fertilizer devoid of micronutrients. As a result low nutritional quality (with respect to micronutrients) food is produced which affects the growth, immune system, brain development, neural function, mental health, reproduction, pregnancy outcome and fertility in human and animal health. Food system must be diversified to ensure balanced micronutrients supply in adequate and affordable amount. He informed that quantitative data regarding the extent and magnitude of MN deficiency in animals and human, resulting from their imbalance transfer from soil/ groundwater to plant-animal-human continuum, are far from adequate in vast geographical areas. He suggested that a national survey should be undertaken to assess the prevalence of micronutrients deficiency in populations in different parts of the country with varied food habits so that focused attention can be given to populations, which are at high risk. There is a need to assess/monitor micronutrients status of soil, water, food and fodder crops, human and animals through case studies in potential areas suspected to be deficient in one or more micronutrients using GPS. Research studies on relationships between deficiencies of micronutrient in soils, in food and fodder crops, in animal nutrition and in human nutrition needs to be carried out. Also there is need to undertake study in other universities, institutes in a mission mode involving their outstanding multidisciplinary faculty for better coordination and implementation of programs to achieve success in the important mission to mitigate soil-plant-animal/human heath problem arising from micronutrients deficiency on sustainable basis. The research study should include bio-monitoring of blood, organs & epidemiological diseases known or suspected in animals & human, in a multidisciplinary modes, involving all concerned disciplines/organizations (ICAR, ICMR) and modern tools for establishing a definite relationship between soil/water micronutrients deficiency and human and animals micronutrients status, deficiency disorders /diseases. Agricultural interventions like, genetic and agronomic biofortification of seed and fodder will be helpful in reducing micronutrient malnutrition in animal and human. Agronomic research studies need to be undertaken on mode (Soil, foliar, fertigation), rate, time, type of micronutrient fertilizer including the Nano micronutrients application alone or in combination with NPKS fertilizers or organic manures/ chelates etc. which would significantly enhance their supply to meet plants needs as well as bring a quantum increase in their concentration in grains, edible parts of staple food crops and fodders without affecting crop productivity.

Dr K. N. Tiwari, Ex Director, IPNI, India programme gave a detailed account of research on secondary nutrients and future needs. He focused on emerging problems of secondary nutrients in Indian agriculture and their causes. He cautioned on imbalanced fertilization leading to secondary nutrients deficiencies (S and Mg) under intensive cropping systems, thus declining NUE, yield and farmers profit. He appraised the research work done on Sulphur at the same time he showed his concern regarding study of Mg and Ca from soil fertility and plant nutrition view point. Dr Tiwari raised several relevant critical questions before the soil scientist regarding adequacy of research on Mg and Ca, particularly on delineation and mapping of deficient areas under these nutrients, generation of data on crop responses to the application of these nutrients in different crops and cropping systems, seriousness about consequences of hidden hunger/apparent deficiencies of these nutrients affecting NUE, crop productivity and farmers profit, cohesiveness of fertilizer policies and research findings with regard to nutrient needs and ratios and options for management of secondary nutrients to sustain high yields in the years to come. He suggested strengthening the research activities on Mg and Ca under AICRP MSPE. He wonders why only acid soils are considered to be Ca and Mg deficient when crop responses to Mg application are now being widely observed in intensively cropped areas, particularly in horticulture sector. Cereals, pulses, oilseeds, fodder, crops, vegetables, jute etc respond significantly to lime in acid soils. He was worried regarding yield loss due negligence of these nutrients. He reiterated that as compared to traditional cultivars the changes in mineral content of different types of cereals, pulses, vegetables and fruits in improved cultivars are responsible for mineral nutrients deficiencies in animal and human being. To create awareness about the necessity of Ca and Mg nutrients, he urged to conduct systematic studies on delineation and mapping through GPS/GIS for intensively cropped areas, acid humid and sub-humid regions, alkaline alluvium of arid and semiarid regions and strengthening the on-going nutrient indexing programme for developing decision support system in order to forecasting secondary nutrient deficiency in different soils and cropping systems. He emphasized on standardization of soil test methods and establishment of critical limits as no critical limit is fixed for these nutrients under Indian condition. He asked for evaluation of contribution of irrigation water towards supply of secondary nutrients particularly Sulphur. This would help in developing appropriate technologies to prevent, correct and to avoid hidden hunger of secondary nutrient deficiencies. He advised to develop strong linkage between AICRP MSPE centers and STLs of State Depts. and fertilizer industry so that each STL could adopt one village in a phased manner and a collaborative program for delineation and mapping of secondary nutrients be initiated by STLs under the guidance of the AICRP MSPE.

On behalf of Dr B. S. Dwivedi, Head, Division of Soil Science and Agricultural Chemistry, IARI, Dr S. P. Datta presented the need for basic research on micronutrients and pollutant elements. He raised basic issues pertaining to methods used for micronutrients analysis. He told that after the invention of DTPA method during seventies, it is widely used for routine analysis of micronutrients because it is simple, rapid and efficient. However, its usefulness as predictor of iron (Fe) availability is still uncertain. Moreover, the total micronutrient content in plant is good criteria to predict micronutrient deficiencies except for Fe because chlorotic plants generally have as much or more Fe than the green ones. Thus, he suggested, Fe^{2+} content in leaves proved to be more useful than total Fe as an indicator of its nutritional status in plant. Extraction of field moist soil with DTPA or NH4OAc for available Fe is more useful than dry soil. B deficiency is coming up in a big way and more no. of samples need to analyzed for B. It is difficult to adopt the hot water extraction for large number of samples on routine basis because it is cumbersome and hot water extraction poses problems due to color from organic matter and turbidity from suspended clay particles in the colorimetric estimation of B. Considering the predictability and other advantages he suggested an alternate extractants, i.e. 0.05 *M* mannitol- 0.01 M $CaCl_2$ for alkaline and calcareous soils (Cartwright *et al.* 1983) and 0.1 M salicylic extraction (Datta *et al.* 1998) for acid soils. Compared to hot water extraction, suitability of these two extractants may be tested across soils, crops and agro-ecological regions for delineation work. In case of molybdenum (Mo), a very limited number of soil samples were analyzed probably due to the tedious method of its estimation. So, concerted efforts should be made to simplify the method of its estimation. Nickel (Ni) is the latest addition to the list of essential plant nutrients, hence, development and calibration of soil test methods for assessing its availability is inevitable. Research work should also be undertaken either to enhance the stability of turbidity (0.15% $CaCl_2$ extractable sulphur) or develop new method for estimation of sulphur. He emphasized on starting collaborative centre at IARI for basic micronutrient research. Chairman suggested that IARI may take up some work on Nano technology for enhancing micronutrients use efficiency and speciation of heavy metals for modifying toxicity in addition to methods development.

Dr K.S. Subramanian, Professor & Head, Department of Nano-Science & Technology, Tamil Nadu Agricultural University, Coimbatore presented scope of Nanotechnology in Micronutrients research in Soils and Plants. He enumerated various use of nano particles, i.e. Quick diagnosis of micronutrients status in soils, used as biosensors to detect micronutrients and toxic metals, smart delivery of nutrients by using nano-based formulations in rhizosphere studies, precision farming and biofortification of micronutrients. Since micronutrient use efficiency is very poor, hence supplying micronutrient in nano form may be useful in enhancing the use efficiency and reducing the cost. In addition, nano particles could be useful in remediation of contaminated soils as it has very large surface area.

Dr Biswapati Mandal, Professor, Soil Science, BCKV Kalyani discussed the chemistry of micronutrients in soils and fate of continuous application of these nutrients in soil-plant system. He suggested that study should be taken on fate of Zn in high P build up soils. The interaction behaviour of micronutrients within micronutrient group and between the micro and macro nutrients need to studied for proper management of micronutrients in different soil and production system.

Dr Kausik Mazumdar, Director, IPNI, showed his concern regarding development of micronutrient management for different soil-crop system in different agro climatic zones. He also briefed about the nutrient manager- software developed for generating NPK recommendation for various crops and wished to be associated with AICRP MSPE for inclusion of micronutrients in the fertilizer package.

Dr Soumitra Das, Director, International Zinc Association, India office gave a concise account of importance of Zn in human health and told that zinc deficiency in soil strongly correlates to zinc deficiency in humans. According to WHO, zinc deficiency is 5^{th} leading cause of death and disease in the developing World. Applying zinc fertilizers to crops is a sustainable solution to zinc deficiency in soils and human. He wished to have collaboration with AICRP MSPE for enhancing the use of Zn in crops for increasing the Zn concentration in grains.

In his concluding remark to presentation made in brain storming session, Dr A.K. Singh, chairman of the session thanked to the panelists and advised to bring out a bulletin by combining all the presentation and prepare plan of action for the XII^{th} plan. He showed his concern for nutritional security in addition to food security. Agronomic manipulation is best option to dense the grains and fodder with micronutrients. Since dietary pattern is changing hence there is need to bring more crops (including fruits, vegetables) under fortification programme and if require collaborations may established with some horticultural institutes for enhancing the productivity and quality of horticultural crops. He stressed upon study of cycling of Ca, Zn, Fe, I Se, F and As, and heavy metal pollutants in soil-plant-animal/human system and therefore put the accent on to extend micro and secondary nutrients and pollutant element research from soil- plant system to soil plant-animal-human continuum. He suggested that initially some systematic case studies may be taken at some centre in collaboration with NIANP, Bangalore and NIN, Hyderabad. He also expressed his concern regarding divided opinion of critical limits of various micronutrients. He suggested to revisit the critical limit under field condition and established the critical limits for Mg under Indian condition. He asked for developing good diagnostic tools so that micronutrients deficiency can be identified at farm. He advocated for developing field based testing unit/kit in collaboration with institution like, IARI. Since micronutrient use efficiency is very poor hence there is need to develop highly water soluble micronutrient fertilizers and its applicability through drip irrigation may be tested. Option of use of micronutrient nano particles may also be tried. Basic work on pollutant elements is required in order to detoxify the element in the soil system or convert in the non toxic form so that its load in plants may be reduced. He also showed his willingness to conduct some systematic studies on role of micronutrients in reducing the negative impact of climate change. Before leaving for New Delhi, Dr Singh appreciated and thanked to the entire panelist and gave the responsibility to Dr S. K. Sanyal, VC, BCKV, Kalyani and Co-chairman of the session for further discussion on the aspect. A good discussion was held on critical limits of micronutrient, regular training and monitoring, fate of micronutrients in conservation agriculture, on line availability of micronutrient report, testing of product from various firms etc. Dr Shukla has replied all the queries very well. Dr K. N. Tiwari, Dr P. N. Takkar and Dr Sanyal emphasized on developing clear technical programme for execution of various recommendation emerged out from this workshop. They also stressed on linkages with various institution in 12^{th} plan for micronutrients and heavy metal study in soil-plant animal continuum. Lastly, Dr Sanyal thanked all the panelist and peer group of scientists for participating in intensive discussion in the session.

Technical Session VI

This session was chaired by Dr. P. N. Takkar, Ex. Director, IISS with panelists like Dr. S. K. Sanyal, Dr. K. N. Tiwari and Dr P. K. Sharma as peer reviewers. Dr. Shukla has presented the technical programme of the project developed on the basis of recommendation emerged out from the discussion held in brain storming as well as in other sessions.

After finalization of technical programme, the chairman thanked to all the participants for fruitful discussion and inputs provided. Dr Sanyal, VC, BCKV, Kalyani, thanked to the ICAR and specially DDG (NRM) and PC MSPE for holding the workshop at BCKV Kalyani. At the last, Dr Shukla thanked all the peer group, panelist, special invitee, scientist of the AICRP and other staff members at PC unit. He thanked the university for providing facility and hosting the workshop successfully.

TECHNICAL PROGRAM

All India Coordinated Research Project of Micro- and Secondary Nutrients & Pollutant Elements in Soils & Plants

Program No. 1. Delineation and Reassessment of micro and secondary nutrients deficient areas and updating soil fertility maps

Objectives

1. To delineate and reassess the changes in secondary and micronutrient fertility in soils based on soil and plant analyses.
2. To prepare secondary and micronutrient fertility maps depicting extent of deficiency using GIS.

Work plan:

a. No. of districts to be covered in a year: Minimum **3-5** districts depending upon size.

b. All samples should have GPS reading.

c. No. of soil samples to be collected: Minimum 250 samples per district (for big districts minimum samples should be 350). Out of this 100 representative surface (0-15 cm depth) samples will be collected based on predominant cropping systems of the districts with background information as per attached proforma (Proforma for background information).

d. Number of plant samples (grain/seed and straw/stover) to be collected : Minimum ten per cent of the soil samples

e. Nutrients to be analyzed:

1. Available secondary (Ca, Mg and S) and micronutrients (Zn, Cu, Fe, Mn, B, Mo) and texture (by quick method followed by confirmation by Bouyoucos method) pH, EC, organic carbon content in soil. However, the analysis of Mo should be undertaken in soils having pH less than 6.
2. Ca, Mg, S, Zn, Cu, Fe, Mn, B and Mo content in collected plant samples.
3. Nutrient fertility maps to be prepared using the point wise data collected as above using GIS.

Action: All the centers

Note:

1. *A repository of soil sample should be maintained using good quality container.*
2. Available Ca, Mg and Mo analysis may preferably be performed in acidic soils (pH less than 6.0).
3. *The interested centre may also go for analysis of available P and K as these nutrients have interrelations with the available S and micronutrients.*

Programme 2. Nutrient indexing of soils and crops in areas of intensive agriculture under different cropping systems and management practices

Objective: To monitor changes in the secondary and micronutrient status over the period through soil and plant analyses and forecast nutrient deficiency

Work plan:

a. Twenty bench mark sites will be identified for two major cropping systems for the purpose.

b. Soil and Leaf sampling should be done at one critical growth stage for the analysis of major, secondary and micronutrients for each crop. Bulk density and other soil properties as programme 1 should also be recorded for all benchmark site.

c. Initial soil samples should be collected in bulk and stored for future use. Analysis of initial soil samples as well as soil samples collected after every 3rd crop cycle for micro and secondary nutrients.

d. Grain and stover yield will be recorded from 5 x 5 m^2 area and grain and Stover/straw samples will be retained and processed for chemical analysis to quantify nutrient uptake and correlation of leaf analysis data with yield and uptake of nutrients.

e. hree profiles samples (0-15, 15-30, 30-45, 45-60 cm depth) from predominate cropping systems of the district should be recorded. Profile samples will be analyzed for total and available nutrients along with physico-chemical properties.

f. If there is any change in the cropping system due to unavoidable reason, it should be recorded.

Action: All the centers except volunteer centers

Note: 1. In plant tissue test (i.e. leaf tissue analysis) the Fe^{+3} and Fe^{+2} forms of iron should be analyzed to diagnose the Fe deficiency in plants.

2. *For B analysis* 0.05 *M* mannitol- 0.01 *M* $CaCl_2$ for alkaline and calcareous soils (Cartwright *et al.* 1983) and 0.1 *M* salicylic extraction (Datta *et al.* 1998) for acid soils should be used.

Programme 3. Refinement of critical values of micro and secondary nutrients in soils and standardization of soil test methods

A. Refinement of critical limits

Objective:

1. To establish the critical limits of secondary and micronutrients in soil
2. To standardize soil test method for available secondary and micronutrients

Work plan:

a. Ten sites will be selected in one of the same villages chosen for nutrient indexing or any intensively cropped village deficiency of much nutrients on the basis of predetermined nutrient status

b. Nutrients: S, Mg, Zn, B, Cu, Fe and Mn

c. Nutrient doses (kg ha^{-1}):

Leaf analysis at one critical growth stage for nutrients in question.

Nutrient	Rate of application				Foliar spray	Source
S	0	20	40	60		Gypsum/SSP
Mg	0	20	40	60		Magnesium Sulphate
Zn	0	2	4	6		Zinc Sulphate
Fe	0	5	10	20	Three spray (0.2% Fe)	Ferrous Sulp hate
Mn	0	5	10	20	Three spray (0.33% Mn)	Manganese Sulphate
B	0	1	1.5	2.0	Three spray (0.2% of B fertilizer)	Borax/solubor/granubor

Action: All the centers

Note: The status of fields in the selected village should be analyzed. The selected 10 sites should be distributed for low, medium and high status to serve the purpose for revisiting of critical limits. The treatments of selected element may be given in replication in each field so that the data can be processed statistically. Only important elements for the area could be targeted first.

B. Evaluation / standardization of AB-DTPA-a multi-nutrient extractant for analysis of major (P K) secondary (S) and micronutrients cations (Fe, Mn, Zn, Cu) as well as and heavy metals (Cd, Cr, Pb and Ni) with established standard methods.

Objective: To evaluate common extractant as a multi-nutrient extractant for assessment of their availability in soils for plants.

Work plan:

1. Soil samples representing different soils will be collected.
2. The samples will be extracted with both DTPA and AB-DTPA extractants to evaluate their comparative efficiency using statistical analysis.
3. Also their comparative efficiency will be further confirmed by carrying out a pot house study to correlate nutrients extracted with their uptake by plant.
4. The AB-DTPA as multi-nutrient extractant will be used against recommended extractant (DTPA and others) for evaluating status in the soils, if found satisfactory and by establishing their critical values already established for DTPA.
5. For B analysis 0.05 *M* mannitol- 0.01 *M* $CaCl_2$ for alkaline and calcareous soils (Cartwright *et al.* 1983) and 0.1 *M* salicylic extraction (Datta *et al.* 1998) for acid soils should be used along with hot water for available B for studying the suitability of extractant.
6. The analysis of soil samples for available P, K and S should also be performed with recommended extractants for comparison with AB-DTPA.

Action: AAU, Anand, TNAU, Coimbatore, ANGRAU, Hyderabad, RAU, PUSA, Bihar and PAU, Ludhiana. IARI, if is approved as collaborative centre in 12^{th} plan, will do the said work.

Note: The study should be taken up by different centers for different soil types. Extractants may be recommended by establishing correlation / regression analysis with yield.

Programme 4. Amelioration of micro and secondary nutrient deficiency in crops

a. Amelioration techniques for different crops and cropping systems (including horticultural crops)

Individual center should submit the technical details of the experiment for amelioration of specific micronutrients to the PC Micronutrients.

Action: Preferably New centers added in 2009 in AICRP (MSPE) while other can take the programme volunteer). Amelioration techniques for correcting micro and secondary nutrients deficiency in horticultural crops will be developed in collaboration with IIHR, Bangalore, CITH, Jammu & Kashmir, NRC, Citrus, Nagpur, CISH, Lucknow, DOPR, Eluru and NRC on Banana, if approved in 12^{th} plan.

b. Assessing influence of P build up on the availability of micronutrients in soils and its nutrition

Treatments:

Field expt.:

1. Identify the soils (similar soil type) with various regime of P build up regime, say very low (~10), low (10-30), medium (30-60), high (60-120), very high (120-180 mg P_2O_5/kg soil) etc.
2. Select any two P build up regime soils. (If possible the amounts of Fe- and Al-oxides P of selected soils should be measured)
3. Add different grades of Zn – 0, 2.5, 5.0, 10.0 mg/kg
4. Take annual grain-crop in system mode, say rice-wheat, maize-wheat, rice-rice etc. (preferably predominate cropping system of the state.)

Laboratory and greenhouse expt.:

1. Take the selected soils and add different grades of P, say 0, 30, 60, 120, 180 mg/kg,
2. Add different grades of Zn – 0, 2.5, 5.0, 10.0 mg/kg
3. Do incubation in laboratory and grow crops in pots.

Observations to be taken:

1. Biomass and grain yield of crops;
2. Concentration of P, Zn, Fe, and other major nutrients in straw and grains
3. Soil pH, available contents of P, Zn, Fe etc.,
4. Contents of amorphous and crystalline Fe- and Al- oxides.

Action: PAU, Ludhiana, CCSHAU, Hisar, CSAUT, Kanpur, BCKV, Kalyani, ANGRAU, Hyderabad)

Programme 5. Screening of crop genotypes for micronutrient efficiency

Screening of different crop cultivars for micronutrient efficiency will be done with the help of Soil scientist, Biochemist/plant physiologist and plant breeders/genticians of crop institutions like CRRI, IIPR, CPRI, DMR and DWR, if approved in 12th plan.

OR

Universities may go collaboration with regional centers of the universities as has been done by ANGRAU, Hyderabad. The interested centers may send their work plan to PC micronutrients for approval.

Programme 6. Study on secondary and micronutrient in soil-plant-animal-human continuum

Objectives:

To monitor secondary and micronutrients content in serum of animals (in human, wherever possible) feeding on the produce from the deficient/sufficient areas in collaboration with veterinarians/physicians.

Action:

a. Centers: AAU, Anand, PAU, Ludhiana, GBPUAT, Pantnagar, ANGRAU, Hyderabad, JNKVV, Jabalpur, HAU, Hisar and TNAU, Coimbatore (collaboration with NIANP, Bangalore and NIN, Hyderabad if approved by the council in 12th plan,)
b. In association with PDFSR, Modipuram in farming system perspective (Two integrated farming system centers module in all five agro ecosystems of the country.

Work plan:

Relationship of secondary and micronutrient in soil and plant with their concentration in serum of animal/human will be worked out.

Note: A separate detail technical methodology/programme will be provided by different centers to PC micronutrients as per need of the state. Centre should hold a meeting with possible collaborators (veterinary scientist/physician) to chalk out technical programme for successful execution. The detail technical programme will be send to PC (M) for approval.

Programme 7. Monitoring of heavy metal toxicity in relation to soil-plant human/animal continuum

Objectives

1. To assess extent of heavy metal pollution in agricultural soils, surface and ground water, fishes and crops especially in vegetables and fodder, in areas where use of sewage and industrial effluents is being practiced for irrigation purpose.
2. To monitor heavy metals content in serum of animals (in human, wherever possible) feeding on the produce from the polluted areas in collaboration with veterinarians and physicians.

Action: PAU, Ludhiana, HAU, Hisar, PDKV, Akola, GBPUAT, Pantnagar, ANGRAU, Hyderabad, CSAUAT, Kanpur, BCKV, Kalyani, AAU, Gujarat and TNAU, Coimbatore.

Work plan:

1. Representative samples of sewage, untreated waste, soil, plant, water and blood (Hair and nail in case of Arsenic) are to be collected from the polluted areas and also from the adjoining non-polluted areas.

2. All the samples used to be processed and analyzed as per the standard procedures for Cd, Pb, Cr, Ni, As.
3. Relationship of heavy metals in soil, plant and water with their concentration in crops as well as in blood serum will be worked out.

Micro plots/ field experiments will be conducted to identify suitable crops and their genotypes preferred fodders which possess restricted absorption and their translocation to edible parts.

Note: A separate detail technical methodology/programme will be provided by different centers to PC micronutrients as per need of the state. Centre should hold a meeting with possible collaborators (veterinary scientist/physician) to chalk out technical programme for successful execution. The detail technical programme will be send to PC (M) for approval

Programme 8. Basic studies

a. Title: Effect of phasing of Zn application on fate of Zn pools in different soils and cropping systems.

Treatment: Zn_1=2.5 kg Zn ha^{-1}

Zn_2=5.0 kg Zn ha^{-1}

Zn_3= 7.5 kg Zn ha^{-1}

Zn_4=10.0 kg Zn ha^{-1}

Cropping system: Predominant cropping sequences of the state (for example, Rice-wheat, maize-wheat, rice-rice, pearl millet-wheat etc)

Treatments details

	Year of experimentation					
Treatment	**I**	**II**	**III**	**IV**	**V**	**VI**
T1	Zn1	0	0	0	0	0
T2	Zn2	0	0	0	0	0
T3	Zn3	0	0	0	0	0
T4	Zn4	0	0	0	0	0
T5	Zn1	0	Zn1	0	Zn1	0
T6	Zn2	0	Zn2	0	Zn2	0
T7	Zn3	0	Zn3	0	Zn3	0
T8	Zn4	0	Zn4	0	Zn4	0
T9	Zn1	Zn1	Zn1	Zn1	Zn1	Zn1
T10	Zn2	Zn2	Zn2	Zn2	Zn2	Zn2
T11	Zn3	Zn3	Zn3	Zn3	Zn3	Zn3
T12	Zn4	Zn4	Zn4	Zn4	Zn4	Zn4
T13	0	0	0	0	0	

Observation to be recorded

1. Initial soil properties
2. Grain and straw yield
3. Nutrient content
4. Zn fractions after every two year

Action: All the regular centre of the project.

Note: As per treatment the fertilizer Zn should be applied to the first crop of the cropping system.

a. Title: Effect of phasing of B application on fate B pools in different soils and cropping systems

Treatment:

B_1=0.5 kg B ha^{-1}

B_2=1.0 kg B ha^{-1}

B_3=1.5 kg B ha^{-1}

B_4=2.0 kg B ha^{-1}

Cropping system: Predominant cropping sequence of the state (vegetable based system may also be taken).

Treatments details

Treatment	I	II	III	IV	V	VI
T_1	B_1	0	0	0	0	0
T_2	B_2	0	0	0	0	0
T_3	B_3	0	0	0	0	0
T_4	B_4	0	0	0	0	0
T_5	B_1	0	B_1	0	B_1	0
T_6	B_2	0	B_2	0	B_2	0
T_7	B_3	0	B_3	0	B_3	0
T_8	B_4	0	B_4	0	B_4	0
T_9	B_1	B_1	B_1	B_1	B_1	B_1
T_{10}	B_2	B_2	B_2	B_2	B_2	B_2
T_{11}	B_3	B_3	B_3	B_3	B_3	B_3
T_{12}	B_4	B_4	B_4	B_4	B_4	B_4
T_{13}	0	0	0	0	0	

Observation to be recorded

1. Initial soil properties
2. Grain and straw yield
3. Nutrient content
4. B fraction after every two year.
5. Analysis of B in irrigation water

Action: All the regular centre of the project.

Note: As per treatment the fertilizer B should be applied to the first crop of the cropping system.

Programme 9. *Frontline demonstrations on effective technologies generated by the centers should be conducted with proper approval from PC (M). Collaboration with PDFSR, if approved in 12th plan, will be useful.*

Action: All the regular centre of the project.

Note: Universities are allowed to have collaboration with local bodies like KVKs, university research stations, NGOs in the area provided regular monitoring of FLDs on farmers fields should be ensured by in charge of micronutrient centre.

Sample Format for collection of information during sampling

1.	State	
2.	District	
3.	Block	
4.	Village	
5.	Survey no. / Identificati on mark of field	
6.	Name of standing crop, if any?	
7.	Name of the farmer	
8.	Cropping System	
9.	Farmers' fertilizer practice (Nutrients applied kg ha^{-1})	
(a)	N	
(b)	P_2O_5	
	(c) K_2O	
	(d) Zn	
	(e) S	
	(f) Other nutrients (if any)	
	(g) Organic manure (FYM/Compost, t ha-1)	
	(h) Green manuring	
	(i)Industrial wastes	
	NB: representative samples of organic manure to be collected and characterized	
10.	Irrigation source (Tube well/canal	
11.	Number of irrigations	
12.	Pest incidence (If any)	
13.	Grain and straw yield	

DETAILS OF MANPOWER

Name	Designation	Date of joining	Date of leaving
	IISS, Bhopal, Madhya Pradesh		
Dr. A.K. Shukla	Project Coordinator	31.03.2011	Continue
Dr. S.K.Behera	Scientist	18.05.2007	31.03.2012
Mr. Pankaj K. Tiwari	Scientist	11.04.2013	Continue
	ANGRAU, Hyderabad, Andhra Pradesh		
Dr. P Surendrabau	Senior Soil Chemist (Officer Incharge)	14.05.2012	Continue
Mr. K.M. Khadke	Asstt. Research Scientist	04.11.2001	30.06.2011
Mrs. M.C. Patnaik	Asstt. Research Officer	26.04.1988	Continue
Dr. M. Shankaraih	Scientist	01.10.2012	Continue
	RAU, Pusa, Bihar		
Dr. M. P. Singh	Chief Soil Scientist	12.07.2011	10.07.2013
Dr. R. Laik	Senior Scientist (Officer Incharge)	13.07.2013	Continue
Dr. S.K. Singh	Junior Scientist	16.07.2008	Continue
Dr. Vipin Kumar	Junior Scientist	31.03.2008	Continue
Dr. S.P. Singh	Junior Scientist	12.05.2011	Continue
	AAU, Anand, Gujarat		
Dr. K.P. Patel	Soil Scientist	29.09.1994	31.03.2012
Mr. V.P. Ramani	Senior Scientist (Officer Incharge)	01.12.1990	Continue
Dr. S. B. Patel	Asstt. Res. Scientist	01.02.2011	continue
	CCSHAU, Hisar, Haryana		
Dr. Ram Kala	Senior Scientist (Officer Incharge)	01.04.1988	Continue

Dr. R.S. Malik	Asstt. Soil Scientist	20.02.2002	Continue
Dr. R. R. Dahiya	Astt. Scientist	01.06.2011	Continue
Dr. Harendra	Asst. Soil Scienctist	01.06.2011	Continue
	JNKVV, Jabalpur, Madhya Pradesh		
Dr. R.S. Khamparia	Principal Scientist	15.10.2012	30.06.2013
Dr. B.L. Sharma	Principal Scientist (Officer Incharge)	01.07.2013	Continue
Dr. P.S. Kulhare	Principal Scientist	16.05.1972	Continue
Shri G. S. Tagore	Scientist	25.06.2012	Continue
	PAU, Ludhiana, Punjab		
Dr. U.S. Sadana	Sr. Soil Chemist	06.11.2007	Discontinue
Dr. M.P. Khurana	Sr. Soil Chemist (Officer Incharge)	05.07.1991	Continue
Dr. J.S. Manchanda	Sr. Soil Chemist	14.02.2001	Continue
Dr. S.S. Dhaliwal	Sr. Soil Chemist	09.01.2006	Continue
	TNAU, Coimbatore, Tamil Nadu		
Dr .P. Stalin	Officer Incharge	09.05.2008	Continue
Dr. D.Muthumanickam	Associate Professor	19.09.2006	Continue
Dr. T. Chitdeshwari	Associate Professor	11.05.2007	03.12.2012
Dr. P. Malathi	Associate Professor	05.12.2012	Continue
	LUCKNOW UNIVERSITY, Lucknow, Uttar Pradesh		
Dr. (Mrs.) N. Khurana	Asstt. Soil Scientist	26.03.1981	31.12.2009
Dr. Y.K. Sharma	Principal Scientist	04.07.2012	Continue
Dr. (Miss) P. Sinha	Sr. Research Asstt.	10.03.1989	Continue
Dr. Sunil Gupta	Sr. Research Asstt.	04.09.1984	Continue
	GBPUAT, Pantnagar, Uttarakhand		
Dr. P.C. Srivastava	Asstt. Professor (Officer Incharge)	01.11.1997	Continue
Dr. A.K. Pant	Asstt. Prof.	01.11.2003	Discontinue
Dr. S. P. Pachauri	Asstt. Prof.	01.05.2009	Continue
	OUAT, Bhubaneswar, Odisha		
Dr. M.R. Patnaik	Professor	26.06.2002	01.06.2009
Dr. A. K. Pal	Professor & OIC	01.06.2009	Continue
Ms Bandita Jena	Asstt. Professor	11.05.2011	Continue
	PDKV, Akola, Maharashtra		
Dr. R.N. Katker	Sr. Soil Scientist (Officer Incharge)	05.08.2009	Continue
Dr. G. S. Laharia	Jr. Soil Scientist	18.01.2012	Discontinue
Dr. A.B. Aage	Jr. Soil Scientist	01.08.2013	Continue

	AAU, Jorhat, Assam		
Dr. (Mrs) A. Basumatary	Soil Scientist (Officer Incharge)	01.04.2009	Continue
Mrs. Gayatri Goswami	R. A.	22.10.2009	Continue
Mrs. Sukritee Hazarika	S. R. F.	29.12.2009	Continue
	BAU, Ranchi, Jharkhand		
Dr. R.P. Singh	Soil Scientist	01.04.2009	9.03.2010
Dr. Arvind Kumar	Soil Scientist (Officer Incharge)	10.03.2010	Continue
	BCKV, Mohanpur, Nadia, W.B		
Dr. G.C. Hazara	Soil Scientist (Officer Incharge)	01.04.2009	Continue
	CSKHPK, Palampur H.P.		
Dr. S.P. Sharma	Soil Scientist	01.04.2009	26.07.2012
Dr. V.K. Sharma	Soil Scientist	27.07.2012	10.02.2013
Dr. Pradeep Kumar	Officer Incharge (Officer Incharge)	11.02.2013	Continue
	CSAUA&T, Kanpur, Uttar Pradesh		
Dr. D.D. Tiwari	Soil Scientist (Officer Incharge)	01.04.2009	Continue

DETAILS OF MANPOWER

Name	Designation	Date of joining	Date of leaving
	IISS, Bhopal, Madhya Pradesh		
Dr. A.K. Shukla	Project Coordinator	31.3.2011	Continue
Dr. S.K.Behera	Scientist	18.05.2007	31.3.2012
Mr. Pankaj K. Tiwari	Scientist	11.04.2013	Continue
	ANGRAU, Hyderabad, Andhra Pradesh		
Dr. P Surendrabau	Senior Soil Chemist (Officer Incharge)	14.05.2012	Continue
Mrs. M.C. Patnaik	Asstt. Research Officer	26.041988	Continue
Sr. Research Associate	Sr. Research Associate	12.08.1998	Continue
	RAU, Pusa, Bihar		
Dr. M. P. Singh	Chief Soil Scientist	23.06.1998	11.07.11
Dr. R. Laik	Senior Scientist (Officer Incharge)	12.07.11	Continue
Dr. K. Choudhry	Senior Scientist	21.01.2000	31.01.2011
Dr. S.K. Singh	Junior Scientist	16.07.2008	Continue
Dr. Vipin Kumar	Junior Scientist	31.03.2008	Continue
Dr. S.P. Singh	Junior Scientist	12.05.2011	Continue
	AAU, Anand, Gujarat		
Dr. K.P. Patel	Soil Scientist	29.09.1994	31.3.2012
Mr. V.P. Ramani	Senior Scientist (Officer Incharge)	01.12.1990	Continue
Mrs. V. George	Senior Scientist	26.11.1975	31.3.2012
Dr. S. B. Patel	Asstt. Res. Scientist	1.02.2011	continue
Shri. D.M. Parmar	Sr. Research Assistant	01-06-09	continue
	CCSHAU, Hisar, Haryana		
Dr. Ram Kala	Senior Scientist (Officer Incharge)	01.04.1988	Continue

Dr. R.S. Malik	Asstt. Soil Scientist	20.02.2002	Continue
Dr. R. R. Dahiya	Research Associated	01.09.1995	Continue
JNKVV, Jabalpur, Madhya Pradesh			
Dr. R.S. Khamparia	Principal Scientist (Officer Incharge)	15.10.2012	Continue
Dr. P.S. Kulhare	Principal Scientist	16.05.1972	Continue
Shri G. S. Tagore	Scientist	25.06.2012 to	Continue
PAU, Ludhiana, Punjab			
Dr. U.S. Sadana	Assistant Soil Chemist	06-11-2007	Continue
Dr. M.P. Khurana	Asstt. Soil Chemist	05.07.1991	Continue
Dr. J.S. Manchanda	Soil Chemist	14.02.2001	Continue
Dr. S.S. Dhaliwal	Soil Chemist	09.01.2006	Continue
TNAU, Coimbatore, Tamil Nadu			
Dr .P. Stalin	Officer Incharge	09.05.2008	Continue
Dr. D.Muthumanickam	Associate Professor	19.09.2006	Continue
Dr. T. Chitdeshwari	Associate Professor	11.05.2007	03.12.2012
Dr. P. Malathi	Associate Professor	05.12.2012	Continue
LUCKNOW UNIVERSITY, Lucknow, Uttar Pradesh			
Dr. (Mrs.) N. Khurana	Asstt. Soil Scientist	26.03.1981	31.12.2009
Dr. (Miss) P. Sinha	Sr. Research Asstt.	10.3.1989	Continue
Dr. Sunil Gupta	Sr. Research Asstt.	4.9.1984	Continue
GBPUAT, Pantnagar, Uttarakhand			
Dr. P.C. Srivastava	Asstt. Professor (Officer Incharge)	01.11.1997	Continue
Dr. A.K. Pant	Asstt. Prof.	1/11/2003	Continue
Dr. S. P. Pachauri	JRO	1/5/2009	Continue
OUAT, Bhubaneswar, Odisha			
Dr. M.R. Patnaik	Professor	26.06.2002	01.06.2009
Dr. A. K. Pal	Professor & OIC	01.06.2009	Continue
Ms Bandita Jena	Asstt. Professor	11.05.2011	Continue
PDKV, Akola, Maharashtra			
Dr. R.N. Katker	Sr. Soil Scientist (Officer Incharge)	05.08.2009	Continue
Dr. G. S. Laharia	Jr. Soil Scientist	18.01.2012	Continue

COOPRATIVE CENTERS

AAU, Jorhat, Assam			
Dr. (Mrs) A. Basumatary	Soil Scientist (Officer Incharge)	1/4/2009	Continue
Mrs. Gayatri Goswami	R. A.	22.10.2009	Continue
Mrs. Sukritee Hazarika	S. R. F.	29/12/2009	Continue
BAU, Ranchi, Jharkhand			
Dr. R.P. Singh	Soil Scientist	1/4/2009	9.03.2010
Dr. Arvind Kumar	Soil Scientist (Officer Incharge)	10.3.2010	Continue
Mr. Manish Kumar	R. A.	10.03.2010	Continue
BCKV, Mohanpur, Nadia, W.B			
Dr. G.C. Hazara	Soil Scientist (Officer Incharge)	01.04.2009	Continue
CSKHPK, Palampur H.P.			
Dr. S.P. Sharma	Soil Scientist (Officer Incharge)	01.04.2009	Continue
CSAUA&T, Kanpur, Uttar Pradesh			
Dr. D.D. Tiwari	Soil Scientist (Officer Incharge)	01.04.2009	Continue

LIST OF PUBLICATION

PCM Unit, IISS Bhopal

Research papers

Shukla A.K., Behera. S.K., Shivay.Y.S., Singh. P. and Singh. A. K. (2012) Micronutrient and field crop production in India: A Review, *Indian Journal of Agronomy* (Special Issue) 57, 124-131.

Shukla, A. K. And Siddiqui S. (2013). Sukshm poshak tatvon ka mahatav avam prabandhan. In Soil health for sustaible productivity.pp 61-69

Shukla, A. K. (2012) Micronutrients beyond soil-plant system. *JINSA*.

Shukla, A. K. (2012). Micronutrients crop productivity and human health. PAU, Bulletin, INM winter school.

Shukla A.K., Behera. S.K., Singh. P. and Singh. A. K. (2012). Enhancing Zn and Fe loading in grains of cerals and pulses: An agronomic approach, *Better Crops*.

Shukla, A. K. and Behera, S. K. (2012). Micronutrient fertilizers for higher productivity. *Indian Journal of Fertilizer* April 2012

Behera, S.K., Shukla, A. K. and Singh, M. V. (2012). Distribution variability of total and extractable copper in cultivated acid soils of India and their relationship with some selected soil properties. *Agrochimica* (Italy).

Shukla, A. K. and Behera, S. K. (2011). Zinc management in Indian Agriculture: Past, present and future. *Indian Journal of Fertilizer* 7 (10):14-33.

Shukla, A. K. (2011) Micronutrient research in India: Current status and future strategies. JINSA,59: S88-98

Popular/technical articles

Shukla, A. K. and Behera, S. K. (2011). Extent of deficiency of micro nutrients in Indian soils and their best management practices for different crops. (Provided to MTC trainee)

Technical bulletins/books/book chapters

Shukla R., Srivastava S. and Shukla A. K. Molecular Mechanism of Nutrient Uptake in Plants (Book Chapter in ZSI 2011)

Shukla R., Shukla A. K. and Sharma Y K. 'Omics': Technique in modern agriculture for crop improvement. Book chapter to be published in book entitled 'Crop Improvement in the Era of Climate Change' (H.N.B. Publishing House, New York, USA

Shukla Arvind K (2013). Current soil micronutrients status, multiple micro-nutrients deficiencies and contribution of micronutrients to food grain production in India. *In Frontier Areas of soil research*. Pp 155-170

Shukla, A. K., Behera, S. K. (2012) Micro- and secondary nutrients and pollutant elements research in India in soils and plants. Coordinator Report- AICRP Micro- and Secondary Nutrients and Pollutant Elements in Soils and Plants, IISS, Bhopal. pp. 1-102.

Shukla, A. K., Behera, S. K., Subba Rao, A. and Singh, A. K. (2012) State wise micro and secondary nutrients recommendations for different crops and cropping systems. Research Bulletin No. 1/2012, IISS, Bhopal. pp. 1-40.

Shukla R., Shukla A. K. and Sharma Y K. 'Omics': Technique in modern agriculture for crop improvement. Book chapter to be published in book entitled 'Crop Improvement in the Era of Climate Change' (H.N.B. Publishing House, New York, USA

AAU, Anand

Rajesh kumar, Butani, M. G., Dhami, A. J. Kavani, F. S. Savaliya, F. P., Ramani, V. P. and Patel, K. P. (2011) Effect of hormonal and antibiotics therapy on fertility and serum trace minerals profile in repeat breeding crossbred cows. *GAU Research Journal* 36 (1): 59-63.

Patel, K. P. (2011). Crop response to zinc cereal crops *Indian Journal of Fertilizers* 7 (10): 84-100.

Parmar, J. K. and Patel, K. P. (2010). Impact of effluent waters on soil-water-plant system due to irrigation from khari cannel around Nawagam-Vatava region of Gujarat (India). *Ecol. Env. & Cons*. 16 (4): 2010; pp. (1-7).

Patel, K. P., Singh, M. V., George, V. and Ramani, V. P. (2010). Four Decades of Research on Management of Micro- and Secondary-Nutrients and Pollutant Elements in Crops and Soils of Gujarat. Published by Project co-ordinator (Micronutrients), IISS, Bhopal.

Maliwal, G. L. and Patel, K. P., (2011) Heavy metals in Soil and Plants. Pub. by Agro-tech Publishing Academy. Udaipur. pp 1-264.

Patel K. P., Singh M. V., Ramani V. P., Patel K. C. and Sasani G. B. (2009) Developing customized micronutrient fertilizer for vegetables yield and profitability in *Gujarat. Indian J. Fert*. 5 (3): 55-57

Meena M. C., Patel K. P. and Rathod D. D (2008) Effect of Zn and Fe enriched FYM on yield and removal of nutrients under mustard-sorghum (fodder) cropping sequence in semi arid region of Gujarat. *Indian J. Dryland Agric. Res*. & Dev. 23 (2): 28-34 (2008)

Patel, K. P., Patel, D. J., Kikani, K. P., Patel, S. B. and Ramani, V. P. (2011). A state level workshop on importance of specialty fertilizers in increasing production of horticultural crops in Gujarat state (Souvenir) held on March 04-05, 2011 at AAU, Anand

Rattan R. K., Patel K. P., Manjaiah K. M. and Datta S. P. (2009) Micronutrients in Soil, Plant, Animal and Human health. Journal Indian Soc. Soil Sci. 57 (4): 546-558

Patel K. C., Patel K. P., Ramani V. P., & V. George (2009) Effect of multi micronutrients mixture on yield of okra (Abelmoschus esculentus L.) grown on Goradu soils of Kheda district. *Veg. Sci.* 36 (3 suppl.): 393-394

Patel K. P., Patel G. J., Patel K. C.,Ramani V. P., Patel P. M. and Patel U. M. (2009) Effect of multi-micronutrients application on yield and their uptake by maize (Zea Mays L.) of middle Gujarat region. *Indian J. Dryland Agric. Res.* and Dev. 24 (1): 45-51

Meena M. C., Patel K. P., Dhyan Singh and Dwivedi B. S. (2009) Long term effect of sewage sludge and FYM on grain yield and availability of Zn and Fe under pearlmillet – Indian mustard cropping sequence *Indian J. Agric. Sci.* 78 (12): 1028-32

AAU, Jorhat

Basumatary, A, Medhi, B.K., Kandali, G.G., and Hazarika, S.,(2012). Appraisal for available micronutrients status in soils of Central Brahmaputra Valley Zone of Assam. Crop Science- accepted.

Basumatary, A, Talukdar, M.C.(2011). Integrated effect of Sulphur and farmyard manure on yield, quality of crops and nutrient status under rapeseed-rice cropping system in fluventic Dystrochrept . *J. Indian Soc. Soil Sci.* 59(4):397-400.

Das, K.N, Basumatary, A and Borkotoky, B. (2011). Interrelationship of forms of Sulphur with its availability indices and soil properties in Entisols of *Assam. J. Indian Soc. Soil Sci.* 59(2):134-140.

BAU, Ranchi

Thakur ,S.,Kumar, S. and Arvind Kumar (2011). “Potential of some wild leafy vegetables as natural source for supplementation of micronutrients in vegetarian diets of Jharkhand area.” Biospectra ; Vol.6(2)Sept.(Spl. Issue) 2011,pp. 199-202

BCKV, Kalyani

Publication of a research bulletin entitled "Micronutrient use in soils of West Bengal".

HAU, Hisar

Meuser., Grewa, K.S., Anlauf, R., Malik, R.S., Narwal, R.K. and Saini, Jag Mohan. 2011. Physical composition, nutrients and contaminant of typical waste dumping sites. American J. of *Environmental Sciences,* 7(1): 26- 34.

Kumar, Daleep, Malik, R.S., Narwal, R.P. and Dahiya, R.R. 2011. Effect of long term continuous application of sewage irrigation on soil characteristics and heavy metal contents. *Environment and Ecology,* 29(2): 651- 654.

Kumar, Daleep., Malik, R.S., Narwal, R.P. and Dahiya, R.R. 2010. Variable tolerance of maize genotypes to excess of Cd, Ni and Cr. Forage Research, 35(1): 42- 44

Grewal, K.S., Godara, O.P. and Malik, R.S. 2009. Effect of potassium application on mustard yield, quality and nutrient uptake in soils of southern Haryana. *Haryana Journal of Agronomy,* 25(1&2): 43- 47

Malik, R.S. 2010. Role of micronutrient, their deficiencies and amelioration techniques in crop production, Khad Patrika, 51(10): 7- 17

R.S. Malik, Ramkala, R.R. Dahiya, R.P. Narwal and K.S. Grewal (2009). Assessment of Fertilizer Use Input on Soil and Water Pollution in Haryana. *Environment & Ecology* 27(3A): 1426-1429.

Daleep Singh, R.S. Malik, R.P. Narwal and R.R. Dahiya (2009). Relative Performance of Maize Genotypes for their Tolerance to Cadmium. Forage Research 34(4): 249-253.

R.P. Narwal, R.S. Malik and R.R. Dahiya (2009). Nutrient Use Efficiency in Elite Genotypes of Important Field Crops. Lecture Presented in Winter School on Genetic Enhancement in Field Crops for Input Use Efficiency & Tolerance to Abiotic Stresses. Organized by Department of Plant Breeding, AAREM CCS H.A.U., Hisar Pp 119-125.

R.P. Narwal, R.S. Malik, Ramkala, M.V. Singh and R.R. Dahiya (2010). Four Decades of Micro and Secondary Nutrients Research Work Done in Haryana. Published by Department of Soil Science, CCS H.A.U., Hisar. Pp 1-104.

GBPAUT, Pantnagar

Debnath, S., Pachauri, S.P. and Srivastava, P.C.(2011). Effect of zinc fertilization on the utilization efficiency of phosphatic fertilizer in rice. 44th Annual Convention of ISAC & National Symposium on balanced fertilizer to sustainable soil health, crop production and food security during Nov. 25-26, 2011, Dept. of Soil Sci., G.B.P.U. A. &T, Pantnagar. pp. 128.

Dwivedi, Rama and Srivastava, P.C.(2011). Contribution of soil Zn fractions to zinc uotake by rice and wheat crops and fate of zinc applied to the soil. 44th Annual Convention of ISAC & National Symposium on balanced fertilizer to sustainable soil health, crop production and food security during Nov. 25-26, 2011, Dept. of Soil Sci., G.B.P.U. A. &T, Pantnagar. pp. 142.

Joshi, Ganga, Singh, P.P.; Singh, S.K.; Srivastava, P.C. and Singh, J.P. (2011). Effect of drip irrigation on quality litchi production under young and old orchards. 44th Annual Convention of ISAC & National Symposium on balanced fertilizer to sustainable soil health, crop production and food security during Nov. 25-26, 2011, Dept. of Soil Sci., G.B.P.U. A. &T, Pantnagar. pp. 140.

Tyagi, A.K.; Pachauri, D.R. and Pachauri, S.P. (2012). Azolla: a cheap green manure and excellent fodder. Kisan Bharti 43(4): 31-33.

Tyagi, R.; Mathpal, B.; Shukla, M.; Pachauri, S.P. ; Sankhdhar, S.C. and Srivastava, P.C. (2010). Performance of rice genotypes under different zinc supply regimes. National Conf. of Plant Physiology on 'Physiological and Molecular Approaches for Crop Improvement under changing Environment'. Nov. 25-27, 2010 at BHU, Varansi, 01-26.

Joshi, A.; Kumar, S. and Srivastava, P.C. (2011). Adsorption study of Zn^{2+} ions from aqueous solutions in the presence of other metal ions on corncob powder using 65Zn radioisotopes. NUCAR, 2011, Visakhapattanam, p. 632-632

Srivastava, P.C.; Singh, M.V.; Tyagi, A.K. and Pachauri, S.P. (2009). Effect of different levels of B supplementation to diammonium phosphate and time of application on yields, B and P uptake by okra (Abelmoschus esculetus (L.) Moench). Presented in Proc. IPNC. 2009.

Singh, S.P.; Singh, R.; Srivastava, P.C. and Singh, P. (2009). Different forms of sulphur in soils of Udham Singh Nagar District, Uttarakhand and their relationship with soil properties. Agropedology 19: 68-74

Ganga Joshi; Srivastava, P.C.; Singh, P.K.; Singh, S.K. and Lal, R.L. (2010). Effect of leaf age on nutrient composition of litchi (Litchi chinensis Sonn.) foliage. *Progressive Horticulturae* 42(1):119-120

PAU, Ludhiana

Walia S S, Gill, M S and Dhaliwal S. S. 2010. Production potential and economics of different cropping systems and their impact on soil health. *Indian Journal of Ecology*. 37 (1): 23-26.

Sadana U. S., J. S. Manchanda, M. P. S. Khurana, S. S. Dhaliwal and Harmanjit Singh. 2010. The current scenario and efficient management of zinc, iron and manganese deficiencies. *Better Crops* Vol. 4 (1): 24-26.

Sidhu S. S. S. S. Dhaliwal, K. Banger, H. S. Dhadli and S. S. Aulakh. 2010. An assessment of changes in groundwater quality with the variation in depth of aquifers in north-eastern districts of Punjab. *Indian Journal of Ecology* 37 (2): 162-164.

Dhaliwal S. S., U. S. Sadana, S. S. Sidhu, S. S. Walia, H. S. Dhadli and V. D. Watts. 2010. Sequential extraction and chemical fractions of Zn and Cu as influenced by manures and fertilizers under long term rice-wheat cropping system in northwest India. *Environment and Ecology*. 28 (4A):2600-2608.

Manchanda, J. S., Benipal, D. S. and Sidhu, A. S. 2011. Yield and sulphur nutrition of sesamum (Sesamum indicum L) and lentil (Lens culinaris L) as influenced by sources and levels of sulphur fertilization. *Indian J Ecology*. 38(1) 58-62.

Sidhu, A. S., Manchanda, J. S., Dalal, R.P.S.and Garg Naveen. 2010. Physico-chemical properties of soils and micronutrient concentration of vegetables as influenced by quality of irrigation water. *Madras Agric. J.* 97: 265-268.

Brar J S, Sidhu A S, Sidhu B S and Khurana M P S (2008) Evaluation of sources , method and rate of zinc application with and without farm yard manure in Bt cotton. *J Cotton Res Dev* 22 : 170-172

Dhaliwal, S.S., Sadana, U.S., Manchanda, J.S. and Dhadli, H.S. (2009) Biofortification of wheat grains with Zn and Fe in Typic Ustocrept soils of Punjab. *Indian J. Fert.* 5: 13-16 & 19-20. (NAAS rating: 3.0)

Sharma, N., Prakash, R., Srivastava, A., Sadana, U.S., Acharya, R., Prakash, N.T., Reddy, A.V. R. (2009) Profile of selenium in soil and crops in seleniferous area of Punjab, India by neutron activation analysis. *J. Radioanal. Nucl. Chem.* (Hungary) 281: 59-62.

Dhaliwal, S.S and Manchanda, J.S. (2009). Critical level of boron in Typic Ustochrepts for predicting response of mungbean (Phaseolus vulgaris L.) to boron application. Indian J. Ecol. 36 (1): 22-27.

Aulakh, S. S., Bhatti, D. S. and Manchanda, J. S. (2009). Micronutreint status of berseem (Trifolium alexandrinum L) and oat (Avena sativa L.) fodders in relation to their availability in soils. *Indian J Ecol.* 36 (2): 152-155.

Aulakh M S, Khurana M P S and Singh D (2009) Water pollution related to Agricultural, Industrial, and Urban Activities, and its effects on the food Chain: Case studies from Punjab. Journal of New Seeds 10 : 112-137.

Walia S S, Kler D S and Khurana M P S (2009) Effect of sources of nutrition on heavy metal in plants and soils. *Journal of Ecology* 36: 487-489.

Dhaliwal, S.S. Bijay Singh, B.D.Sharma and K. L. Khera. 2009. Soil quality and yield trends of different crops in low productive submontaneous tract and highly productive area in Punjab, India. Indian Journal of Dryland Agriculture *Research and Development*. 24 (2): 39-45.

Dhaliwal SS, Sadana US, Khurana MPS, Dhaldi HS and Manchanda JS (2010) Enrichment of rice grains with zinc and iron through ferti-fortification. *Indian J. Fert*. 6(7): 28-35. (NAAS rating: 3.0)

Kaur, A.J., Sadana, U.S. (2010) Nitrogen source and manganese application effects on manganese dynamics in the rhizosphere of wheat cultivars grown on manganese deficient soils. *J. Plant Nutr*. (USA) 33: 831-845 (NAAS rating: 7.5)

Dhaliwal, S.S., J. S. Manchanda, S. S., Walia, and R. P. Phutela. 2010. Nutrition management in maize (Zea mays L.) -Potato (Solanum tuberosum L.) - Onion (Allium cepa L.) cropping sequence through organic and inorganic sources. *Environment and Ecology*. 28 (1):136-143.

Arneja S, and Sadana US 2012. Mixed cropping effects on yield, manganese influx and manganese depletion in the rhizosphere of fodder crops grown in Mn-deficient soils. Comm. *Soil Sci. Plant Anal*. 43: 533-540.

Aulakh, MS., Manchanda, JS., Garg Ahok and Shravan Kumar., Gerd Dercon and Minh-Long Nguyen (2012). Crop production and nutrient use efficiency of conservation agriculture for soybean-wheat rotation in the Indo-Gangetic plains of northwestern India. *Soil Tillage Res*. 120: 50-60.

Dhaliwal S. S., U. S. Sadana and J. S. Manchanda. 2011. Relevance and essentiality of ferti-fortification of wheat grains with manganese and copper. Indian Journal of Fertilizers. 7 (11): 48-55.

Gurpreet Singh, S. S. Dhaliwal, U.S. Sadana and S. S. Walia. 2011. Surface and subsurface distribution of Zn, Cu, Fe and Mn as influenced by different cropping systems in Typic Ustocrepts soils of Punjab, India. The *Journal of Plant Science Research*. 27 (2): 175-188.

Dhaliwal S. S., Sadana U.S., Manchanda J.S. and Dhadli H.S. 2012. Critical level of hot water soluble boron for predicting response of toria (Brassica compestris) in alluvial soils of Punjab. *International Journal of Agricultural Sciences*, 8(1):5-12

Jhanji S, Sekhon N K, Sadana U S and Gill T P S 2011. Characterization of morpho physiological traits of rice genotypes with diverse manganese efficiency. *Indian J Plant Physiol* 16 (4): 245-257.

Dhaliwal, S.S., U.S. Sadana, M.P.S. Khurana and S.S. Sidhu. 2012. Enrichment of wheat grains with zinc through fertifortification. *Indian Journal of Fertilzers,* Vol. 8 (7): 34-45.

Khurana M P S and Kansal B D (2012): Influence of zinc supply on the Phytotoxicity of Cadmium in Maize (Zea mays L) grown on cadmium-contaminated soil. *Acta Agronomica Hungarica,* 60: 37–46.

Khurana M P S, Gill T P S, Sidhu V P S, Jhangi S (2012): Effect of nickel contaminated soils on dry matter yield and mineral composition of maize. 38 :184-188

Khurana M P S, Kuldip Singh and Dhanwinder Singh (2012): Heavy metal content in soils and crops irrigated with untreated sewage water in Sangrur district of Punjab. *Indian Journal of Ecology* 39(1) : 58-62

Manchanda, JS., Benipal, DS and Bhatti, DS (2011). Yield and sulphur nutrition of paddy-wheat cropping system as influenced by sources and levels of sulphur fertilization. *Crop Res* (42) 10-14.

Manchanda, JS, Sadana, US and Dhaliwal, SS (2011). Soil tests for zinc and their correlation with crop response. *Indian J Fert*. 70-80.

Pritpal Singh, Hargopal Singh and Khurana M P S (2010) Micro nutrients fertility status of recent floodplains soils of Punjab. *Journal of Research (PAU)*, 46 :140-144

Singh P, Saini S P, Khurana M P S and Matharu G S (2011) : Impact of manganese sulphate application on wheat in subtropical soils through on-farm trials. *Indian J Fertilisers* 7: 24-31

Achla Sharma, U. S. Sadana R. Pandey, M. P. S. Khurana, S. S. Dhaliwal and N. K. sekhon. 2011.Variation for manganese efficiency in wheat cultivars. Extended summary submiited in proceedings International Conference on Preparing Agriculture for Climate Change, PAU,Ludhiana, Februay 6-8, 2010, published in *special issue of Crop Improvement* pp 170-171

Khurana, M.P.S., U.S. Sadana AND MV Singh (2009) Evaluation of manganese efficiency of wheat (Triticum aestivum L.) and raya (Brassica juncea L.) grown in manganese-deficient soils. The proceedings of Plant Nutrition Colloquium XVI, University of California, USA, paper no. 1373, 1-5. (presented by MV Singh)

Sharma B. D., Raj-Kumar, J. S. Manchanda, S. S. Dhaliwal, H. S. Thind and Yadwinder-Singh. 2011. Geospatial fertility status of Punjab soils. Bulletin published in Niche Area of excellence under Soil and water Management in high Intensity Cropping System, Department of soil science, PAU, Ludhiana.

Sanyal SK, Rao JK and Sadana US 2012. Toxic elements and other pollutants- a threat to nutritional quality. Soil Science in the Service of Nation. Proceedings of the Platinum Jubilee Symposium on "Soil Science in Meeting Challenges to Food Security and Environment Quality" held during 74th Annual convention of ISSS at N. Delhi, pp. 266-291.

RAU, Pusa

Vipin Kumar, Pandey, A. K., Prasad, R. K. And Prasad, B., (2011) Long term influence of organic and inorganic sulphur and fertility levels on yields, distribution and build-up of sulphur under rice-wheat cropping system in calciorthents, Journal of the Indian Society of Soil Science, 59, 278-282.

Vipin Kumar, Prasad, R. K., Prasad, B and Pandeya, S.B. (2011) Thermodynamics of Cd-fulvate and Ni-fulvate adsorption in sewage-sludge treated old alluvial soils. Journal of the Indian Society of Soil Science, 59, 283-285.

Vipin Kumar, Prasad, R.K., Suman, S.N. and Tiwari, S. (2011) Integrated nutrient management for better soil fertility and rice productivity, Oriza, 48 (4) : 335-338.

Prasad, R. K. and Vipin Kumar (2011) Mineralization of carbon and nitrogen in zinc treated rice field in calcareous soil, *Agropedology* 21, 23-27.

Kumar, Dilip, Singh, Ram Raksha, Singh, Shiveshwar Pratap, Jha, Shankar and Srivastava, Prashant_(2011). Selection of Suitable Extractant for Predicting the Response of Chickpea to Zinc Application in Vertisols. Communications in Soil Science and Plant Analysis. 42(6): 728-740.

Singh Shiveshwar Pratap, Singh Room, Singh Mukesh Prasad and Singh Vijay Prasad. Impact of sulfur fertilization on different forms and balance of soil sulfur and the nutrition of wheat in wheat-soybean cropping sequence in Tarai soil. *Journal of Plant Nutrition- Manuscript* ID: LPLA 2011-0200. (Communicated).

Vipin Kumar, Prasad, R. K., Prasad, B. and Singh, A. P. (2010) Depthwise distribution of horizontal movement of Cd and Ni in sewage sludge amended soils and their uptake by vegetable crops grown thereon. *Journal of the*

Indian Society of Soil Science 58, 286-292.

Prasad, R. K., Vipin Kumar, Prasad, B. and Singh, A. P. and (2010). Long term effect of crop residue and Zn fertilizer on crop yields, nutrient uptake and fertility buildup under Rice-Wheat cropping system in calciorthents. *Journal of the Indian Society of Soil Science* 58, 205-211.

Vipin Kumar and Singh A.P. (2010) Long-term effect of green manuring and farmyard manure on yield and soil fertility status in rice-wheat cropping system. *Journal of the Indian Society of Soil Science* 58, 409-412.

Prasad R.K., Vipin Kumar, Prasad B. and Singh A.P. kinetics of decomposition of wheat straw and mineralisation of micronutrients in zinc-treated rice field. *Agropedology* 20, 60-66.

Vipin Kumar, Prasad, R.K., Prasad, B and Singh, A.P. (2011) Kinetics of nickel fulvat reaction in sewage effluents irrigated soils. *Journal of the Indian Society of Soil Science*. (Communicated)

Vipin Kumar, Prasad, R.K. and Prasad, B. (2011) Mathematical regression model uptake and translocation of Ni by Rajmash (Pha vulganis L.) in sewage effluents irrigated soils. Journal of the *Indian Society of the Soil Science*.

Sunil Kumar, Tiwari, S. and Vipin Kumar (2011) Impact of organic and inorganic fertilizers management on yield and farms of nitrogen in rice under rice-wheat cropping system Oryza.

Vipin Kumar, Singh S.K. and Prasad R.K. (2011) Zinc-Boron interaction effects on yield, nutrient uptake and quality parameter of mustard in calciorthents. *Journal of the Indian Society of the Soil Science*. (Communicated).

Suman, S.N., Thakur, S.K. and Vipin Kumar (2011) Effect of sludge on sorption of cadmium in calcareous soils. *Journal of the Indian Society of the Soil Science.* (Communicated)

Pandey, A. K; Vipin Kumar and Rajesh Kumar (2009) Long-term integrated effect of organic and inorganic fertilizer on yield, uptake and fertility buildup in transplanted rice under rice-wheat cropping system in calciorthents, Oryza 46 (3) : 209-212.

Prasad, R. K; Vipin Kumar, Mandel K. and Rajesh Kumar (2009) Long Term Application of Zinc and Crop Residues on Yield and Uptake of Micronutrients in Transplanted Rice under Rice-Wheat Cropping System in Calcirothents, *Environment & Ecology*, 27 (3A) : 1440-1443.

Vipin Kumar, Prasad, R. K and Rajesh Kumar (2009) Efficiency of applied nutrients in soil amended with green manuring and green gram straw incorporation under rice-wheat cropping system, *Environment & Ecology*, 27 (3A) : 1436-1439.

Vipin Kumar, Prasad, R. K., Prasad, B. and Singh, A. P. (2009) Depthwise distribution of horizontal movement of Cd and Ni in sewage sludge amended soils and their uptake by vegetable crops grown thereon. Journal of the *Indian Society of Soil Science* (Accepted).

Prasad, R. K., Vipin Kumar, Sing, A. P. and Prasad, B. (2009). Long term effect of crop residue and Zn fertilizer on crop yields, nutrient uptake and fertility buildup under Rice-Wheat cropping system in calciorthents. *Journal of the Indian Society of Soil Science* (Accepted).

Singh, A. P., Singh, S. K., Choudhary, K. and Kumar Vipin (2009) Micronutrient status in soils of Bihar and its management for sugarcane production, Souvenir, S.R.I., RAU, Pusa.

Jha, Shankar, Singh, S. P., Prasad, J., Mishra, G.K., Singh, A.P. and Singh, R.R. (2010) Vermi Compost Ek Safal Jaiveek Khad, Department of Soil Science, RAU, Pusa, Bihar

Singh, A.P., Kumar, Vipin and Singh, R.R. (2010) Adhunik Krishi Men Mrida Prabandhan – Ek Awasyak Sansadhan, Department of Soil Science, RAU, Pusa, Bihar.

A. P. Singh, Vipin Kumar and R. R. Singh (2012)

Adhunik Krishi Men Mrida Prabandhan – Ek Awashyak Sanshadhan (vk/qfud Ñf"k esa e`nk izca/u & ,d vko';d lalk/u). Publication Division, Rajendra Agricultural University, Bihar, Pusa, Samastipur pp. 1-176.

Jha, Shankar; Pandey, R. K.; Singh, S.P.; Singh, M.P. and Mandal, K. (2012) Vermicompost-awam jivanu khad (oehZ dEiksLV ,oa thok.kq [kkn). Publication Division, Rajendra Agricultural University, Bihar, Pusa, Samastipur.

Jha,Shankar; Singh,S.P.; Prasad,J.; Mishra, G.K.; Singh,A.P. and Singh, R.R. (2010). Vermicompost-ek safal javik khad. Publ. Rajendra Agricultural University, Pusa, Samastipur, Bihar

Prasad, Janardan, Tiwari, Sanjay, Jha Shankar and Singh, S.P. (2011). Mrida Swasthya Parichan anv Urvra Shakti Prabandhan: Prashiksan Margdarshika-2011. Deptt. of Soil Science, RAU, Pusa.

Jha Shankar and Singh, S.P. (2011). Vermicompost anv banana ki bidhi. In: Mrida Swasthya Parichan anv Urvra Shakti Prabandhan: Prashiksan Margdarshika-2011 ed by Janardan Prasad, Sanjay Tiwari, Shankar Jha and S.P. Singh. Deptt. of Soil Science, RAU, Pusa, p 31-34

PDKV, Akola

Katkar R.N., B.A. Sonune and P.R. Kadu (2011) Long term effect of fertilization on soil chemicals and biological characteristics and productivity under sorghum – wheat system in Vertisol, *Indian Journal of Agricultural Sciences* 2011, 81 (8) : 734 – 739

Katkar R.N., B.A. Sonune, Mohan Rao Puli and V.K. Kharche(2011) Effect of Integrated Nutrient Management on Productivity and Soil Fertility under Soybean – Wheat Cropping System, Effect of Integrated Nutrient Management on Productivity and Soil Fertility under Soybean – Wheat Cropping System *PKV Research Journal* 2011 (Accepted)

Souvenir : State Level Seminar on "Soil Resource Management for Sustainable Soil Health and Food Security" organized by the Akola Chapter of Indian Society of Soil Science at Department of Soil Science and Agricultural Chemistry, Dr. PDKV, Akola on Jan. 2-3, 2010.

Abstracts of Research Papers : State Level Seminar on "Soil Resource Management for Sustainable Soil Health and Food Security" organized by the Akola Chapter of Indian Society of Soil Science at Department of Soil Science and Agricultural Chemistry, Dr. PDKV, Akola on Jan. 2-3, 2010.

TNAU, Coimbatore

Muthumanickam, D., Kannan,P., Kumaraperumal, R., Natarajan,S., Sivasamy, R. and Poongodi, C. (2011) Drought assessment and monitoring through remote sensing and GIS in western tracts of Tamil Nadu, *India. International Journal of Remote Sensing* 32, 5157-5176.

Stalin, P., Thejas Das, Muthumanickam, D., Chitdeshwari, T. and Velu V. (2011) Foliar nutrition of rice to enhance micronutrient concentration in grains. *International Rice Research Notes* (0117-4185), 1- 6.

Muthumanickam,D. (2010) Soil Nutrient Dynamics in Intensively cultivated the Sugarcane-Sugarcane Cropping System. *International Journal of Agriculture and Food Science Technology* 1, 115-126.

Chitdeshwari,T. Richard W. Bell, Anderson, J.D and I. Phillips (2011). Zinc forms in compost- and red mud-amended bauxite residue sand. Journal of Soils and Sediments, 11, 101-114.

Stalin,P., Thejas Das, D.Muthumanicakm, T.Chitdeshwari, and V.Velu (2011) Foliar nutrition of rice to enhance micronutrient concentration in grains IRRN, 36, 1-6

Venkatachalam Velu (2010). Foliar Nutrition of rice for enhancing the Micronutrient Concentration in Grain and Straw for Nutritional Health Security Paper accepted for presentation in the International conference of World Soil Congress to be held at Brisbane, Australia during August 1 -6th 2010.

Muthumanickam Dhanaraju, Chitdeshwari Thiyagarajan and Stalin Palaniyandi (2010). Assessing threshold limit of Nickel for Okra (Abelmoschus esculentus) grown in contaminated soils. Paper accepted for presentation in the International conference of World Soil Congress to be held at Brisbane, Australia during August 1 -6th 2010.

Chitdeshwari Thiyagarajan, Stalin Palaniyandi, Muthumanickam Dhanaraju and Velu Venkatachalam (2010). Boron and Zinc interactions on the yield and nutrition of Sunflower Paper accepted for presentation in the International conference of World Soil Congress to be held at Brisbane, Australia during August 1 -6th 2010.

Muthumanickam, D., Kannan, P., Natarajan,S., Sivasamy, R. and Kumaraperumal, P. (2010) Soil resource inventory using remote sensing and GIS - A case study in Kangeyam tract, Erode district, Tamil Nadu. *Agropedology* 20, 89 -96.

Kannan, P., Natarajan,S., Sivasamy, R., Kumaraperumal, R and Muthumanickam, D. (2010) Crop water balance model for suggesting suitable crops on major soils of Cauvery delta of Tiruvarur district, Tamil Nadu. *Agropedology* 20, 165 - 174.

Stalin, P., Muthumanickam, D., Chitdeshwari, T, Duraisamy,V.P., Poongothai, S. and Singh, M.V. (2011) Studies on the response of Millets, Pulses and Oilseeds to Zinc Fertilization in Red soils. Advances in Applied Research 2, 134-145.

Chitdeshwari,T., V.Velu and T.Thilagavathy (2011) Nutrient balance studies in the soils under intensive rice – rice system. *Indian J. Agric. Res.* 45 (1): 11-20

P.Stalin, D.Muthumanickam,T.Chitdeshwari, V.P.Duraisami, S.Poongothai and M.V.Singh (2011). Studies on the response of millets, pulses and oilseeds to zinc fertilization in red soils, Adv. Appl. Res. 3(2): 134-145

Rajendran, R., Stalin,P, Ramanathan, S and Buresh, R.J. (2010). Site specific nitrogen and potassium management for irrigated rice in the Cauvery Delta. *Better Crops-South Asia*.4(1) : 7 -9

Chitdeshwari,T. I. R. Phillips, B. Dell, and Richard W. Bell (2009) Micronutrient fractionation and plant availability in bauxite-processing residue sand, *Australian Journal of Soil Research*, 2009,47,1-11

Stalin, P. D.Muthumanickam, T.Chitdeswari, V.P. Duraisami, V. Velu and S. Poongothai. 2009. Studies on optimizing copper requirement of cauliflower and tomato in sandy loam red soil. Research on crops.10 (3); 612-615.

Stalin, P., M.V.Singh, D.Muthumanickam, T.Chitdeshwari, V.Velu and K.Appavu (2010) Four decades of research on management of micro and secondary nutrients and pollutant elements in crops and Soils of Tamil Nadu *Research bulletin* pp.1-105.

Stalin, P., Chitdeshwari, T, Muthumanickam, D., Duraisamy, V.P., Velu, V. and Sukla, A.K. (2012). Micronutrient recommendations for crops in Tamil.

Stalin, P., Chitdeshwari, T, Muthumanickam, D., Duraisamy, V.P., Velu,V. and Sukla, A.K. (2012). Importance and Management of Secondary and Micronutrients in crops in Tamil.

Stalin, P., Chitdeshwari, T, Muthumanickam, D. and Velu, V. (2011) Management of Secondary and Micronutrients in cotton. In Hi-Tech Cotton Cultivation. Eds. Kalaiselven, P., Sivakumar, S.D., Shanmugasundram, R. and Krishnamurthi, V.V. published by A.E. Publications, Coimbatore. pp 88-90. (ISBN: 978-9380460-03-1).

Chitdeshwari, T. and Muthumanickam, D. (2011). Estimation of K,Ca,Mg and Na in Soil, Water and Plants. International training on "*Analytical Laboratory Facility*" pp 69-79.

Stalin,P and T.Chitdeshwari (2011) Measurement of cations using Atomic Absorption Spectrophotometer, Lecture given in the International training on "Analytical laboratory facility" halt at TNAU during 14th February to 13th March, 2011 pp. 23-31

D. Muthumanickam, Stalin, P., T.Chiteshwari and V.Velu. 2009. Nutrient disorders and remedies in continuous sugarcane- sugarcane cropping system. Valarum Velanmai Vol.1(6) :15-19. (Tamil)

T.Chiteshwari, Stalin, P and D. Muthumanickam. 2009. Nutrient depletion and management due to continuous rice- rice cropping system. Valarum Velanmai Vol.1(4) :47- 51. (Tamil)

ANGRAU, Hyderabad

Patnaik,M.C. , Srinivasa Raju, A and Bhupal Raj, G. (2010) Effect of rate and frequency of zinc application on hybrid rice –soybean cropping system in Andhra Pradesh, *Journal of Oilseed Research* 27(1):136- 140.

Sandhya Rani, K., Uma Devi M., Raj Kumar M and Chandini Patnaik M.(2011) Effect of integrated use of organic manures, Bio-fertilisers with inorganic nitrogenous fertiliser on nutrient composition and uptake at different growth stages of medicinal plant Coleus (Coleus forskohilic). *Journal of Medicinal and Aromatic Plant Sciences* 33 (1) : 64-68.

Sandhya Rani, K., Uma Devi,M., Chandini Patnaik,M and Raj Kumar, M.(2009) Effect of integrated use of organic manures , Bio-fertilisers with inorganic nitrogenous fertilizer on growth and yield of medicinal Coleus. *The Andhra Agricultural Journal,* 56:324-329

Patnaik,M.C. , Srinivasa Raju, A and Bhupal Raj, G. (2010) Effect of rate and frequency of zinc application on hybrid rice –soybean cropping system in Andhra Pradesh., *Journal of Oilseed Research* 27(1):136- 140.

Lucknow University, Lucknow

Gopal, Rajeev and Nautiyal, Nirmala 2012. Variability in response to Zn application in ten high yielding wheat varieties. *Communications in Soil Science and Plant Analysis,* 43: 1930- 1937.

Sinha, Pratima and Nautiyal, N 2012. Excessive cobalt induced oxidative stress in groundnut. *Indian Journal of Plant Physiology*, 17: 71-74.

Sinha Pratima, Khurana, Neena, and Nautiyal, N. 2012. Induction of oxidative stress and antioxidant enzymes by excess cobalt in mustard. *Journal of Plant Nutrition*, 35:952–960.

Gopal Rajeev and Nautiyal, N. 2012. Growth, antioxidant enzymes activities, and proline accumulation in mustard due to nickel. *International Journal of Vegetable Science*, 18:223–234.

Nautiyal, Nirmala and Pratima Sinha 2012. Lead induced antioxidant defense system in pigeon pea and its impact on yield and quality of seeds. Acta Physiologiae Plantarum, 34:977-983.

Sinha Pratima and Chatterjee, C. 2011 Assessment of disturbances caused by interaction of multinutrient deficiencies of sulphur, zinc and boron in mustard *African Journal of Plant Science*, 5: 842-847.

Gopal, Rajeev and Khurana, Neena. 2011. Impact assessment of pollutant elements on sunflower. *African Journal of Plant Science*, 5: 531-536.

Bhakuni, Geetanjali and Gopal, Rajeev. 2011. Changes in metabolism and biochemical composition in response to micronutrient limitations in cowpea. *Indian Journal of Plant Physiology*, 2011, 16:103-108.

Gopal, Rajeev and N.Nautiyal 2011. Phyto-toxic effects of cadmium exposure and metal accumulation in sunflower. *Journal of Plant Nutrition,* 34:1616-1624.

हर कदम, हर डगर
किसानों का हमसफर
भारतीय कृषि अनुसंधान परिषद
Agrisearch with a human touch