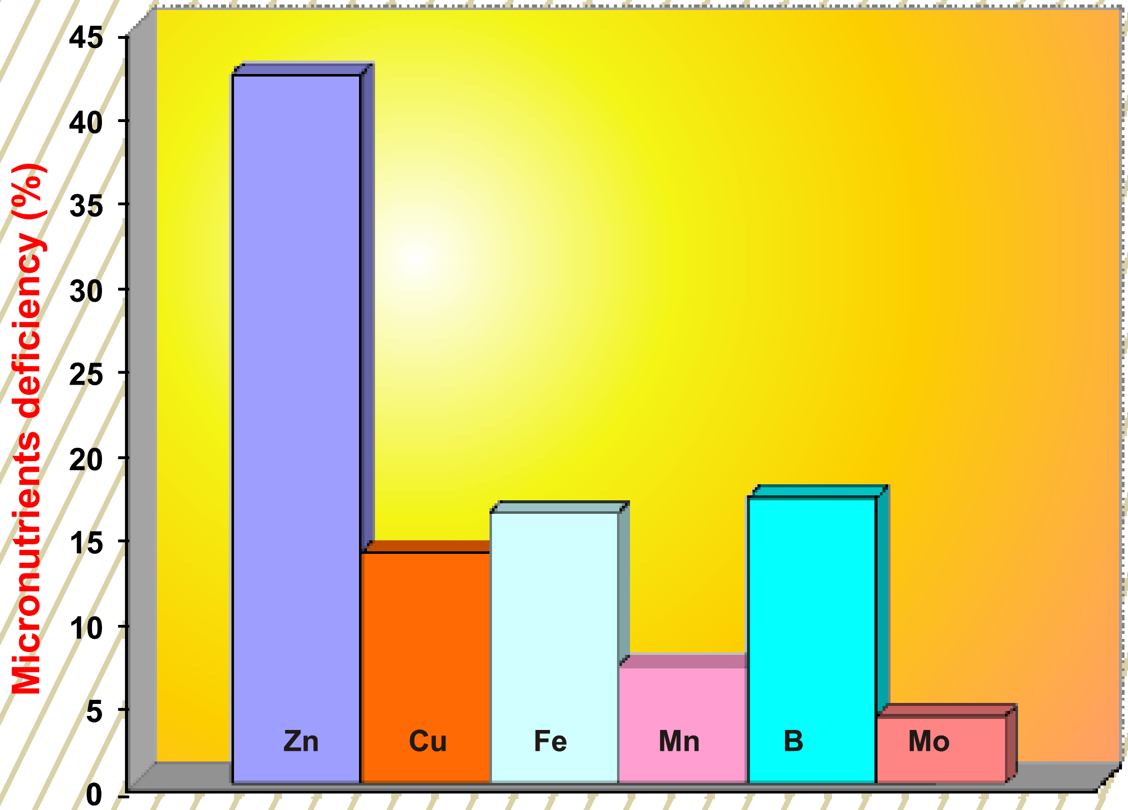
PROGRESS REPORT 2007- 10

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



Arvind K. Shukla
Project Coordinator (MSPE)

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

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

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Arvind K. Shukla
Project Coordinator (MSPE)
Sanjib Kumar Behera
Scientist

Progress Report

2007- 10

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ICAR

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Editors: **Dr. Arvind K. Shukla**
Project Coordinator (MSPE)
Dr. Sanjib Kumar Behera
Scientist

Year of Publication: 2012

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

Correct citation:

Shukla, Arvind K. and 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. 1-103.

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

Cover Page : Graph on cover page shows micro- and secondary nutrient deficiency status during the period under report - 2007-10

Printed by Neo Printers, 17, Sector-B, Industrial Area,
Govindpura, Bhopal, Phone : 0755-4235558

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Progress Report

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

(2007- 2010)

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)

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- 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

PREFACE

The issue of micronutrient is no more micro in nature, rather they 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 3333 atoms of N, 833 atoms of K, 200 atoms of P and 100 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 Micronutrient Project 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. Due to over mining, the deficiencies of micronutrients in soil is affecting plant and animal/human health as well. Because plants get micronutrients from the soil, animals fed on fodder and humans fed on plant and animal food. 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.

Because of enhanced pace of industrialization the bye 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, identification and amelioration of multi micronutrient deficiencies in different cropping systems and agro ecological regions, 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 acknowledged. 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. Singh, Deputy Director General (NRM) for his noble guidance, generous support, painsting efforts and encouragement all the time in planning and implementation of the research programme. Thanks are due to Dr. P. S Minhas, Assistant Director General (SWM), and ICAR, New Delhi for his 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 importing the report.

Thanks are also due to Dr. M.V. Singh, Ex. PC, Micronutrient, Dr. Muneshwar Singh, PC, LTFE, and Dr. D.L.N. Rao, NC, Biofertilizer for their valuable suggestion and encouragement.

I sincerely thank Mr. Venny Joy for his valuable co-operation, dedication and keen interest in the activities of this project. The valuable help and assistance extended by Mrs Pooja Singh, RA, NAIP, sub project C4/C30022 is also acknowledged.

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

- Delineation of micro and secondary nutrients deficient areas, 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 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.

- Effect of micronutrient and pollutant elements on physiology of different crops has been studied at deficient and toxic levels. The threshold toxic limits for Cd, Cr, Ni, Pb, Cu and Mn in different crop plants have been worked out.

- The physiological parameters like Nitrate reductase activities in leaves, pollen producing capacity of anthers, reduction in concentration of non-reducing sugars, starch and protein-N and increase in phenols content were severely affected under both Mo deficiency and excess condition rice (*Oryza sativa* L.) cv. Indrasan.

- Similarly, in black gram seeds the content of proline, total protein, starch, electrolyte leakage and reducing and non reducing sugars and phenols increased at low B supply and decreased at excess B.

- Seed yield was decreased in both Cu deficiency and excess in wheat varieties. The decrease in seed yield at low Cu was comparatively less (73% and 85%) in var. UP226 and PBW373 as compared to vars. UP343 and UP2338 (97% to 100%). Similarly decrease in seed yield at excess Cu was 74% to 86% in var. PBW373 and UP226 as compared to 97.7% to 98.4% in UP343 and UP2338.

- In another study, the excess and deficient Cu supply has affected the physiological parameters like chlorophylls, carotenoids, Hill reaction activity, catalase, superoxide dismutase and total protein content in cucumber.

- The excess and low supply of Co, Cr, Ni and Cd in mustard affected the physiological and biochemical parameters, which in turn resulted in reduction in dry matter yield. Pod formation did not take place in excess Co supply. The specific activity of antioxidant enzymes- catalase decreased and that of peroxidase, superoxide dismutase and ascorbate peroxidase increased with an increase in Cr supply.

- Under delineation programme, about 15090 surface soil samples were collected from fifty seven districts of different states for estimation of available micro- and secondary nutrient during the period under report. The Zn deficiency ranged from 3.4 to 74.98% with mean value of 42.14%. The deficiency of Cu, Fe and Mn varied from 0 to 35.7 (mean 13.73), 0 to 32.7 (mean 16.11) and 0 to 17.1 (mean 7) respectively.

- Crop response trials were conducted by the different centers of the project to showcase the effect of micro and secondary nutrient application on crop yield. Significant response to multinutrient application was recorded in several crops at Jablapur, Pusa, Hyderabad, Pantanagar, Anand, Akola, Punjab, Hisar and Palampur although percent response varied significantly with crops and nutrients.

- Several amelioration techniques were standardized for mitigation of micro and secondary nutrient deficiencies in soil-plant system for enhanced crop production. In red sandy loam soils of Andhra Pradesh the sunflower yield increased by 28% over control with the application of 2.0, 5.0, and 20.0 kg B, Zn and respectively. Higher rice yield could be obtained in iron toxic soils of Odisha by application of Zn @5 kg ha^{-1} along with recommended doses of NPK. The application of B was inevitable in B deficient soils of Odisha for higher rice yield.

- Application of granubor a new source of boron is equally effective as borax and application of 1.25 kg B ha^{-1} provided higher cauliflower curd yield at Palampur.

- Application of 1 kg B ha^{-1} to hybrid rice crop ensures higher grain yields of both rice and wheat crop in hybrid-rice -wheat rotation in Mollisol of *Tarai* region.

- Among the methods of application, soil application of Zn, B and Mo had significantly increased the soybean yields over seed treatments with Zn, B and Mo at Rudrur, Andhra Pradesh.

- Growing of micronutrient efficient cultivars is need of the hour to cope up micronutrient deficiency in soils of the country and produce micronutrient dense grain. Therefore, cultivars of major food crops were screened to identify micronutrient efficient and inefficient cultivars of different crops.

- Basic and strategic research carried out by different centers revealed that application of farm yard manure can protect the plant roots from the adverse effect of higher concentration of Co and Cd in soil. A critical value of 4.5 µg Cu g^{-1} in wheat grain was observed by Ludhiana center of the project. Similarly, 1.1 and 0.83 mg B kg^{-1} soil were found to be the critical limit of hot water extractable B for mustard and moong crop, respectively grown in alkaline soils of Hisar.

- The cumulative uptake of Zn, Cu, Fe and Mn up to 63^{rd} crop i.e. after 21 complete cycles under rice-wheat-sorghum (R-W-S) and rice-mustard-moong (R-M-M) rotations at Pusa, Bihar under different fertility levels was found to vary from 5.59 to 13.27, 2.143 to 5.637, 44.83 to 109.24 and 10.63 to 29.86 kg ha^{-1} and from 4.70 to 10.15, 1.683 to 4.314, 35.56 to 83.89 and 8.95 to 21.15 kg ha^{-1}, respectively.

- The DTPA extractable metal content in soils irrigated with various industrial effluents varied widely with the type of industry in Coimbatore district of Tamil Nadu. The highest metal contents were noted in soils receiving casting, painting and sewage effluents. The highest DTPA Zn (26.7mg kg^{-1}) and Cu (70.97 mg kg^{-1}) content was recorded in casting industrial effluent irrigated areas, Ni in Painting industrial effluent irrigated areas (31.35mg kg^{-1}) Cd in Gold processing effluent irrigated areas (2.34 mg kg^{-1}) and Pb in sewage effluent irrigated soils (15.01 mg kg^{-1}). Among the metals, the order of higher availability was Cu > Zn > Ni > Pb > Cd.

- The heavy metal content in the plants grown in different industrial contaminated soils showed the higher metal content in the order of Pb > Zn > Ni > Cu > Cd in all the areas except in foundries and electro plating industrial areas where Ni content was higher followed by Pb, Zn, Cu and Cd. Among the plant species collected, Amaranthus was found to accumulate almost all metals in sewage irrigated areas, Castor contains higher metal content in foundry, electro plating and painting industrial areas, weed species (Parthenium and Abutilon sp.) contains higher metal status in casting and dye effluent irrigated areas.

- Higher translocation coefficient values were observed with Cluster bean> Mary gold > Fodder cowpea > Amaranthus. Among the hyper accumulators, Amaranthus, Cluster bean and Mary gold were found superior in removing higher Pb with better phyto remediation potentials. However Mary gold and non food crop being hyper accumulator can be recommended for phytoremediation of contaminated soils along with 100 mg kg^{-1} EDTA and 5 t FYM or GLM ha^{-1}.

सराँश

- इस परियोजना के अर्न्तगत, सूक्ष्म एवं गौण पोषक तत्वों की कमी वाले क्षेत्रों का चित्रांकन, सुधार तकनीकी का विकास, उर्वरक उपयोग दक्षता बढाने के लिए रणनीति का विकास, सूक्ष्म तत्व दक्ष प्रजातियों का निर्धारण एवं शस्य विधियों द्वारा सूक्ष्म तत्व की अधिकता वाली प्रजातियों का विकास एवं मृदा–पौध तंत्र में भारी धातु प्रदूषित क्षेत्रों का मूल्यांकन एवं आँकलन आदि मुख्य शोध कार्यो जो कि पिछले वर्षों में किये गये, की संक्षिप्त विवर्णिका प्रस्तुत है ।
- सूक्ष्म पोषक एवं प्रदूषक तत्वों की कमी एवं विषाक्तता से विभिन्न फसलों की पादप दैहिकी पर पडने वाले प्रभाव का अध्ययन किया गया। कैडमियम, क्रोमियम, निकिल, सीसा, कॉपर एवं मैंगनीज के लिए देहलीज विषाक्तता स्तर का निर्धारण किया गया । धान (प्रजाति इंद्रासन) में मोलीबिडिनम की कमी एवं विषाक्तता स्तर पर किये गये प्रयोगों से पता चलता है कि पादप दैहिकी प्राचालो, जैसे नाइट्रोजन रिडक्टेज गतिविधि, एन्थर की पराग उत्पादन क्षमता, नान रिडुसिंग सुगर, स्टार्च एवं प्रोटीन नाइट्रोजन में कमी आ जाती है तथा फिनॉल की अधिकता हो जाती है ।
- इसी प्रकार बोरॉन की कमी एवं अधिकता की स्थिति में चने के बीजों में प्रोटीन, कुल प्रोटीन, शुगर, स्टार्च तथा फिनॉल की मात्रा पर व्यापक असर पडता है । गेहूँ में कॉपर की कमी एवं अधिकता पर किये गये एक तुलनात्मक अध्ययन से पता चलता है कि उपज की दृष्टि से गेहूँ की किस्में यू.पी. 226 एवं पी. बी. डब्लू 373 की अपेक्षा यू.पी. 343 एवं यू.पी. 2338 कॉपर के प्रति ज्यादा सहनशील है ।
- खीरे पर किये गये एक अन्य अध्ययन से पता चलता है कि कॉपर की कमी एवं अधिकता खीरे की पतियों में हरित लवण, रंगीन लवण, इन्जाइम केटालेज एवं सुपर आक्साइड डिसक्यूटेज तथा प्रोटीन की मात्रा पर व्यापक रूप से असर डालता है।
- सरसों की खेती में कोबाल्ट, क्रोमियम, निकिल एवं कैडमियम की विषाक्तता से पादप कायिकी एवं जैव रसायन पैरामीटरों पर अत्यन्त असर पडता है जिससे उत्पादन में भारी कमी आती है । कोबाल्ट की अधिकता से फलियों का बनना बंद हो जाता है, जबकि क्रोमियम की अधिकता में एंटी आक्सीडेन्ड एंजाइम जैसे केटालेज, पैराक्सीडेज, एस ओ डी एवं एसकार्बेट पैराक्सीडेज की मात्रा बढ जाती है
- पोषक तत्व आलेखन कार्यक्रम के अंतर्गत सूक्ष्म एवं गौण तत्वों के चित्रांकन के लिए 67 जिलों से लगभग 15095 मृदा नमूने एकत्र किये गये । जिसमें से 3.4–75 (औसत 42.1 प्रतिशत) प्रतिशत नमूनों में जिंक, 0–36 प्रतिशत नमूनों में कापर (औसत 16.1 प्रतिशत), 0–32.8 प्रतिशत नमूनों में लोहा (औसत 16.1 प्रतिशत) तथा 0–17 नमूनों में प्रतिशत मैंगनीज (औसत 7 प्रतिशत) की कमी पाई गई ।
- सूक्ष्म एवं गौण पोषक तत्वों का विभिन्न फसलों पर प्रभाव जानने के लिए इस परियोजना के विभिन्न केन्द्रों पर किये गये अध्ययनों से पता चलता है कि इन तत्वों के उपयोग से फसल उत्पादन में महत्वपूर्ण वृद्धि हुई।
- फसल उत्पादन बढाने के लिए मृदा में विभिन्न सूक्ष्म एवं गौण पोषक तत्वों की कमी को दूर करने के लिए विभिन्न सुधार तकनीकों को मानकीकृत किया गया । आंन्ध्रप्रदेश की मिट्टियों में 2किग्रा बोरैक्स, 5 किग्रा जस्ता तथा 20 किग्रा गंधक डालने से सुरजमुखी में 28 प्रतिशत उत्पादन की वृद्धि हुई । उडीसा की लौह विषाक्तता वाली जमीनों में 5 किग्रा जस्ता प्रति हेक्टेयर डालने से धान उत्पादन में आसातीत वृद्धि हुई ।
- चावल उत्पादन के लिए बोरॉन की कमी वाली मिट्टियों में बोरॉन का प्रयोग अतिआवश्यक है ।
- इसी प्रकार पालमपुर में फलगोभी पर किये गये अनुप्रयोग से ज्ञात हुआ है कि बोरॉन के लिए एक अन्य स्रोत ग्रेनूबोर, बोरेक्स के समान रूपी है ।

- तराई क्षेत्र की मोलीसॉल मृद्राओं में धान–गेहूँ फसल चक्र में हाइब्रिड धान में 1 किग्रा बोरॉन प्रति हेक्टेयर डालने से उपज में वृद्धि दर्ज की गई ।
- आंध्र प्रदेश में सूक्ष्म तत्वों के प्रयोग विधियों पर किये गये एक अनुप्रयोग से ज्ञात होता है कि फसलों में सूक्ष्म तत्वों की कमी को पूरा करने के लिए मृदा प्रयोग अन्य विधियों की अपेक्षा ज्यादा प्रभावी हैं ।
- मृदा में सूक्ष्म तत्वों की कमी के निष्पादन के लिए एवं सूक्ष्म तत्व युक्त घनित अनाज उत्पादन हेतू आज के युग में सूक्ष्म तत्व दक्षता वाली प्रजातियों का उत्पादन आवश्यक है इसलिए इस परियोजना के अन्तर्गत मुख्य फसलों की विभिन्न प्रजातियों का सूक्ष्म तत्व दक्षता के आधार पर पहचान की जा रही है
- परियोजना के विभिन्न केंद्रों पर मूलभूत एवं रणनीतिक अनुसंधानों से पता चलता है कि कोबॉल्ट एवं कैडमियम की अधिकता के दुष्प्रभाव को गोबर की खाद के अनुप्रयोग से कम किया जा सकता है ।
- परियोजना के लुधियाना केंद्र द्वारा गेहूँ में कॉपर का क्रांतिक स्तर 4.5 पी.पी.एम पाया गया । जबकि हिसार केंद्र द्वारा सरसों एवं मूंग में बोरॉन का क्रांतिक स्तर 1.1 एवं 0.83 पी.पी.एम स्थापित किया गया ।
- पूसा बिहार में एक दीर्घकालीन प्रयोग के अन्तर्गत धान–गेहूँ–ज्वार एवं धान–सरसों–मूंग की 21वीं फसल चक्र तक जस्ता, ताँबा, लौह एवं मैगनीज का कुल अवशोषण ज्ञात किया गया । विभिन्न उत्पादकता स्तरों पर धान–गेहूँ एवं फसल चक्र में कुल अवशोषण क्रमशः 5.59 से 13.27, 2.143 से 5.673, 44.83 से 109.27 और 10.63 से 29.86 कि.ग्रा. प्रति है, तथा धान सरसों मूँग में 4.7 से 10.15, 1.683 से 4.314, 35.56 से 83.89 तथा 8.95 से 21.15 कि.ग्रा. प्रति है पाया गया।
- तामिलनाडु के कोयम्बटुर जिले की विभिन्न औद्योगिक इकाइयों के सीवर जल में विभिन्न भारी धातुओं की डी.टी.पी.ए अवशोषित मात्रा देखी गई । सबसे अधिक भारी धातुओं की मात्रा उन मृदाओं में दर्ज की गई जिनमें सिंचाई के लिए कासटिंग, पेंटिंग एवं सीवेज जल का प्रयोग होता है । कासटिंग उद्योग से निकले जल से सिंचाई करने पर DTPA जिंक एवं कॉपर की मात्रा सबसे अधिक पाई गई जबकि पेंटिंग इन्डस्ट्रीज से निकले जल से सिंचित मृदाओं में निकिल एवं सोने की प्रकिया पर आधारित इकाइयो के क्षेत्र की मृदाओं में कैडमियम (2.34 मि. ग्रा प्रति कि. ग्रा. मृदा) एवं सीवेज जल से सिंचित मृदाओं में सीसा की मात्रा सर्वाधिक पाई गई ।
- फाउंडी एवं इलेक्ट्रोप्लेटिंग इण्डस्ट्रीज को छोड़कर अन्य औद्योगिक इकाइयों के सीवर जल से दूषित मृदाओं में पनपने वाले पौधें में भारी धातुओं की मात्रा भी बढ़ते कम में निम्नानुसार Pb>Zn>Ni>Cu पाई गई । समस्त भारी धातुओं की मात्रा सीवर जल में आरोही क्रम में निम्नानुसार पाई गई Cu >Zn>Ni> Pb>Cd ।
- पौधों की विभिन्न प्रजातियों में अवशोषित व समायोजित भारी धातुओं की मात्रा के अध्ययन में ज्ञात हुआ कि सीवेज जल से सिंचित चोलाई में सर्वाधिक भारी धातुओं की मात्राा एकत्र करने की क्षमता देखी गई, जबकि प्लेटिंग व विद्युत प्लेटिंग इकाइयों के सीवर से सिंचित क्षेत्र में पनपने वाले अरण्डी के पोधों में भारी धातुओं की मात्रा अधिक पाई गई, यही नहीं कुछ खरपतवार पौधे जैसे पारथीनियम व एब्युटीलान प्रजाति के पौधे जोकि औद्योगिक इकाइयों के सीवर सिंचित क्षेत्र में पनपते हैं, उनमें भी भारी धातुओं की अधिक मात्रा देखी गई ।
- एक अन्य अध्ययन में वभिन्न पौधों में भारी धातु ट्रांसलोकशन गुणांक निम्नानुसाार ग्वांर >गैन्दा >लोबियाचारा > चोलाई, देखा गया। जिन पौधों में भारी धातुओं का अधिकतर जमाव था उनमें चोलाई, ग्वार तथा गेन्दा थे जो कि मृदा से भारी धातुओं को अधिक मात्राा में अवशोषित कर सकने में सक्षम है । जहां तक जैव भार उत्पादकता का प्रश्न है वहां अभोज्य फसलों में गेंदा की फसल उपयुक्त पाई गई जो कि दोषित मृदाओं में सर्वाधिक जैव भार उत्पादन में सक्षम है । भारी धातु दूषित मृदाओं के सुधार के लिए गेंदे की फसल में 100ग्राम ईडीटीए (EDTA) एवं 5 टन गोबर की खाद डालने की संस्तुति की जाती 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 projections, 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 phytoavailable 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 deficiencies in agricultural soil. Now, micronutrient deficiency has become a limiting factor for crop productivity in many agricultural soils. 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 crops. Hence, many food systems in country are not able to provide sufficient micronutrients concentrations 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).

Such wide scale micronutrient deficiencies and their impact in plant/animal/human health make plant nutrition research a major promising area in meeting the global demand for sufficient food production with enhanced nutritional value in this millennium. Integration of plant nutrition research with plant genetics and molecular biology is indispensable in developing plant genotypes with high genetic ability to adapt to nutrient deficient and toxic soil conditions and to allocate more micronutrients into edible plant products such as cereal grains. Considering ecological concerns, cultivation and breeding of micronutrient-efficient genotypes in combination with proper agronomic management practices appear as the most sustainable and cost effective solution for alleviating food-chain micronutrient deficiency. Micronutrient-efficient genotypes could provide a number of benefits such as reductions in the use of fertilizers, improvements in seedling vigor, and resistance to abiotic and biotic stresses. Use of micronutrient-dense crop cultivars can also improve the micronutrient nutritional status in animal/human.

Initially in order to delineate the

micronutrient deficient areas and to alleviate the micronutrient stresses, the All India Coordinated Scheme of Micronutrient in Soils and Plants was launched by the Indian Council of Agricultural Research in 1967 with its National Headquarter at the Punjab Agricultural University, Hisar with 6 Coordinating centre located at Lucknow, Hisar, Jabalpur, Ranchi, Anand and Coimbatore. Later on its head quarter was shifted to Punjab Agricultural University, Ludhiana in 1970 with new centre at Ludhiana and Hyderabad. The deficiencies of secondary nutrients and toxicities of heavy metal elements were subsequent noticed in many parts of the country. In view of this, the project mandate was expanded and its objectives were enlarged to include these aspects in the research project and coordinating unit was shifted to Indian Institute of Soil Science, Bhopal w.e.f. 28.4.1988. Three new centers viz: Akola (Maharashtra), Bhubaneswar (Orissa) and Pantnagar (Uttaranchal) were added in 1996 assessing the importance of micronutrient research in enhancing food grain production. The large scale micronutrient deficiencies were reported by different centers and its impact on crop yield has further expanded the project domain and consequently, five new centers, CSKV, Palampur, AAU, Jorhat, BCKV, Mohanpur, CSAUAT, Kanpur and BAU, Ranchi were included in 2009. 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 projects are:

1 To delineate micro- and secondary - nutrients (MSN) deficient/toxic areas by soil and plant analysis as well as by response studies under field and green house conditions.

2. Micronutrient indexing to forecast efficiencies/toxicities in soils and crops under different soil-cropping- management systems.

3. To standardize and develop soil test methods and establish critical/toxic limits of different secondary/micronutrients/pollutant elements for various soils and crops.

4. To develop techniques for ameliorating the MSN deficiencies in crops and soils and increasing fertilizer-use-efficiency by various means

5. To monitor extent of heavy metal or trace element pollution and its impact on soils-plant-animal/human health.

6. To induce and catalogue deficiency symptoms for diagnosing micro- and secondary nutrient deficiencies in field crops.

7. To identify crops tolerant to micronutrient stress as well as to heavy metal toxicities and study nutrient interactions and their role in reproductive physiology of plants.

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 semiarid region	Medium and deep black alluvial soil
Cooperative Centres				
CCSHAU, Hisar	01.01.1967	Haryana	Western plain and K utch 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 semiarid 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 & Bundel khand 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 sand 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, Bhubneshwar	01.04.1996	Orissa	Eastern Ghat hot sub-humid	Red loam, red and lateritic soils

Voluntary Centre

Location	Date	State	Agro-eco. region	Soil type
CSKHPKV Palampur, H.P.	01.04.2009	Himachal Pradesh	Hill, sub humid	Hill & mountaneous soils , alfisol
CSUAT, Kanpur.U.P.	01.04.2009	Uttar Pradesh	Northern plain , hot semi-arid	Alluvium derived Indo Gangatic alluvial soil
Assam Agril. Univ. Johrat, Assam	01.04.2009	Assam	Hot sub-humid	Alluvium, hill, red, lateritic soils
BAU, Ranchi, Jharkhand	01.04.2009	Jharkhand	Eastern Santhal pargana hot semi-arid,	Red loam, red and laterite soils
BCKV,Mohan-pur, West Bengal	01.04.2009	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	Budget Sanctioned 2008-09	Budget Released 2008-09	Budget Sanctioned 2009-10	Budget Released 2009-10
Lucknow University	38.30	38.30	22.55	29.11
PAU, Ludhiana	34.73	34.73	21.83	21.00
HAU, Hisar	33.69	33.69	21.83	23.50
RAU, Pusa	42.00	42.00	24.08	22.00
AAU, Anand	32.45	32.45	54.53	33.00
JNKVV, Jabalpur	27.23	27.23	23.33	21.00
ANGRAU, Hyderabad	31.73	31.73	23.33	47.00
TNAU, Coimbatore	20.85	20.85	24.08	14.00
PKV, Akola	11.51	11.51	11.55	15.00
OUAT, Bhub aneswar	16.75	16.75	11.55	12.00
GBPUAT, Pantnagar	15.64	15.64	14.18	14.00
PC Unit IISS Bhopal	15.15	15.15	21.20	9.49
CSKHPKV, Palampur	-	-	5.20	8.10
AAU, Jorhat	-	-	5.20	7.70
BCKV, Kal yani	-	-	5.20	7.70
BAU, Ranchi	-	-	5.20	7.70
CSAUS&T, Kanpur	-	-	5.20	7.70
Total	320.00	320.00	300.00	300.00

Table 3. Details of manpower at various centres

Sl. No	Name of the centre	Posts sanctioned in XI plan				
		Scientific	Technical*	Admn.	Supporting	**Total**
1.	RAU, Pusa	4	2	1	1	**8**
2.	PAU, Ludhiana	4	3	1	1	**9**
3.	GAU, Anand	4	2	1	1	**8**
4.	TNAU, Coimbatore	3	3	1	1	**8**
5.	CCSHAU, Hisar	3	3	1	1	**8**
6.	JNKVV, Jabalpur	3	3	1	1	**8**
7.	ANGAU, Hyderabad	3	3	1	1	**8**
8.	PDKV, Akola	2	1	-	1	**4**
9.	GBPUAT, Pantnagar	2	1	-	1	**4**
10.	OUAT, Bhubneshwar	2	1	-	1	**4**
11	Lucknow University	2	4	1	2	**9**
12.	PC Unit, Bhopal	4	3	3	2	**12**
13.	A.A.U Jorhat	-	2	-	-	**2**
14.	B.A.U Ranchi	-	2	-	-	**2**
15.	B.C.K.V Mohanpur	-	2	-	-	**2**
16.	C.S.K. HPKV, Palampur	-	2	-	-	**2**
17.	CSAUA&T Kanpur	-	2	-	-	**2**
	Total	**36**	**39**	**11**	**14**	**100**

*SRF and RA in fixed scale included in technical manpower

CHAPTER –I

DIAGNOSIS OF MICRONUTRIENT DISORDERS

Diagnosis is a tool to assess micronutrient deficiencies/disorder in soil and plants. In order to develop efficient ways and means for correcting micronutrient deficiencies/disorders and maximizing yields a precise diagnosis is key input. The most common methods employed for diagnosis and monitoring the nutritional disorders includes visual deficiency symptoms, soil and plant analysis and fertilizer response trials. The studies carried out on these aspects are summarized below:

1.1 Effect of Molybdenum deficiency/excess on reproduction, yield and seed quality of rice

Rice (*Oryza sativa* L.) cv. Indrasan was grown in refined sand culture at six Mo levels ranging from deficiency to excess (0.00001 to 2.0 mg Mo l^{-1}). The Molybdenum (Mo) concentration in leaves as well as in seeds increased with an increase in Mo supply from 0.00001 to 2.0 mg Mo l^{-1}. The dry matter and economic yield (total and 100 seed weight) of plants was reduced in both Mo deficiency (<0.02) and excess (>0. 2) mg Mo l^{-1}) situation, however, decrease was greater due to Mo deficiency than Mo excess (Table 1.1). Nitrate reductase activities in leaves, pollen producing capacity of anthers (without marked change in anther length) were severely affected under both Mo deficiency and excess (<0.02 mg Mo l^{-1}>) condition (Table 1.2). Accordingly, reduction in concentration of non-reducing sugars, starch and protein-N and increase in phenols content influenced the grain quality under deficiency/excess situation (Table 1.3).

Table 1.1. Dry matter yield (g dry weight plant^{-1}) of rice cv. Indrasan at variable Mo rates at 145 DAS

Plant parts	mg Mo l^{-1}					
	0.00001	0.0001	0.001	0.02	0.2	2.0
Inflorescence	9.58	10.92	13.41	14.22	11.79	10.55
Leaves	10.85	13.42	16.72	18.90	17.44	15.76
Stem	9.00	9.91	11.15	13.97	9.64	5.65
Roots	3.50	3.94	3.97	4.39	3.27	2.92
Whole plant	32.93	38.19	45.25	51.48	42.14	34.88

Table 1.2. Anther length, pollen diameter and pollen producing capacity (PPC) of anthers, yield and quality of rice var. Indrasan as influenced by variable Mo rates

Parameters	mg Mo l^{-1}					
	0.00001	0.0001	0.001	0.02	0.2	2.0
Anther length (mm)	2.45	2.35	2.30	2.25	2.44	2.26
PPC (Pollen grain anthers^{-1})	696.0	704.0	704.0	800.0	815.0	452.0
Anther diameter (µM)	57.2	39.3	44.0	47.0	44.0	38.8
Total se ed w eigh t g plant^{-1}	6.77	7.63	8.07	8.58	6.43	5.01
100 seed weight (g)	1.78	1.87	1.87	1.88	1.79	1.78

Table 1.3. Activities of certain enzymes and their soluble protein content in rice var. Indrasan leaves (60 days after sowing) and seeds (20 days after anthesis) at variable Mo supply

Parameters	mg Mo l^{-1}					
	0.00001	**0.0001**	**0.001**	**0.02**	**0.2**	**2.0**
Biochemical parameter in seed						
Amylase (mg starch hydrolysed 100 mg^{-1} fresh seed)	3.6	3.5	2.8	2.9	2.8	3.0
Amylase (mg starch hydrolysed 100 mg^{-1} protein)	1.45	1.36	0.95	0.92	0.87	0.84
Starch phosphorylase (µg Pi released 100 mg^{-1} fresh weight)	8.0	25.6	28.8	40.8	43.8	50.2
Starch phosphorylase (µg Pi released 100 mg^{-1} protein)	2.93	9.92	9.69	13.07	13.73	13.97
Protein (mg 100 mg^{-1} fresh weight)	2.75	2.59	2.97	3.12	3.17	3.60
Biochemical parameter in leaves						
Nitrate reductase (n moles NO_2 formed g^{-1} fresh weight h^{-1}) at 60 days	188	6000	7475	7650	3938	2250
Nitrate reductase (n moles NO_2 formed mg^{-1} protein h^{-1})	13	264	402	489	265	173
Protein (n moles NO_2 formed g^{-1} fresh weight h^{-1}) at 60 days	1.50	2.28	1.88	1.66	1.52	1.31

DAA, Days after anthesis

1.2 Boron stress induced antioxidants and metabolic changes in blackgram

Black gram (*Vigna mungo* L.) cv PU19 was grown at six levels of boron viz., 0.0033, 0.033, 0.33, 0.66, 1.65 and 3.3 mg B l^{-1}. Variation in B supply influenced the growth of plants. At low B (< 0.33 mg B l^{-1}) supply, plants showed marked shortening of internodes, young leaves became chlorotic, thick and brittle, apical growth ceased to grow and turned necrotic, affected plants withered and collapsed. Under severe B deficiency situation (i.e. 0.0033 mg B l^{-1} supply) no pod and seed formation took place. Under excess B (3.3 mg B l^{-1}) supply, plant showed toxicity symptoms as depression in growth and marginal chlorosis and necrosis of old leaves. These leaves became thin papery and shed prematurely. In both leaves and seeds, an increase in boron supply increased the boron concentration, however, both low (0.0033 mg B l^{-1}) and excess (3.3 mg B l^{-1}) boron supply decreased the dry matter, photosynthetic pigments, activities of catalase and ascorbate peroxidase and increased the cysteine content and activities of peroxidase and superoxide dismutase in black gram leaves. The proline and MDA content increased in leaves at low B supply and decreased at excess B. The quality of seeds deteriorated in both low (0.033 B l^{-1}) and excess (3.3 mg B l^{-1}) B supply, which was reflected as decrease in seed yield, total protein content, sugars (non-reducing and total), starch, electrolyte leakage and accumulation of reducing sugars, phenols in seeds of black gram.

1.3 Screening of wheat varieties for copper stress

Four varieties of wheat (*Triticum aestivum* L.) viz., UP226, UP2338, UP343 and PBW373 were grown at three Cu levels i.e. 0.001 (deficient), 1.0 (adequate) and 100 µM (excess) Cu supply till maturity (d 97). Growth of all four varieties was poor at Cu deficient (0.001 µM) and excess (100 µM) situation, however, reduction in plant growth was reflected early at excess Cu than that in Cu deficient condition. The symptoms of excess Cu i.e. interveinal chlorosis and bleaching of young leaves were more marked in var. UP2338 and UP343 as compared to var. UP226 and PBW 373 (Plate 1). Similarly, these cultivars (UP2338 and UP343) were also showed marked Cu deficiency symptoms (i.e. rolling of young leaves, which failed to emerge from subtending leaves giving a hook like appearance) than that of UP226 and PBW373. The reduction in biomass, pod and seed yield were recorder at both deficient and excess Cu supply, Seed yield was decreased in both Cu deficiency and excess in all four wheat varieties. The decrease in seed yield at low Cu was comparatively less (73% and 85%) in var. UP226 and PBW373 as compared to vars. UP343 and UP2338 (97% to 100%). Similarly decrease in seed yield at excess Cu was 74% to 86% in var. PBW373 and UP226 as compared to 97.7% to 98.4% in UP343 and UP2338 (Table 1.4). The concentration of chloroplast pigments (chlorophyll a, b and carotenoids) were more affected at excess Cu supply in all four wheat varieties. The decrease in these parameters was more pronounced in UP2338 and UP343 both in deficiency and excess of Cu. The increase in specific activity of peroxidase at both low and excess Cu was highest in var. PBW373. The activity of polyphenol oxidase decreased both in deficiency and excess of Cu and the decrease was most marked in UP2338 and least in var. PBW373. The activity of superoxide dismutase was directly related to Cu supply and var. UP2338 had higher activity than UP 226 at all Cu levels. Tissue Cu concentration was directly related to Cu supply in all plant parts in all four wheat varieties but Cu concentration in all plant parts was higher in var. UP226 and PBW373 as compared to var. UP2338 and UP343 (Table 1.5).

On the basis of the above parameters var. UP2338 and UP343 appeared to be more susceptible to deficiency as well as Cu excess supply while var. UP226 and PBW373 were

Plate 1. Cu Stress in wheat

Table 1. 4. Effect of Cu deficiency and excess on total biomass, seed yield and chlorophyll content of wheat cultivars.

Cu supply (µM)	Wheat varieties			
	UP 226	UP 2338	UP 343	PBW 373
Dry weight g plant^{-1} at30 DAS				
0.001	0.341 (-17)	0.388 (-8)	0.347 (-13)	0.329 (-19)
1.0	0.412	0.421	0.398	0.407
100	0.251 (-39)	0.129 (-69)	0.302 (-24)	0.264 (-35)
Seed yield g plant^{-1}				
0.001	0.64 (-73)	Nil (-100)	0.08 (-97)	0.33 (-85)
1.0	2.34	2.44	2.63	2.25
100	0.33 (-86)	0.04 (-98)	0.06 (-98)	0.59 (-74)
Chlorophyll (mg g^{-1} fresh weight)				
0.001	1.77 (-21)	2.16 (+1.4)	2.28 (+3.2)	1.99 (+2.1)
1.0	2.23	2.13	2.21	1.95
100	1.12 (-50)	0.80 (-62)	1.03 (-53)	1.20 (-38)

Figures in parenthesis denote % increase (+) or decrease (-) over control (i.e. 1.0 µM Cu supply)

Table 1.5. Cu concentration in different parts of wheat varieties in relation to Cu supply.

Cu supply (µM)	Plant parts	Wheat variety			
		UP 226	UP 2338	UP 343	PBW 373
	µg Cu g^{-1} dry weight at 55 days after sowing				
0.001	Young leaves	4.0	1.4	3.1	3.6
	Old leaves	3.6	3.0	3.3	4.5
	Stem	3.2	2.6	2.9	3.2
	Roots	6.0	3.0	3.9	5.7
1.0	Young leaves	8.0	7.6	7.1	8.5
	Old leaves	7.8	5.0	6.9	7.3
	Stem	6.6	6.6	5.3	6.8
	Roots	5.8	5.8	5.7	5.3
100	Young leaves	27.7	21.5	17.7	29.1
	Old leaves	37.3	33.8	26.5	36.0
	Stem	24.3	19.2	16.7	29.3
	Roots	272.0	214.8	245.6	304.8

1.4 Assessing Copper Requirement of Cucumber

Cucumber (*Cucumis sativus* L) cv. Sonali was grown in polyethylene containers of 10 L capacity at variable levels of copper ranging from acute deficiency to excess viz; 0.00065, 0.0065, 0.013, 0.065, 6.5, 13.0 and 26.0 mg L^{-1}. Cu supply. The differences in plant growth were apparent in response to variable copper supply rates at d 30. The growth and height of plants were maximum at 0.065 mg Cu L^{-1}. Copper deficient (0.00065 mg Cu L^{-1}) plants developed secondary branches with smaller leaves on them. The tendrils were shorter in length. Young leaves showed mild yellowing and curling of leaf margins (Plate 2). Later the affected leaves appeared wilted and chlorotic. At low Cu flower and floral buds formed in groups were smaller in size and failed to produce fruits. The excess Cu supply (13 and 26 mg Cu L^{-1}) resulted in interveinal chlorosis of young leaves from base to apex at 30 days after sowing. Flowers formed on these plants were smaller in size, faded in colour, and shed prematurely (Plate 3).

Biomass of cucumber plants increased with an increase in copper levels from 0.00065 to 0.065 mg L^{-1} and further increase in copper caused appreciable decline in the dry matter production (Table 1.6) at both stages (d 42 and 64). The effect of Cu supply on dry matter was more pronounced in Cu toxicity (13 and 26 mg Cu L^{-1}) situation than that of deficiency. Owing to acute deficiency, young leaves contained only 4.4 mg L^{-1} copper as compared to 25.7 mg L^{-1}copper in control (at normal supply) plants whereas at excess copper (26.0 mg L^{-1}) supply the Cu concentration was many fold higher (187 mg g^{-1} dry matter) than that of normal supply.

The concentration of copper in different parts of cucumber increased with an increase in Cu supply (0.00065 to 26.0 mg Cu L^{-1}) and ranged between 4.4 to 187 µg g^{-1} dry matter. Accumulation of copper was maximum in roots under excess Cu supply. The concentrations of chlorophylls, carotenoids, Hill reaction activity, catalase and total protein content in leaves were decreased and peroxidase and chlorophyll a/b ratio increased at deficient (< 0. 065 mg Cu L^{-1}) and excess (> 6.5 mg Cu L^{-1}) Cu. The activities of polyphenol oxidase (PPO) and superoxide dismutase (SOD) were parallel with the increase in Cu from 0.00065 to 26 mg Cu L^{-1} (Table 1.6).

Plate 2. Copper deficiency in cucumber

Plate 3. Copper toxicity in cucumber

Table 1.6. Effect of variable copper supply on dry matter yield and physiology of cucumber

Plant Part	mg Cu L^{-1}						
	0.00065	0.0065	0.013	0.065	6.5	13.0	26.0
Dry matter (g plant) at 42 DAS							
Y.L.	1.205	1.54	1.805	2.430	1.650	1.417	0.423
O.L.	1.685	1.975	1.755	1.790	1.970	1.452	0.766
Stem	1.380	1.450	1.575	1.975	1.725	1.375	0.496
Root	0.175	0.355	0.285	0.355	.295	0.255	0.166
Whole plant	4.445	5.300	5.420	6.550	5.64	4.499	1.851
	(-32)	(-19)	(-12)		(-14)	(-31)	(-72)
Dry matter (g plant) at 64 DAS							
Flowers/fruits	0.31	0.52	0.47	1.60	0.49	0.29	0.13
Leaves	5.85	6.41	9.98	17.70	15.74	7.78	4.46
Stem	2.68	3.08	6.31	6.93	8.28	4.47	1.82
Roots	0.24	0.26	0.63	0.99	0.85	0.38	0.25
Whole plant	9.04	10.27	17.39	26.44	25.36	12.92	6.66
	(-66)	(-61)	(-34)		(-4)	(-51)	(-75)
Physiological parameters							
Chlorophyll (mg g^{-1} fresh weight)	1.171	1.472	1.579	1.899	1.174	1.061	0.241
Hill reaction activity Change in O.D.!00 mg^{-1} fresh weight	0.135	0.190	0.325	0.420	0.600	0.217	0.130
SOD EU	5.9	7.0	7.3	8.1	8.7	14.9	20.4
Catalase µ moles H2O2 decomposed	543	565	679	699	596	528	457
Peroxidase (cahnge in OD	3.14	2.76	2.01	1.85	2.34	2.76	4.47

Figure in parenthesis denote % depression over control (normal concentration)

1.5 Phytotoxic Effects of Excess Cobalt on Oxidative Stress and Metabolic Changes in Mustard

Mustard (*Brassica campestris* L.) cv. T-59 was grown at 0.0001 (control), up to 39 days thereafter treatments were applied as 0.1, 0.2, 0.3, 0.4 and 0.5 mM Co on 40th day. Variation in cobalt supply influenced the growth of mustard plants first (Plate 4). The effects became visibly apparent at 3 days after the metal (Co) supply (d 43). Plants grown at the highest level of Co supply (0.5 mM) became restricted due to shortening of internodes and reduction in size of leaves. After 6 days of Co supply (46 DAS), chlorotic spots initiated from base of young leaf lamina, leaving the margins dark green, which gradually became more intense and spread towards the apex of the lamina. Chlorotic spots eventually turned into necrotic (mosaic like) areas and affected areas appeared dry and papery, leaf size was reduced markedly. Leaves appeared dry and papery along with reduced leaf size (Plate 5). At severity, upper part of stem became dry and hung down. At 0.5 mM Co, flowers formed were lesser in number, aborted and dried.

Dry matter yield of mustard plants was maximum at 0.0001 mM Co (control). Compared to the control plants, dry matter decreased with an increase in Co supply from 0.1 to 0.5 mM Co at all stages of determinations i.e. d 46, 54, 80 and 92 (6, 15, 40 and 52 days after metal supply{DAMS}). The effect of variable Co on dry matter was conspicuous even at 6 days of metal supply. At d 46 and 54, reduction in dry matter at 0.5 mM Co were 66 and 41 percent, respectively as compared to the respective control plants, whereas reduction in dry weight at d 80 was 77 percent at 0.5 mM Co supply.

With increase in age of plants depression in economic yield became more pronounced and the reduction in dry weight at 0.5 mM Co was 74 and 77 percent, respectively at d 80 and 92. At d 92 (52 days after metal supply) pod and seed yield at 0.4 mM Co were reduced by 82 and 98 percent, respectively as compared to control plants (Table 1.7). There was no pod formation at the highest (0.5 mM) level of cobalt.

The accumulation of Co was more in husk than in seeds. At d 43 (3 DAMS), as compared to adequate Co, the activity of catalase and MDA content increased both in leaves and roots. At 6 DAMS, the concentration of chlorophylls, carotenoids, MDA and the activity of catalase and MDA concentration (in leaves and roots) decreased with an increase in Co supply. The ratio of chlorophyll a: b was highest at 0.5mM Co. Increase in Co supply increased the activities of peroxidase, superoxide dismutase and ascorbate peroxidase and concentration of proline both in leaves and roots after 3 and 6 DAMS. The increase in peroxidase activity was more marked in roots than in leaves.

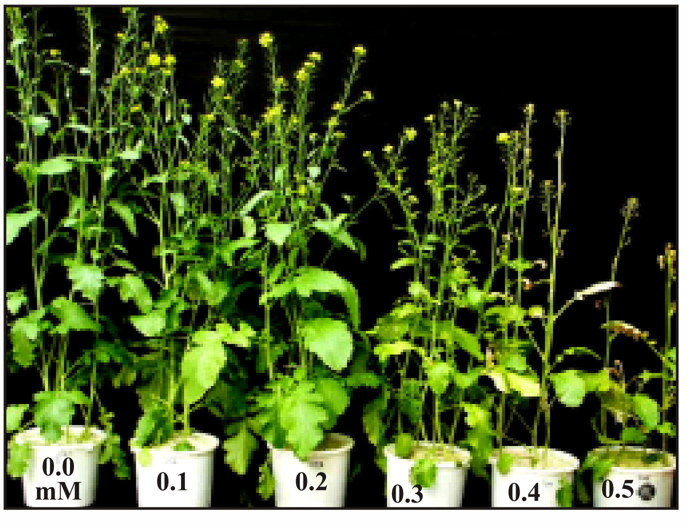


Plate 4. Cobalt response in mustard

Plate 5. Cobalt toxicity in mustard

1.6 Impact of Nickel Toxicity on growth and physiology of Mustrad

Mustard (*Brassica campestris* L.) cv T59 was grown in refined sand at six variable levels of nickel viz. 0.0001, 0.1, 0.2, 0.3, 0.4, and 0.5 mM Ni. (Plate 6.) Initially mustard plants were raised from seeds sown in polyethylene containers of 10 L capacity. At d 45, excess Ni induced visible symp-

Table 1. 7. Effect of variable Co supply on dry weight and economic yield of mustard

Plant part	mM Co supply					
	Control (0.0001)	0.1	0.2	0.3	0.4	0.5
Dry matter (g plant^{-1}) 54 DAS or 15 DAMS						
Pods	0.40	0.03	0.09	0.04	0.03	0.05
Leaves	1.45	1.30	1.11	0.95	0.89	1.02
Stem	3.05	0.99	0.97	0.70	0.67	0.54
Roots	0.22	0.15	0.30	0.21	0.26	0.17
Whole plant	3.03	2.47	1.90	1.90	1.85	1.78
Dry matter (g plant) 80 DAS or 40 DAMS						
Pods	2.94	3.00	1.17	0.98	0.20	0.14
Leaves	3.32	3.50	5.57	2.62	1.66	1.29
Stem	9.19	8.59	7.15	3.21	3.74	1.85
Roots	1.37	1.02	1.57	0.55	0.72	0.66
Whole plant	16.82	16.11	15.46	7.36	6.32	3.94
Pods and seed weight (g plant^{-1}) 92 DAS or 52 DAMS						
Pods weight	6.25	5.87	4.41	4.24	1.11	--
Seed weight	2.99	2.85	2.15	1.65	0.83	--

DAMS = Days after metal supply

toms of nickel toxicity as chlorosis from the apex of young leaf lamina with depression in growth which was apparent at 0.4 and 0.5 mM Ni. (Plate 7) Later, the affected leaves turned yellow, necrotic and were reduced in size as compared to control. Flowers that formed failed to produce pods.

Compared to control plants (0.0001mM Ni), where maximum dry matter yield of plants was obtained, dry matter of plants decreased gradually with an increase in Ni supply from 0.1 to 0.5 mM at different stages of determination (Table 1.8). At d 50 (10 DAMS), reduction in dry matter yield was 64% at 0.5mM Ni supply. At harvest (d 70, 20 DAMS), dry matter yield of mustard plants was highly reduced at higher levels of nickel (more than 0.2 mM Ni) where pod formation was completely checked. The decreased concentrations of chlorophyll and carotenoids in leaves associated was with a marked increase in the activities of superoxide dismutase, ascorbate peroxidase and peroxidase, proline content, lipid peroxidation and decreased activity of catalase.

Plate 6. Nickel response in mustard

Plate 7. Nickel toxicity in mustard

Table 1.8. Effect of excess nickel on biomass (d50 and 70) and concentration of nickel (d 50) in different parts of mustard.

Plant part	mM Ni supply					
	0.0001	**0.05**	**0.10**	**0.20**	**0.40**	**0.50**
Dry matter (g plant^{-1}) 50 DAS						
Y. leaves	1.53	0.83	1.00	0.72	0.74	0.69
O. leaves	2.18	1.88	1.01	1.36	0.93	0.83
Stem	3.58	2.04	1.45	1.22	0.96	0.96
Root	0.70	0.42	0.35	0.25	0.23	0.27
Whole Plant	7.99	5.17	3.81	3.55	2.86	2.75
Dry matter (g plant^{-1}) 70 DAS						
Pods	2.06	1.29	0.67	0.39	---	---
Leaves	6.26	4.75	5.03	2.85	2.89	3.35
Stem	8.14	6.12	5.61	3.93	3.87	3.55
Root	1.45	1.55	1.45	0.91	0.57	0.49
Whole Plant	17.91	13.71	12.76	8.08	7.33	7.39

1.7 Effect of Chromium Supply Rates on Mustard Growth

Mustard (*Brassica campestris* L. cv. T-59) plants were grown from seeds in refined sand in polyethylene pots and supplied with complete nutrient solution. Forty four days after sowing, when proper growth of plants had taken, pots were divided into six lots of three pots each. One lot was allowed to grow as such with normal supply of all

Plate 8. Effect of Cr supply on mustard growth

nutrients to serve as control; the remaining five lots were supplied with chromium at 0.05, 0.1, 0.2, 0.3 and 0.4 mM as potassium dichromate (Plate 8). The study was made on the effect of excess chromium on visible symptoms, biomass, yield and concentration of Cr in different plant parts at two stages of growth (d 60 and 80) (Table 1.9).

At d 50 (5 days after Cr supply), the effect of Cr supply was studied on concentration of chlorophyll, carotenoids and activities of some enzymes – catalase, peroxidase, ascorbate peroxidase and superoxide dismutase. The concentration of soluble protein was measured in fresh leaf extract prepared for the enzymes to express the activity on protein basis.

Later, the affected old leaves appeared wilted, hung down and turned golden yellow. Number and size of leaves were reduced in Cr stress (Plate 9). The pod formation was checked at higher levels of Cr (> 0.2 mM). Compared to control plants, the number and size of pods and biomass decreased with an increase in Cr supply from 0.05 to 0.2 mM (Table 1.9). The concentration of chromium increased with an increase in Cr supply in all plant parts at d 60 and 80. Accumulation of Cr was maximum in roots irrespective of Cr supply.

Compared to young leaves of mustard at control, the concentration of chlorophyll a, b and carotenoids and proteins decreased and that of proline increased in leaves with an increase in Cr levels from0.05 to 0.4mM. The specific activity of antioxidant enzymes- catalase decreased and that of peroxidase, superoxide dismutase and ascorbate peroxidase increased with an increase in Cr supply to a maximum at 0.4 mM Cr.

Plate 9. Chromium toxicity in mustard

1.8 Effect of excess Cd on Growth and physiology of mustard

Mustard (*Brassica campestris* L. cv T59) plants were raised at variable levels of Cd viz. nil, 0.1, 0.2, 0.3, 0.4, and 0.5 mM. Growth of mustard plants grown at 0.3, 0.4, 0.5 mM Cd was depressed after 3 days of metal (Cd) supply as compared to control plants (without Cd). At 0.5 mM Cd, symptoms of Cd toxicity initiated as interveinal chlorosis of young leaves at the base of lamina after 6 days of Cd addition. Later chlorosis became more intense with marked reduction in leaf size and lower leaves showed loss of turgor. Flowering was delayed by 4-5 days and flower formed were faded in colour and lesser in number at 0.4 and 0.5 mM Cd. At these levels of Cd, pod formation was highly restricted and pods formed also showed loss of green colour. Plants subjected to Cd stress were not infected with insect/pathogen.

Compared to control plants (without Cd addition), where maximum dry matter yield of plants was obtained, dry matter of plants decreased gradually with an increase in Cd doses at different stages of determination (Table 1.10). At harvest, economic yield of mustard was highly reduced (> 0.2 mM Cd). Both at 6 and 30 DAMS, the concentration of Cd in different plant parts increased with an increase in Cd supply and the accumulation of Cd was maximum in roots.

At 3 DAMS, the activities of superoxide dismutase and ascorbate peroxidase were increased and that of catalase and peroxidase decreased in roots and increased in leaves with an increase in Cd supply. At 6 DAMS, the activity of these antioxidant enzymes increased in Cd stress both in roots and leaves (except SOD in roots). Ascorbate peroxidase activity was elevated more in roots than leaves by Cd stress. Proline, non-protein-SH and thiobarbuteric acid reactive substances (TBARS) content increased in roots and leaves at 3 DAMS. The concentration of photosynthetic pigments (chlorophyll a, b and carortenoids) and relative water content were highly reduced at higher levels of Cd (>0.2 mM).

Table 1.9. Effect of chromium stress on biomass of mustard.

Plant Part	mM Cr supply					
	Control	0.05	0.1	0.2	0.3	0.4
	Dry weight(g plant^{-1}) DAS 60 or 15 DMS					
Flowers/ pods	0.34	0.30(-12)	0.22(-35)	0.14(-59)	0.12(-65)	0.09(-74)
Leaves	2.25	1.43(-36)	0.90(-60)	0.40(-82)	0.36(-84)	0.35(-84)
Stem	2.98	2.03(-32)	1.13(-62)	0.46(-85)	0.43(-86)	0.34(-89)
Roots	0.94	0.62(-34)	0.56(-40)	0.23(-76)	0.19(-80)	0.16(-83)
Whole Plant	6.50	4.38(-33)	2.81(-58)	1.23(-81)	1.10(-83)	0.94 (-86)
Top/Root	5.93	6.06(+2)	4.01(-32)	4.34(-27)	4.78(-19)	4.88(-18)
	Dry weight(g plant^{-1}) DAS 80 or 35 DMS					
Pods	4.10	1.64(-60)	0.69(-83)	0.26(-94)	---	---
Leaves	4.05	1.49(-63)	0.78(-81)	0.33(-92)	0.24(-94)	0.19(-95)
Stem	7.29	2.75(-62)	1.55(-79)	0.96(-87)	0.59(-92)	0.42(-97)
Roots	1.53	0.48(-68)	0.40(-74)	0.31(-80)	0.20(-87)	0.15(-90)
Whole Plant	16.97	5.86(-65)	3.42(-80)	1.85(-89)	1.03(-94)	0.76(-96)
Top/Root	10.09	12.25(+21)	7.55(-25)	5.00(-50)	4.15(-59)	4.06(-60)

Figures in parenthesis indicate increase (+) or decrease (-) in comparison to control.
DAMS= days after metal supply, DAS= days after sowing

Plate 10. Effect of Cadmium response in mustard growth

Table 1.10. Influence of excess Cd on mustard growth and Cd concentration in seed.

Parameters	**mM Cd**					
Plant part	Nil	0.1	0.2	0.3	0.4	0.5
Pod yield (g plant-1)	5.44	5.06	2.71	1.56	1.55	0.71
Seed (g plant-1)	1.67	1.58	1.12	0.37	0.21	0.03
		(-5)	(-33)	(-78)	(-87)	(-98)
Cd concentration ppm						
Pods	0.0	134.9	239.4	244.9	256.2	384.5
Seeds	8.8	147.5	157.1	167.9	201.6	236.0

1.9 Effect of Sulphur Deficiency on the Reproductive Physiology of Wheat

Wheat (*Triticum aestivum* L.) cv. Kundan plants were supplied with complete nutrient solution including sulphur at two levels: Normal i.e. control (2 mM S) and deficient (0.02 mM S). At 0.02 mM S, visible effects of S deficiency appeared as depression in growth at d 35. At deficient S leaves became pale and upright and stem appeared weaker, tillering was reduced and weak tillers showed lodging Sulphur.

Low (0.02 mM) supply of S caused mild retardation in plant growth at d 35. At d 39, plants exhibited slight paling on young leaves, leaves upright and stem appeared to be weaker. Paling of leaves gradually became more intense, tillering was reduced and weak tillers showed lodging. The decrease in the dry matter of plants at the time of harvest was significant. Biomass of S deficient plants was reduced and reduction in dry matter was about 35% deficiency decreased pollen producing capacity of anthers, pollen size and *in vitro* germination of pollen grains as well as affected the development of ears, reduced number and weight of grains, biomass of wheat (Table 1.11). S concentration decreased in all plant parts and the magnitude of decrease in S concentration was 24 % in ear and 61 % in young leaves as compared to normal supply (Table 1.12).

Development of ears was reduced in S deficient wheat plants. Grain production, number and weight of grains per plant and unit grain weight were reduced by 17% from that of control plant. There were significant decreases in ear length and number and weight of grains produced per plant.

Table 1. 11. Effect of Sulphur deficiency on anther length, Pollen producing capacity of anther and pollen diameter of wheat.

Treatments	Anther length (mm)	Pollen producing capacity (no. of pollen grains anther^{-1})	pollen grains diameter (µM)	In vitro germination (%)
Control	3.48	2576	48.85	48.85
S deficient	2.78	2138	40.37	24.66

Table. 1.12. Effect of sulphur deficiency on the concentration of sulphur in different parts of wheat.

Treatments	Ear	Young leaves	Old leaves	Stem	Root
Control	0.42	0.61	0.52	0.40	0.31
S deficient	0.32	0.45	0.24	0.25	0.10

1.10 Potassium Stress Alters Phytotoxic Effects of Cadmium on Spinach Physiology

Spinach (*Spinacea oleracea*) Var. All Green, plants were grown in refined sand at three levels of potassium i.e. low (0.02 mM), adequate (2.0 mM) and excess (8.0 mM) as potassium chloride, for 66 days. On day 67, the pots were supplied with Cd as $CdSO_4$ at nil and 0.25mM.

Compared to adequate (2.0 mM) K, the effects of K deficiency were apparent in spinach at d 55 as growth depression at 0.02 mM K. The symptoms of K deficiency were observed in old leaves as brown necrotic spots, which were initiated from apex and margins of young leaf lamina. With increase in age, K deficiency intensified gradually, as the growth of plants was highly reduced, necrosis became more severe and leaf size was markedly reduced.

At excess K (8.0 mM), no K toxicity symptoms were observed. At d 75, as compared to K adequate plants, growth was slightly increased at 8.0 mM K. But, with increase in age at d 96, no visible K toxicity symptoms were observed except for marked depression in growth.

Visible symptoms of Cd toxicity were more pronounced at adequate K + excess Cd. In adequate K+ excess Cd treatment, chlorosis appeared on young leaves, starting from the base and spread along the midrib of leaf lamina, at this stage growth of plants was markedly reduced. Later, the chlorotic areas turned into necrotic patches on leaf lamina on both sides of midrib and midrib showed blackening and necrosis. Cd toxicity symptoms were in the order - adequate K+ excess Cd > excess K+ excess Cd >low K+ excess Cd. The decrease in drymatter was more pronounced with adequate K + excess Cd supply (Table. 1.13).

Maximum Cd toxicity effects were observed in adequate K. K deficiency enhanced the effects of excess Cd by increasing concentration of Cd and proline and decreasing the biomass, activity of catalase, concentrations of MDA and chlorophyll, showing synergism. (Table 1.14) Whereas at excess K the effects of excess Cd were less severe as increase in biomass, activities of catalase, APX and decrease in that of SOD and concentrations of Cd and MDA in leaves of spinach.

Table1. 13. Interactive effect of K and Cd on dry matter yield and chloroplast pigments in spinach.

Plant part	0.02 mM K		2.0 mM K		8.0 mM K	
	Nil	0.25 mM Cd	Nil	0.25 mM Cd	Nil	0.25 mM Cd
Dry weight(g plant^{-1}) 21 DAMS or 96 DAS						
Top	1.75	0.82	18.93	2.26	6.09	2.74
Root	0.36	0.10	3.84	0.70	1.69	0.48
Whole plant	2.11	0.92	22.77	2.96	7.78	3.22
Chlorophyll (mg g^{-1} fresh weight) at 8 DAMS or 75 DAS						
Chlorophyll a	1.11	0.53	1.50	1.34	1.11	1.09
Chlorophyll b	0.29	0.16	0.29	0.37	0.31	0.31
Carotenoids (mg g^{-1} fresh weight)	0.39	0.21	0.43	0.48	0.40	0.41

d= days after sowing; DAMS: days after metal supply

Table 1.14. Interactive effect of K and Cd on tissue K and Cd concentration of spinach

Plant part	0.02 mM K		2.0 mM K		8.0 mM K	
	Nil	0.25 mM Cd	Nil	0.25 mM Cd	Nil	0.25 mM Cd
% K in Dry matter at 8 DAMS or 75 DAS						
Young leaves	0.16	1.68	5.30	4.0	6.4	17.6
Older leaves	0.28	1.56	9.60	1.6	18.4	20.0
Roots	0.7	2.8	7.75	3.02	2.0	3.2
% Cd in Dry matter at 8 DAMS or 75 DAS						
Young leaves	2.50	355	4.20	300	4.65	242
Older leaves	5.06	300	4.30	152	4.4	192
Roots	3.96	1117	2.95	482	13.28	448

d= days after sowing; DAMS = days after metal supply; Y.L. = young leaves; O.L. = Old leaves;

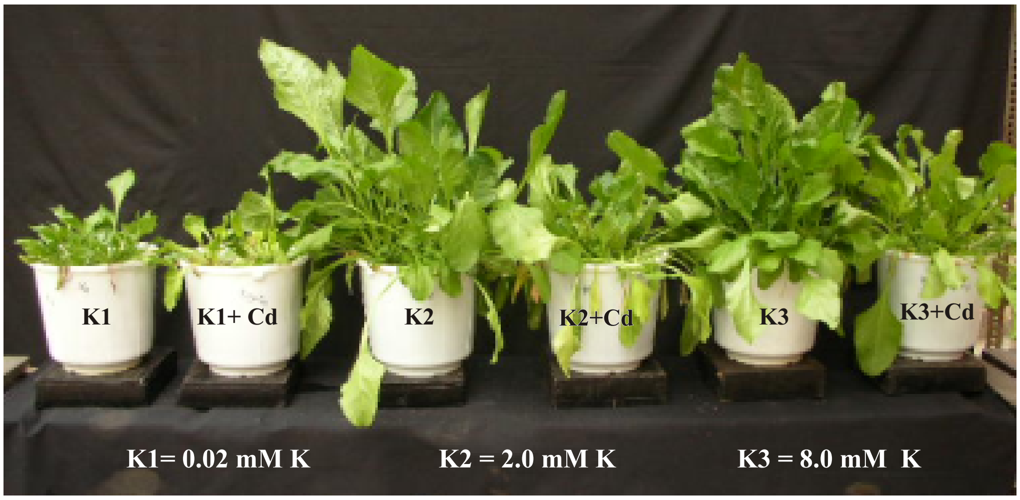


Plate 11. Potassium – cadmium interaction in spinach

1.11 Growth and Metabolism of Clusterbean at Excess Cadmium

In cluster bean (*Cyamopsis tetragonoloba* Taub.) cv. Desi plants supplied with excess Cd (0.01-0.5 mM) showed depression in growth as compared to those of control (without Cd) after 15 days of Cd supply (Plate 12). The apical part of young leaves of the plants at 0.5 mM Cd showed paling, which gradually became more intense and spread downward covering the entire lamina. At maturity the growth of plant was completely checked, lower leaves dried and withered. Excess Cd delayed flowering, reduced number, length and weight of pods and total biomass as compared to plants without Cd. The cadmium concentration in different plant parts increased with an increase in Cd supply. In young leaves of cluster bean, the concentration of chlorophylls and carotenoids, relative water content and soluble protein content decreased with an increase in Cd supply. The activities of catalase, acid phosphatase and ribonuclease decreased and that of peroxidase increased in leaves as Cd supply increased from 0.01

Plate 12. Cadmium toxicity in Guar

1.12. Pigeon Pea Metabolism as Influenced by Excess Cobalt

To study the tolerance limit of cobalt in pigeon pea (*Cajanus cajan* Mill) cv. Upas, 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 six graded levels of Co viz. 0.0001, 0.01, 0.05, 0.1, 0.2 and 0.4 mM as cobalt sulphate with three replicates in each treatment. The plants were examined periodically for visible foliar symptoms and changes in growth parameters (Plate 13). Biomass and concentration of Co in different parts of pigeon pea were determined at d 60 (30 days after treatment). Plants of pigeon pea treated with excess Co (> 0.0001 mM) had lower biomass, pod yield, concentration of chlorophylls, carotenoids, MDA content and activities of SOD and protease on leaves of pigeon pea (Table 1.12 and Table 1.16). Plants treated with excess Co had increased activity of POD, CAT and APOD in leaves with a significant accumulation in proline and cysteine content. The Co concentration in different plant parts increased with an increase in Co supply from 0.0001 to 0.4 mM.

Table 1.15. Excess cobalt and dry matter, ion leakage and cobalt concentration in different parts of pigeon pea at d 60 (30 days after treatment).

Plant part	mM Co supply					
	0.0001	0.01	0.05	0.1	0.2	0.4
Dry weight (g plant^{-1})						
At 30 DAS	2.34	1.99	1.95	1.33	1.34	1.32
At 60 DAS	9.97	6.08	5.70	3.45	3.32	2.30
Cobalt concentration (µg g^{-1} dry matter) at 60 DAS						
Seeds	7.6	8.5	---	---	---	---
Leaves	2.0	39.7	61.0	84.7	145.0	261.0
Stem	4.5	28.9	48.4	100.0	222.0	429.0
Roots	9.4	105.0	124.0	318.0	847.0	951.0
Ion leakage (%)	3.4	4.4	5.3	6.5	6.8	7.6

Table. 1.16. Excess cobalt and concentration of chloroplastic pigments, cysteine, MDA and specific activity of certain enzymes in pigeon pea leaves.

Biochemical parameter	mM Co supply rates					
	0.0001	0.01	0.05	0.1	0.2	0.4
Chlorophyll a (mg g^{-1} fresh weight)	2.406	2.256	1.450	1.233	0.977	0.923
Chlorophyll b (mg g^{-1} fresh weight)	0.748	0.692	0.353	0.265	0.211	0.186
Catalase(µmoles H_2O_2 decomposed)	1132	1644	1689	1906	1939	1944
Peroxidase (Change O.D.)	5.28	6.88	7.05	8.76	10.76	14.05
Superoxide dismutase (EU)	10.4	9.12	9.33	5.42	4.43	2.06
Protease (µg peptide fragments)	11.25	11.56	9.79	8.64	7.19	5.62

1.13. Changes in Metabolism of Pigeon Pea under Nickel Stress

Pigeon pea (*Cajanus cajan* Mill) cv. Upas, plants were grown in purified sand with complete nutrient solution (0.0001 mM $NiSO_4$) for 35 days. On day 36, pots with plants were separated into six sets and Ni as nickel sulphate was supplied at graded levels viz. 0.0001, 0.01, 0.05, 0.1, 0.2 and 0.4 mM Pigeon pea plants subjected to Ni stress (> 0.05 mM) developed characteristic foliar symptoms of Ni toxicity after 7 days of treatment as interveinal chlorosis followed by development of necrotic areas along veins in young leaves, apart from

Plate13. Cobalt toxicity in pigeon pea

depression in growth (Plate 14). Excess supply of Ni from 0.1 to 0.4 mM reduced biomass, economic yield, photosynthetic pigments (chl a and b), MDA contents and activities of catalase, peroxidase and protease in leaves. Leaves at excess Ni showed increase in the electrolyte leakage, carotenoid, proline and cysteine contents and activities of superoxide dismutase and ascorbate peroxidase in leaves of pigeon pea with an increase in Ni supply. The effects of excess Ni were more pronounced at 0.2 and 0.4 mM Ni supply and accumulation of Ni was more in roots than in stem and leaves. Pigeon pea appeared to be very susceptible to Ni toxicity as the development of flowers and pods was totally inhibited at levels above 0.05 mM Ni supply.

Plate14. Nickel toxicity in pigeon pea

1.14 Phytotoxicity of cadmium and induced metabolic changes in pigeon pea

Visible effects of excess Cd in pigeon pea initiated after 3 days of metal supply at 0.5 mM Cd as growth depression, initiation of chlorosis from apex and margins of the old leaf lamina(Plate 15.). Later, lower part of stem developed black spots, and in leaves chlorotic spots became necrotic and increased in size, coalesced and a major portion of lamina turned necrotic and withered. Only some distorted and rudimentary leaves were left at the top at 0.5 mM Cd supply where the symptoms were most severe. Owing to excess Cd dry weight of plants decreased markedly and Cd concentration increased in leaves, stem and roots with an increase in Cd supply.

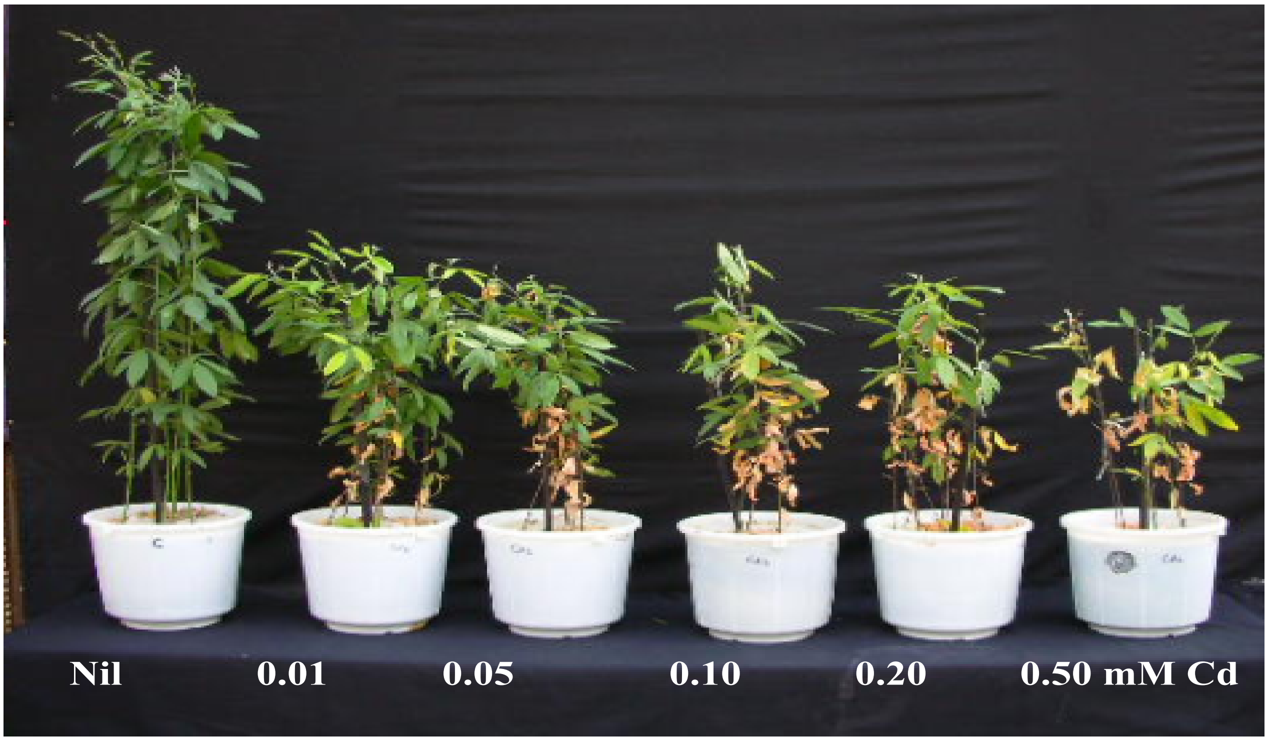


Plate 15. Effect of excess Cadmium supply on in pigeon pea growth

1.15. Response of pigeon pea to excess chromium

Pigeon pea (*Cajanus cajan* Mill) var. Upas plants were grown from seeds in purified silica sand in polyethylene pots and were supplied with complete nutrient solution. Thirty five days after sowing, when sufficient growth had taken place, plants were supplied with complete nutrient solution along with Cr as chromium dichromate at nil (control), 0.01, 0.05, 0.1, 0.15 and 0.2 mM Cr. The study was made of visible effects of excess chromium, biomass, yield and concentration of Cr in different plant parts of pigeon pea at two stages of growth d 70 and 140 i.e. 35 and 105 days after metal supply (DAMS). Pigeon pea plants grown at excess Cr (> 0.1 mM Cr) showed adverse effects on plants such as chlorosis and wilting of old leaves (Plate 16). Later these leaves turned golden yellow and collapsed. Compared to control plants (nil Cr), where yield of plants was maximum, excess Cr reduced dry matter, seed yield and seed protein content (Table 1.17). The concentration of Cr increased in leaves, stem and roots with an increase in Cr supply. Apart from this the concentration of chloroplast pigments and activity of catalase decreased and that of peroxidase increased along with increase in proline and MDA contents in leaves with an increase in Cr levels from 0.05 to 0.2 mM.

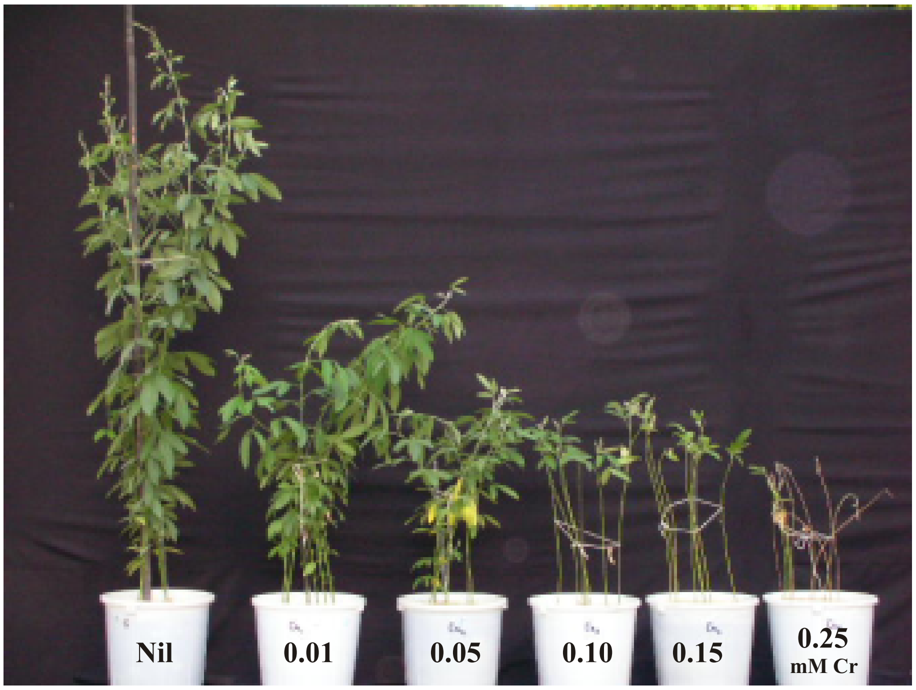


Plate 16. Effect of Chromium levels on pigeon pea growth

Table 1.17. Influence of variable chromium on dry matter, economic yield and seed protein of pigeon pea.

Plant Part	mM Cr supply rates					
	Control	0.01	0.05	0.1	0.15	0.2
Dry matter (g plant^{-1}) 35 DAMS or 70 DAS						
Leaves	2.04	2.57	0.92	0.25	0.12	0.11
Stem	1.79	2.38	0.69	0.56	0.44	0.45
Roots	0.33	0.33	0.21	0.20	0.11	0.08
Whole plant	4.16	5.28	1.83	1.01	0.66	0.62
Dry matter (g plant^{-1}) 105 DAMS or 140 DAS						
Pods	15.09	14.31	5.08	1.03	---	---
Y.L	4.12	2.60	1.71	0.84	---	---
O.L.	5.11	2.63	2.01	0.81	---	---
Stem	5.09	4.56	3.69	1.98	---	---
Roots	0.36	0.35	0.25	0.23	---	---
Whole Plant	29.77	26.09	20.70	4.89	---	---
Number of pods plant^{-1}	21	38	20	7	---	---
Weight of seeds (g plant^{-1})	13.46	10.23	3.36	0.36	---	---
Seed protein % (fresh weight basis)	21.6	21.0	19.7	---	---	---

DAMS = Days after metal supply

1.16 Effect of Lead Toxicity in Pigeon Pea

Pigeon pea (*Cajanus cajan* Mill) cv. Upas was grown in refined sand in 5 L polyethylene pots. Each pot was provided with a free drainage hole to leach out excess nutrient solution, which was applied daily. The plants received a supply of complete nutrient solution soon after the emergence of seedlings upto 27 days. Lead (as $Pb(NO_3)_2$) was superimposed on the complete nutrient solution from d 28 at six levels: Nil (control), 0.05, 0.1, 0.2, 0.4 and 1.0 mM.

Compared to the control plants (Nil Pb supply), pigeon pea plants supplied with excess Pb (from 0.40 to 1.0 mM) showed reduction in growth, branching and number of leaves. The visible symptoms of excess Pb were marked at 30 DAMS only at 1 mM Pb as discolouration followed by development of red pigmentation in major veins and surrounding areas in older leaves. Flowering at > 0.2 mM Pb was delayed by one week and petals showed red colour in major veins which became more prominent after anthesis as compared to yellow colour of veins in petals of control plants (Plate 18). An increase in Pb supply from nil (control) to 1.0 mM Pb, decreased the total dry weight, pod and seed weight of plant and increased the Pb concentration in all parts of pigeon pea (Table 1.18). Maximum accumulation of lead was in roots followed by stem and leaves (27 DAMS) irrespective of Pb supply (Table 1.19). Seeds contained lesser amount of Pb than leaves at 110 DAMS. Chlorophyll and carotenoid contents in leaves were induced to a maximum at 0.05 mM Pb and decreased with further increase in Pb supply. At 1.0 mM Pb, the specific activities of antioxidant enzymes: peroxidase and superoxide dismutase in leaves were increased approximately 3 times of that of control plants. The concentration of non-enzymatic antioxidants, cystein, NPSH and proline were maximum at 1.0 mM Pb and accumulation of NPSH was more in roots than leaves at all levels of Pb supply.

Control (normal Pb supply)

Excess (1.0 mM Pb) supply-toxicity

Plate 17. Lead toxicity in pigeon pea flowers

Table 1.18. Dry weight of different plant parts of pigeon pea at variable Pb supply

Plant Part	DAS/ DAMS	mM Pb supply					
		Nil (Control)	0.05	0.1	0.2	0.4	1.0
		g dry weight $plant^{-1}$					
Leaves	40/13	0.480	0.383	0.366	0.358	0.382	0.338
Stem		0.264	0.209	0.194	0.178	0.145	0.168
Roots		0.046	0.047	0.040	0.036	0.036	0.021
Whole plant		0.790	0.639	0.600	0.572	0.563	0.527
Leaves	54/27	2.09	2.06	2.07	1.84	1.62	1.47
Stem		1.65	1.38	1.08	1.10	0.98	1.05
Roots		0.28	0.35	0.23	0.21	0.20	0.16
Whole plant		4.02	3.78	3.37	3.14	2.80	2.67
Pods	137/110	21.12	20.91	20.61	19.79	19.12	19.03
Leaves		7.26	6.50	6.62	6.39	4.55	3.51
Stem		11.70	10.71	9.53	7.67	7.80	6.65
Roots		1.98	1.60	1.76	1.31	1.22	1.16
Whole plant		42.06	39.71	38.52	35.15	32.69	30.35

Table 1.19. Seed yield and total protein content and tissue Pb concentration in seeds of pigeon pea at variable Pb supply

Plant Part	mM Pb supply					
	Nil (Control)	0.05	0.1	0.2	0.4	1.0
Seeds yield (g $plant^{-1}$)	15.15	14.81	14.61	14.49	13.47	12.85
Protein (g 100 $seeds^{-1}$)	9.21	9.16	9.16	9.21	9.16	8.68
Concentration (mg kg^{-1})	31.6	31.5	31.0	27.3	24.0	20.1

1.17 Effectiveness of Foliar Boron Spray for Enhancement of Seed Yield and Quality in Green Gram Grown under Boron Deficiency

Green gram (*Vigna radiata* L. cv. PDM 39) was grown in refined sand at low (0.0066mg B l^{-1-}) and adequate (0.33 mg B l^{-1-}) boron. Plants supplied with low B were sprayed with 0.01% borax (10 ppm) at 4 different stages. The treatments were: (i) control (0.33 mg B l^{-1}), (ii) low B (0.0066 mg B l^{-1}), (iii) low B + one spray of B (0.01 % borax) at 3-4 leaf stages, (iv) low B + 2 sprays of B one at 3-4 leaf stage and another at pre flowering stage (d 28), (v) low B + 3 sprays of B: two sprays as above and the third at the time of flowering (d 38), (vi) low B + 4 sprays of B: three as above and the fourth at d 46, during pod filling stage.

The growth of plants at low B was highly reduced and plants developed B deficiency symptoms. Low B plants sprayed with 10 ppm B at different stages improved growth and yield of green gram depending (Ptate 18) upon number of sprays. Compared to low B, the foliar sprays of B increased the dry matter, pod and seed yield, fruiting efficiency, concentration of B in leaves and seeds as well as quality of seeds which was evident from the increase in the concentration of protein, sugars and starch and decrease in the concentration of phenols depending on number of foliar B sprays. The improvement in these parameters was greater after3-4 foliar sprays of B as compared to 1-2 foliar sprays but the total seed weight and 100 seed weight were maximum after 3 foliar sprays of B.

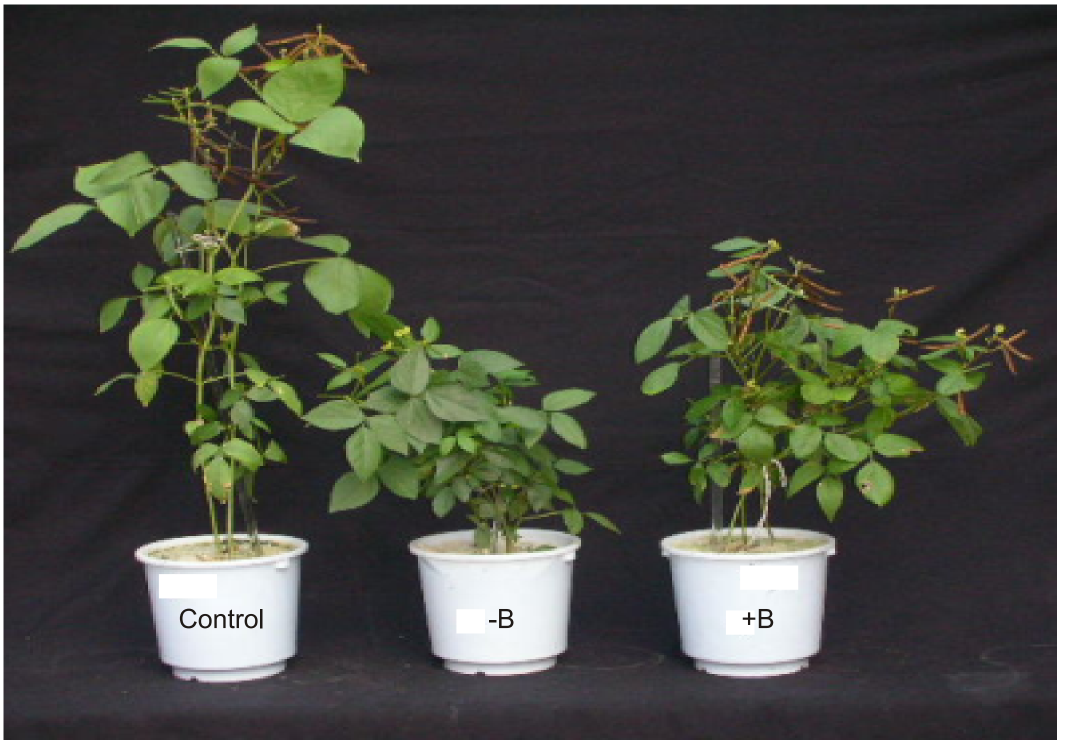


Plate 18. Effect of boron spray on green gram

1.18 Effect of Cu Stress and Toxicity on Different Rice Cultivars

An experiment was conducted at Lucknow with five varieties of rice (*Oryza sativa* L.) Moti, Garima, MTV-7029, PRH-10 and Saurabh NP-950 at three Cu levels 0.0065 (deficient), 0.065 (adequate) and 6.5 mg l^{-1} Cu (excess) supply till maturity. Plants were harvested at d 22, 44 and 146 for total biomass and seed yield at harvest (d 146). Young fully expanded leaves were sampled at d 42 for chloroplast pigments such as chlorophyll 'a', 'b' and carotenoids and Hill reaction activity.

Compared to adequate Cu, growth of all five varieties of rice was poor at deficient (0.0065 mg l^{-1}) and excess (6.5 mg l^{-1}) Cu supply (Plate 19). At deficient Cu, leaves became thin, needle-like and rolled in and developed flaccid areas in the middle part of lamina. This was followed by rolling of youngest leaves which failed to emerge and gave hook like appearance. Cu deficiency symptoms were more marked in var. Moti and Garima as compared to MTV-7029, PRH-10 and Saurabh NP-950. Plants at excess Cu developed interveinal chlorosis of young leaves at d 20, intensified in due course and later on young emerging leaves were completely bleached. The effects of Cu excess were more marked in variety Garima as compared to var. Moti, MTV-7029, PRH-10 and Saurabh NP-950

Both deficient and excess Cu decreased plant height, panicle number, biomass, grain yield, chloroplast pigments and altered specific activities of peroxidase, catalase and superoxide dismutase in almost all the varieties. On the basis of these parameters varieties Moti, Garima and MTV-7029 appeared to be susceptible whereas varieties Saurabh NP-950 and PRH-10 appeared relatively tolerant.

Plate 19 Cu stress and toxicity in rice cultivars

1.19. Effect of Variable Rates of Mn on Yield and Quality of Black Gram

Black gram (*Vigna mungo* L.) cv. PU 19 was grown in refined sand at six Mn levels viz., 0.0055, 0.055, 0.11, 0.55, 55 and 110 mg Mn l^{-1} in culture till maturity. Plants subjected to Mn deficiency showed interveinal chlorosis and necrosis on young mature leaves and Mn toxicity symptoms appeared as reddish brown spots along veins and margins of old leaves. Both deficiency and excess of Mn (< 0.55 mg Mn l^{-1} >) reduced dry matter and economic yield (pod and seed weight) of black gram. Maximum dry matter of black gram at both the stages (d 35 and 70) of growth was obtained at 0.55 mg Mn l^{-1}. Compared to this, the decrease in dry weight was greater at excess (110 mg Mn l^{-1}) than at deficient (0.0055 mg Mn l^{-1}) Mn supply at d 70.

The pod yield as well as seed weight increased with an increase in Mn supply from 0.0055 to 0.55 mg Mn l^{-1}. Further increase in Mn supply from 0.55 to 110 mg Mn l^{-1} drastically reduced the pod and seed weight of black gram. (Table 1.20). The decrease in seed weight was 63% at 0.0055 (low) mg Mn l^{-1} and 45% at 110 (excess) mg Mn l^{-1} as compared to the plants supplied with adequate Mn (0.55 mg Mn l^{-1}).

The critical values of deficiency, threshold of deficiency, threshold of toxicity and toxicity respectively were 20, 30, 250, 380 µg Mn g^{-1} in young leaves, 30, 40, 300, 480 µg Mn g^{-1} in old leaves and 15, 20, 65 and 100 µg Mn g^{-1} dry matter in seeds. In black gram 60-150 µg Mn g^{-1} in young leaves, 80-180 µg Mn g^{-1} in old leaves and 30-45 µg Mn g^{-1} dry matter in seeds represented adequacy of Mn. Mn deficiency lowered the black gram yield as well as seed quality, as decrease in total sugars, starch, total protein, albumin and globulin and increase in that of phenols(Table 1.20). The concentration of sugars, phenols and globulin increased while that of starch, total protein and albumin decreased in seeds at 110 mg Mn l^{-1}.

Table 1.20. Effect of variable level of manganese on economic yield, and concentration of Mn in leaves and seeds of black gram and biochemical parameters

Parameters	**mg Mn l^{1}**					
	0.0055	**0.055**	**0.11**	**0.55**	**55**	**110**
Total seed weight: g plant^{-1}	1.03	1.80	2.20	2.80	2.27	1.55
Mn concentration (μg g^{-1} dry matter) at 70 DAS						
Young leaves	12.2	20.7	41.8	110.2	313	448
Old leaves:	19.0	24.9	49.5	125.2	451	609
Seed	10.2	18.7	24.6	33.5	59.9	108.8
Husk:	20.2	27.1	33.1	38.4	235.8	293.6
Biochemical parameters						
Reducing sugars (% fresh weight)	0.03	0.028	0.020	0.025	0.040	0.075
Non reducing sugar (% fresh weight)	0.20	0.230	0.270	0.275	0.320	0.280
Protein	15.02	18.37	18.80	20.10	21.90	19.50

1.21. Determination of Deficiency, Threshold of Deficiency, Adequate Conc. Threshold Toxicity and Toxicity in Various Crop Plants

Lucknow centre established deficiency, threshold of deficiency, adequate conc. threshold toxicity and toxicity of micro and pollutant elements in various crop plants (Table 21)

Table 1.21 Critical concentration of micro and pollutant elements in different crop plants

crop	**Element**	**Plant part**	**Days growth**	**Micro and secondary nutrients/**				
				deficiency	**Threshold of deficiency**	**Adequate conc.**	**Threshold toxicity**	**toxicity**
Cucumber	Cu	Leaves	70	5.4	10	25-40	95	160
Mustard	Co	Young Leaves	46			< 2.0	44	92
		Seed	92			< 10.0	45	170
	Cd	Young Leaves	48			< 15.0	45	140
	Cr	Old Leaves	46			< 0.6	1.8	20
Cluster bean	Cd	Leaves	87			< 2.0	6.6	30
		Seeds				< 0.8	3.2	12
Black gram	B	Leaves	62	15	25	<60-110	250	400
Pigeon pea	Co	Leaves	40			< 10.0	75	160
	Cd	Leaves	38			< 3.0	22	96
	Ni	Leaves	65			< 40.0	90	190
	Cr	Leaves	35			< 40.0	110	320
	Pb	Leaves	137			< 12.0	27	56
		Seeds				< 14.0	28	-
Cucumber	Cu	Leaves	70	5.4	10	25-40	95	160

CHAPTER –II

DELINEATION OF MICRO- AND SECONDARY NUTRIENTS DEFICIENT AREAS

2.1 Micro- and Secondary Nutrient 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 for enhancing crop production. During the period under report, the centres of AICRP on Micronutrients collected 15090 surface soil samples, analyzed for available Zn, Cu, Fe and Mn using DTPA method (Lindsay and Norvell, 1978) covering Andhra Pradesh, Bihar, Gujarat, Punjab, Haryana, Madhya Pradesh, Tamil Nadu, Odisha, Maharashtra and Uttar Pradesh. Similarly, 8051 surface soil samples were collected from Tamil Nadu, Haryana, Punjab, Madhya Pradesh, Bihar, Odisha and Maharashtra Assam and West Bengal and analyzed for available B using hot water extraction method. For analysis of available molybdenum (using acid ammonium oxalate method) about 1031 surface soil samples were collected from Maharashtra state and analyzed. Available sulphur (extracted with 0.15% $CaCl_2 2H_2O$ solution) content was assessed in 6150 surface soil samples collected from states like Haryana, Madhya Pradesh, Bihar, Odisha, Uttar Pradesh and Tamil Nadu. Analysis of soil samples revealed that about 42.14, 13.73, 16.11, 7.0, 17.02, 4.0 and 25.2% soil samples were deficient in Zn, Cu, Fe, Mn, B, Mo and S respectively (Table 2.1)

Table 2.1 Extent of micro- and secondary nutrient deficiency in various states during the period under report

Elements	No. of samples analyzed	PSD*
Zn	15090	42.15
Cu	15090	13.73
Fe	15095	16.11
Mn	15090	7.00
B	8548	17.02
Mo	1031	4.00
S	6150	25.22

* PSD = per cent sample deficient

2.1.1 Deficiency of Cationic Micronutrients

During the period under report 15090 surface soil samples were collected by different centre of project for estimation of available Zn, Cu, Fe and Mn. The DTPA extractable Zn varied form 0.01-151 mg kg^{-1} with mean value of 1.21 mg kg^{-1} (Table 2.2). However the per cent sample deficiency ranged from 3.40 to 74.98 with mean value of 42.14. Available Cu, Fe and Mn concentration spanned from 0.01-92.16, 0.05-454 and 0.05-321 mg kg^{-1} respectively with mean value of 3.71, 18.46 and 13 mg kg^{-1}. Per cent of sample deficient in Cu, Fe and Mn in various states varied from 0 to 35. 74 (with mean value of 13.73), 0 to 32.76 (with mean value of 16.11) and 0 to 17.14 (with mean value of 7.00) respectively.

Reassessment of deficiency status of revealed that Zn, Fe, Mn and Cu deficiency in Indian soils changed from was 49, 12, 4 and 3 %, respectively to 44, 15, 6 and 8 %, respectively (Figure 2.1, 2.2, 2.3, 2.4). Zn deficiency is declining in the states of Punjab, Haryana, Uttar Pradesh and Andhra Pradesh due to regular application of Zn fertilizers in these states. But Mn deficiency is emerging very fast, particularly in wheat crops

Table 2.2 Extent of cationic micronutrient deficiency in soils of various states

State	No. of Samples	Available Zn			Available Cu			Available Fe			Available Mn		
		Range (mg kg^{-1})	Mean (mg kg^{-1})	PSD	Range (mg kg^{-1})	Mean (mg kg^{-1})	PSD	Range (mg kg^{-1})	Mean (mg kg^{-1})	PSD	Range (mg kg^{-1})	Mean (mg kg^{-1})	PSD
Andhra Pradesh	245	0.33-13.63	1.41	13.52	1.0-20.99	3.84	0.00	4.6-128	33.54	2.86	4.32-321	35.66	0.00
Assam	1638	0.10-1.89	0.71	25	0.10-10.8	2.54	0.60	8.77-168	47.3	0	2.28-54.4	10.3	0
Bihar	1351	0.10-5.00	1.04	36.19	0.46-80.0	4.50	0.47	1.60-64.5	25.30	2.27	0.91-64.78	12.08	2.55
Gujarat	544	0.28-17.38	1.64	25.00	0.16-8.50	2.17	0.00	1.36-57.76	12.43	9.00	1.33-53.7	16.80	0.00
Haryana	1212	-	1.73	11.06	-	1.41	0.41	-	16.98	4.48	-	11.60	2.01
Madhya Pradesh	906	0.02-151	0.97	42.23	0.09-22.67	3.74	3.11	0.50-113	31.75	13.82	0.68-64.9	21.87	5.32
Maharashtra	1508	0.16-14.2	2.01	28.84	0.08-24.4	4.41	7.03	0.24-122	14.15	16.21	0.36-182.4	25.46	3.67
Odisha	373	-	2.13	10.06	-	1.21	0.00	-	16.20	4.33	-	15.80	0.00
Punjab	931	0.26-95	2.03	14.26	0.06-3.78	1.06	3.54	0.08-44.8	13.60	17.59	0.68-41.62	8.11	17.14
Tamil Nadu	5260	0.01-8.0	0.85	74.98	0.01-92.16	4.83	35.74	.05-72.31	15.91	32.76	0.05-72.31	6.75	13.91
Uttar Pradesh	625	0.11-5.71	1.05	33.4	0.042-4.38	1.29	0.63	0.35-40.0	23.77	2.88	0.35-50.5	22.88	0.64
West Bengal	497	0.03-13.16	1.40	3.4	0.06-18.45	8.54	0	6.64-454	194.15	0	3.52-20	33.5	0
Total/average	**15090**	**0.01-151**	**1.21**	**42.14**	**0.01-92.16**	**3.71**	**13.73**	**0.05-454.0**	**25.75**	**16.11**	**0.05-321**	**13.50**	**7.0**

grown after rice in Haryana and Punjab (Figure 2.5). Multi-nutrient deficiencies are now becoming an emerging problem and deficiencies like Zn and B, Zn and Fe, and Zn and Mn are increasing and leading to stagnation or a decline in productivity (Figure 2.6).

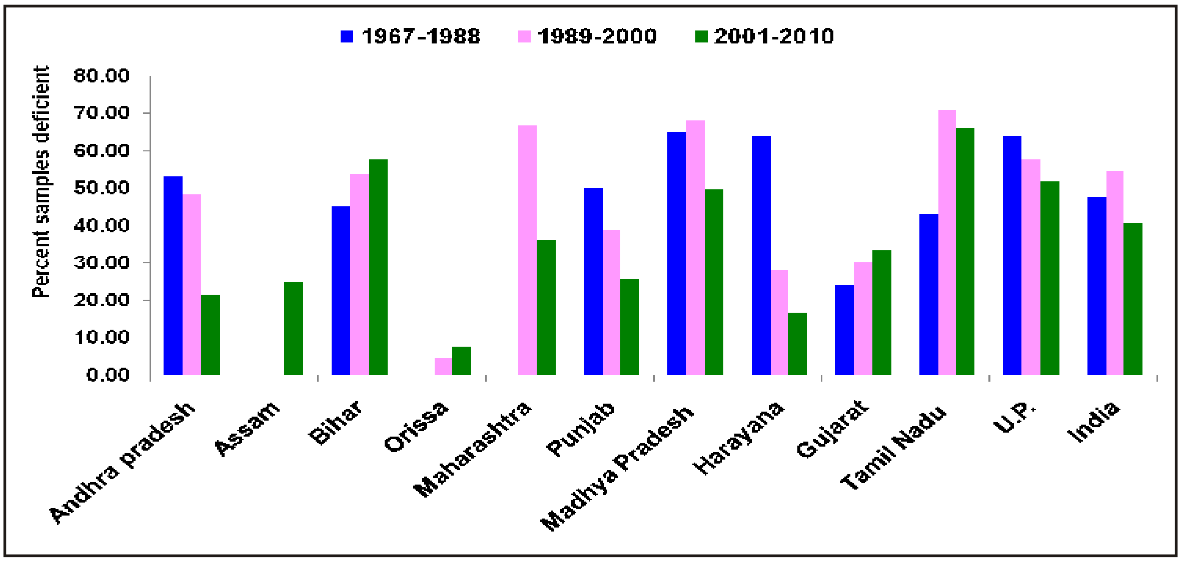


Figure 2.1 Trends of Zn deficiency in different states of India

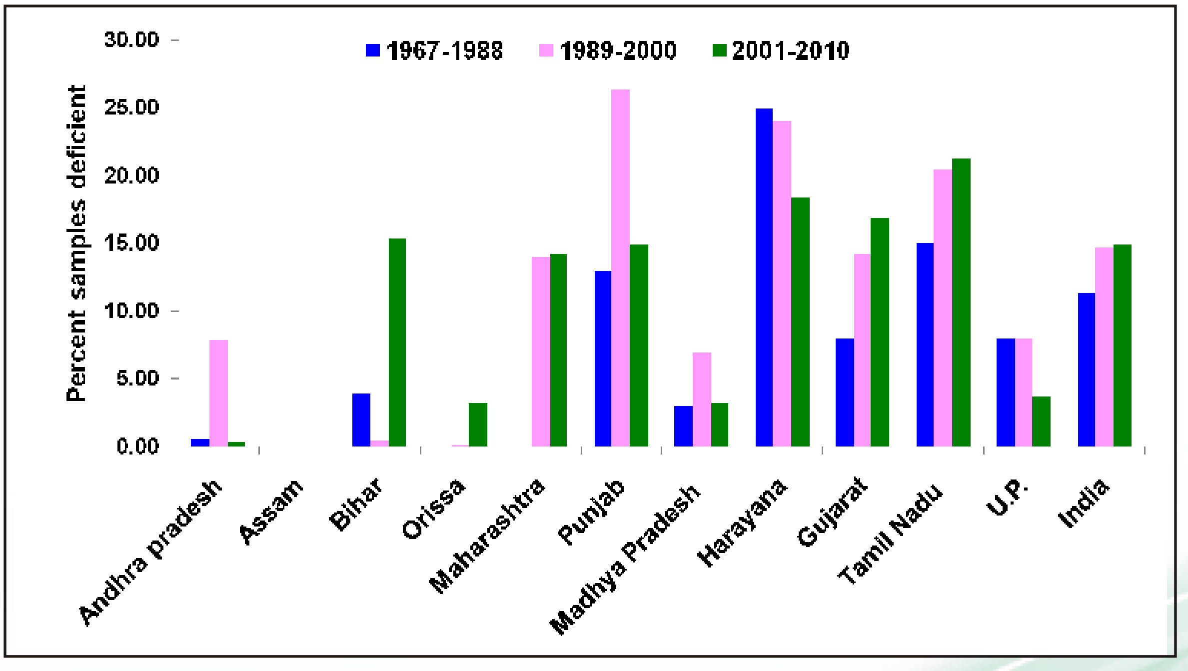


Figure 2.2 Trends of Fe deficiency in different states of India

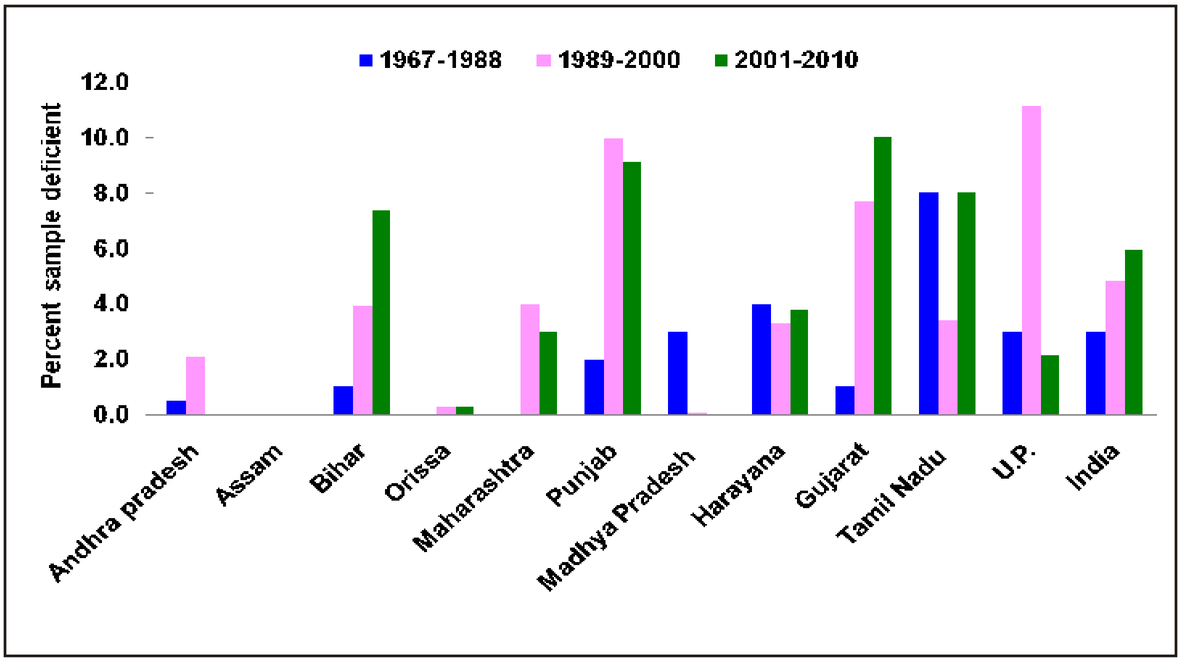


Figure 2.3 Trends of Mn deficiency in different states of India

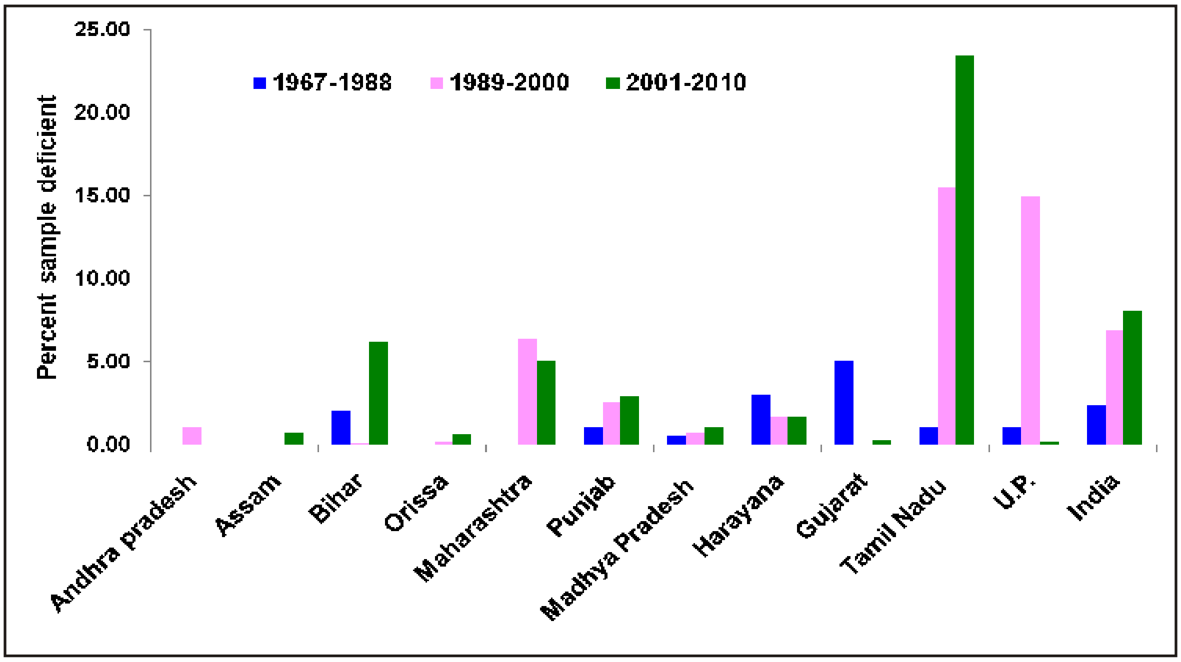


Figure 2.4 Trends of Cu deficiency in different states of India

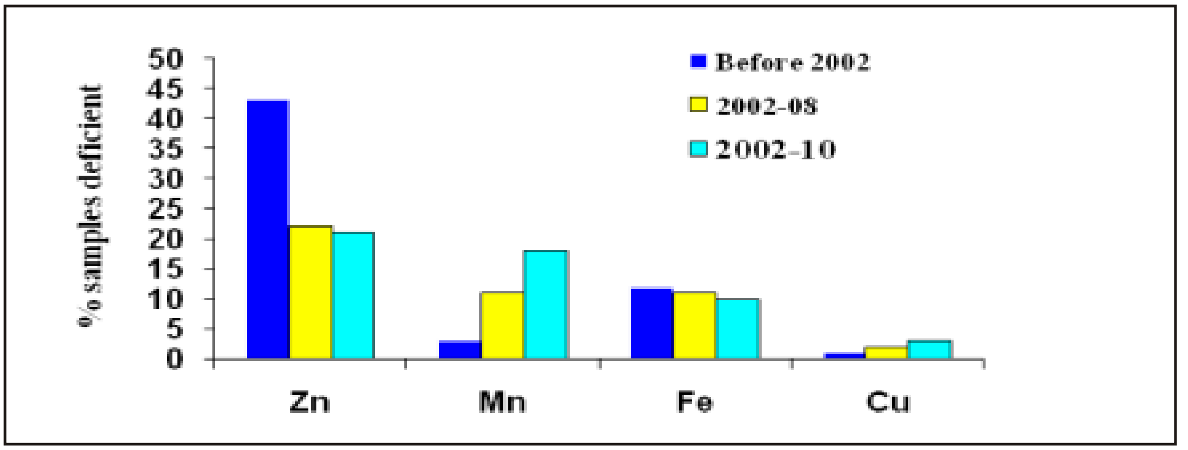


Figure 2.5 Temporal changes in and Mn deficiencies soils of Punjab

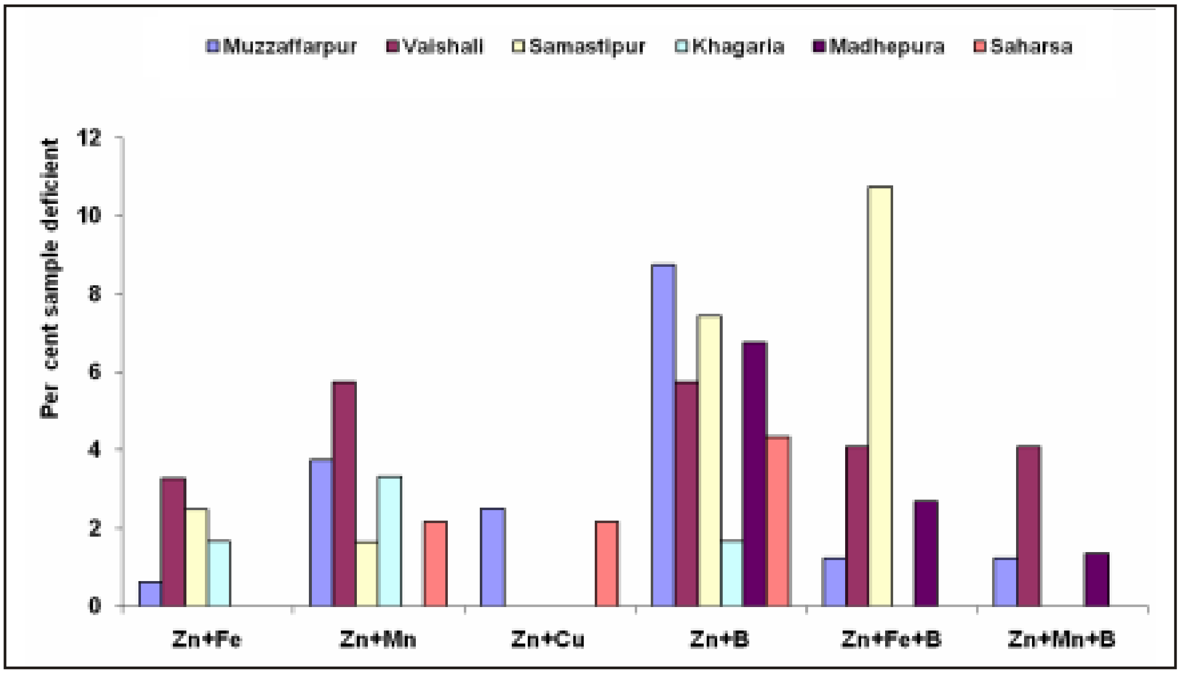


Figure 2.6 Multiple micronutrient deficiencies in different districts of Bihar

2.1.2 Deficiency of Boron and Molybdenum

Analysis of 8548 surface samples collected from different sates of the country during report period revealed that the concentration of available B spanned from 0.01 to 12.7 mg kg^{-1} with mean value of 1.29 mg kg^{-1} (Table 2.3). However, the per cent sample deficient in available b varied from 0.83 to 43.4 with mean value of 17.0. Higher deficiency per cent was reported in Odisha, West Bengal and Bihar and lowest in Madhya Pradesh. Akola centre of the project collected 1030 soil samples from various districts of Maharashtra and analyzed for available Mo. The concentration of available Mo varied from 0.02 to 2.40 mg kg^{-1} with mean value of 0.46 mg kg^{-1}. About 4 per cent soil samples were found to be deficient in Mo. Highghest Mo deficiency was found in Gadchiroli district followed by Ahmednagar and Yavatmal districts.

Table 2.3 Extent of Boron deficiency in soils of various states

State	No. of Samples	B		
		Range (mg kg^{-1})	Mean(mg kg^{-1})	PSD
Tamil Nadu	3375	0.01-5.52	1.64	8.43
Haryana	738		1.46	2.96
Punjab	374	0.36-5.12	1.55	17.25
Madhya Pradesh	505	0.20-12.7	2.10	0.83
Bihar	1273	0.03-5.60	0.65	42.47
Gujarat	544	0.40-9.79	1.30	8.44
Odisha	212	0.01-5.98	0.90	43.40
Maharashtra	1030	0.008-4.38	0.77	23.79
West Bengal	497	0.033-2.37	0.67	31.0
Total/average	**8548**	**0.008 12.70**	**1.29**	**17.00**

2.1.3 Deficiency of Sulphur

About 6150 soil samples were collected and analyzed by various centers of the project covering Haryana, Madhya Pradesh, Bihar, Odisha, Uttar Pradesh and Tamil Nadu for available sulphur content. The concentration of avialble S ranged from 0.01 to 493 mg kg-1 with mean value of 43.84 mg kg-1 (Table 2.4). However, the per cent soil sample deficient in S varied from 8 to 43.95 with mean deficiency percent of 25.22. Higher deficiency percentage was reported in Bihar followed by Haryana and Odisha. In Haryana, sulphur deficiency was found maximum in soils of Jhajjar district (52.6%) followed by Ambala (50.0%), Gurgaon (38.8%) and Panchkula (35.5%).

Table 2.4 Extent of Sulphur deficiency in soils of various states

State	No. of Samples	S		
		Range (mgkg^{-1})	Mean (mgkg^{-1})	PSD
Haryana	1212	-	71.59	28.35
Madhya Pradesh	906	1.40-96	18.04	25.16
Bihar	1313	0.06-493	22.81	43.95
Odisha	696	0.01-106.8	22.42	26.88
Uttar Pradesh	225	4.00-248	52	8.00
Tamil Nadu	1798	0.00-458.7	60.78	11.00
Total/average	**6150**	**0.01 493**	**43.84**	**25.22**

2.2 Micronutrient fertility mapping

GPS based soil sampling helps in preparation of the micronutrient fertility maps which are useful for planners and policy makers and other stake holders. Geo- referenced surface soil samples collected by Coimbatore centre from Coimbatore and Tirunelveli districts at block levels for preparation of micronutrient fertility maps (Figure 2.7 and 2.8).The highest Zn deficiency in Sulthanpet (94.7%) and the lowest deficiency of

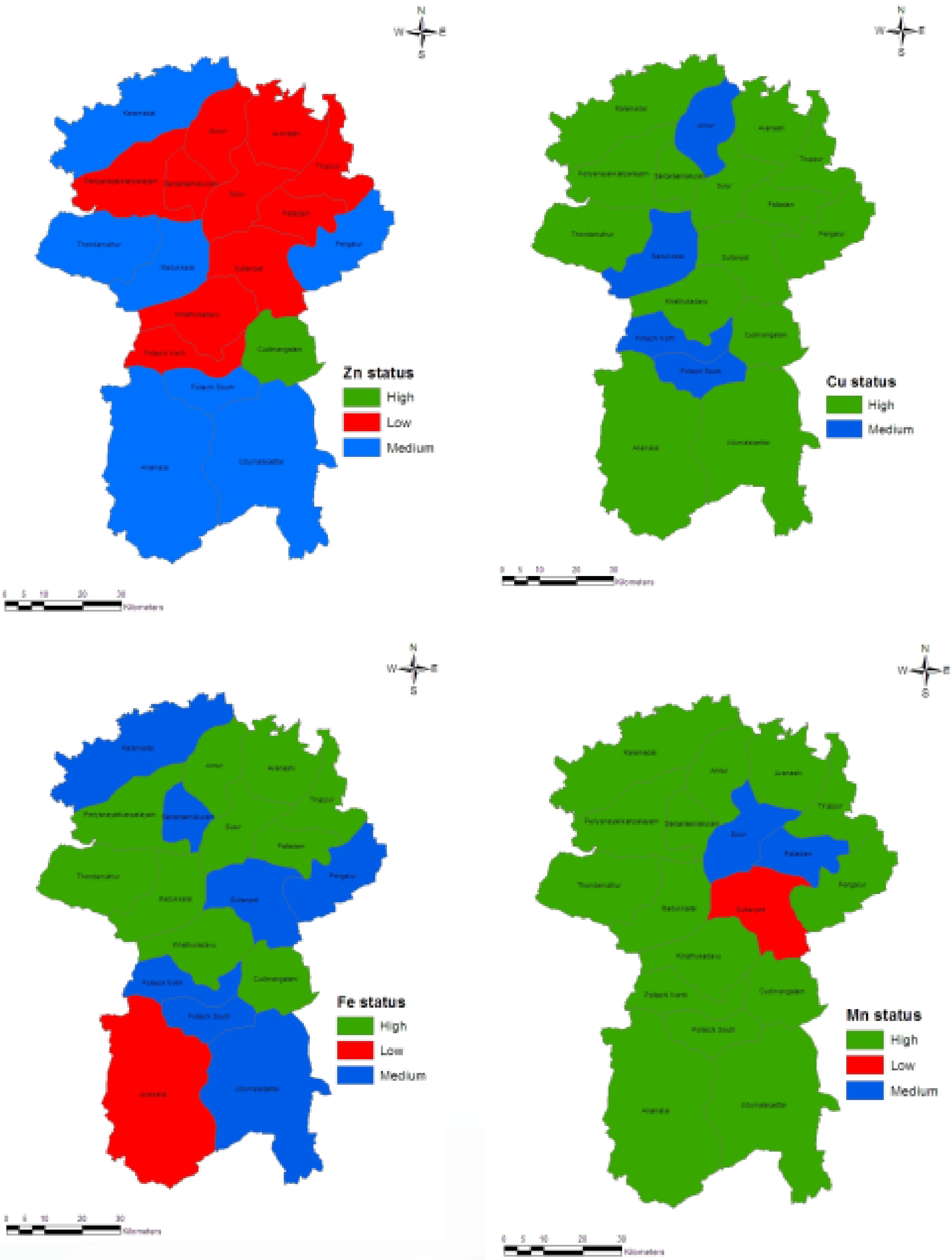


Figure 2.7 Zn, Cu, Fe and Mn fertility maps of Coimbatore district of Tamil Nadu

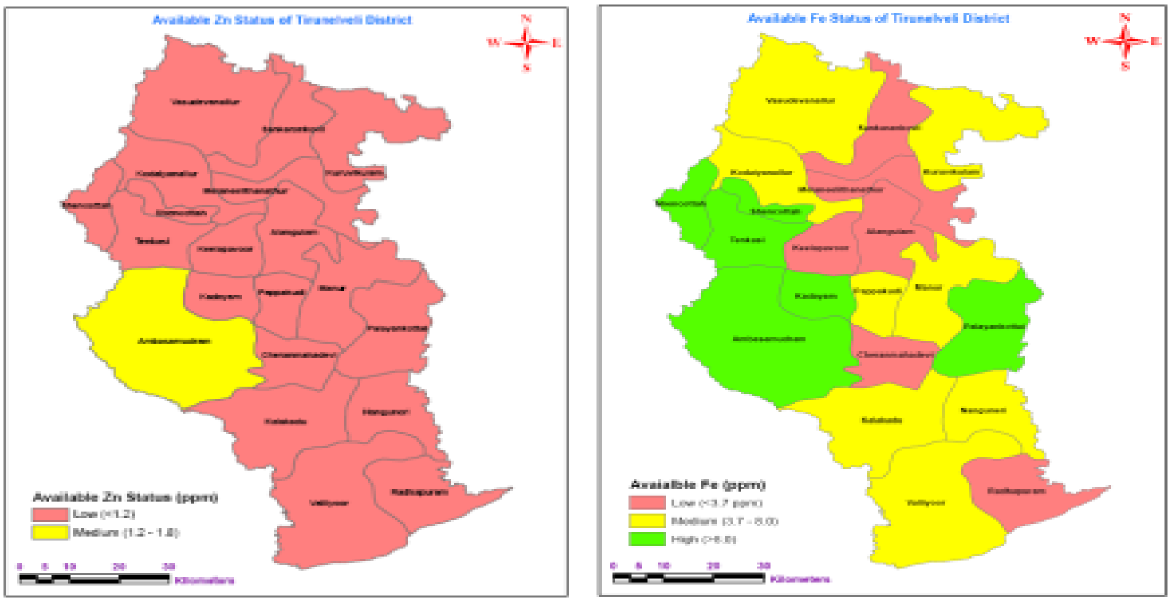


Figure 2.8 Zn, and Fe fertility maps of Tirunelveli district of Tamil Nadu

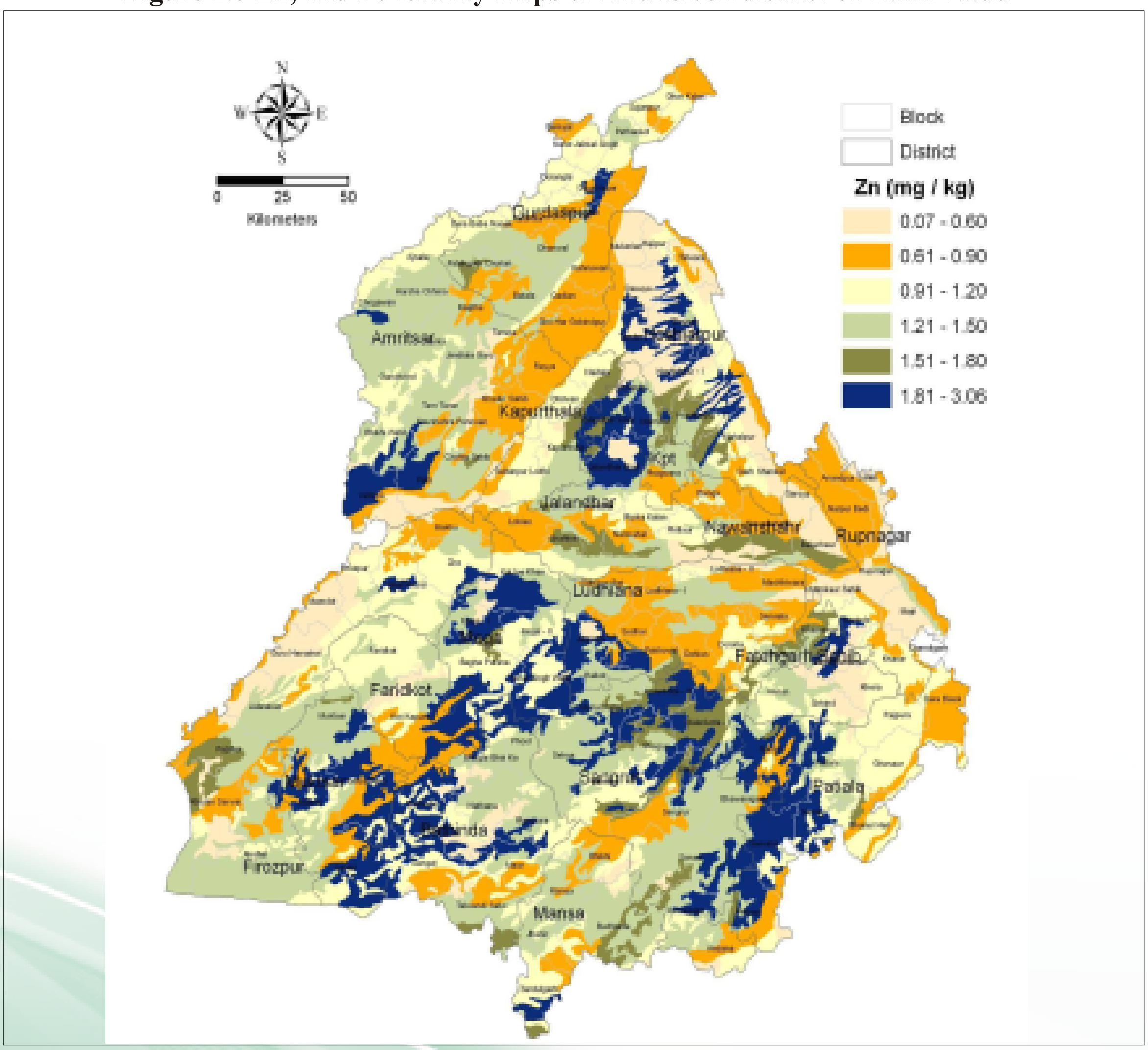


Figure 2.9 DTPA extractable zinc in Punjab Soils

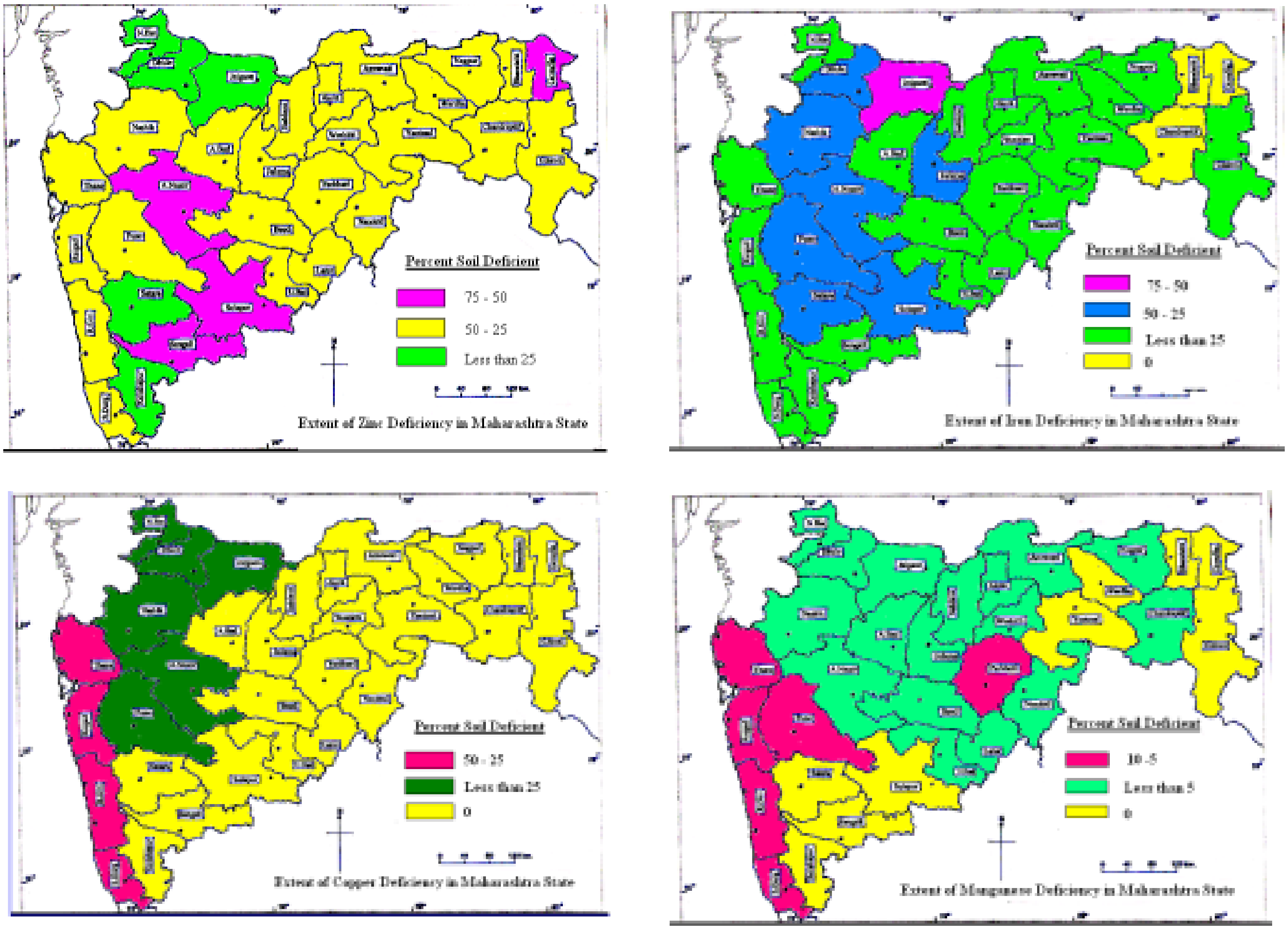


Figure 2.10 Zn, Fe, Cu and Mn fertility maps of Maharashtra

4.60 per cent in Valparai block . The highest Fe, Mn and Cu deficiency was recorded in Udumalpet block (70.5 per cent), Sulthanpet (80.3 per cent) and Madukarai block (83.6 per cent) respectively. The lowest deficiency of Fe, Cu and Zn in Valparai (1.50, 1.50 and 4.60 per cent) and Mn in Madukarai (1.70 per cent) was observed. Comparing the various micronutrients, Zn was predominantly deficient in most of the blocks followed by Cu, Fe and Mn. As a whole, 68.5 per cent Zn, 56.6 per cent Cu, 40.4 per cent Fe and 15.3 per cent Mn deficiency was noted in Coimbatore district. Similarly, Zn status map of Punjab and Zn, Fe, Cu and Mn fertility maps of Maharashtra have been prepared (Figure 2.9 and 2.10). The soils of Maharashtra were found to be deficient in zinc followed by iron, copper and manganese. An area of 379856 ha (39% of total geographical area of Vidarbha region) was suffering from zinc deficiency, 876636 ha (9% of total geographical area) deficient in iron and 487020 ha (5% of total geographical area) found deficient in Manganese & 48702 ha (0.5 % of total geographical area) deficient in copper. The soils of Maharashtra state require zinc fertilization for better crop growth and productivity of crops. Apart from zinc and iron deficiency may cause a nutritional problem in the soils in near future. The maps generated will be useful for guiding the farmers to decide the amount of nutrient to be applied for optimum returns, as the nutrient management will be different for areas having deficiency of one or more nutrients than those having the sufficient nutrients.

2.2 Nutrient Indexing Programme

Nutrient indexing programme carried out under the aegis of All India Coordinated Research Project on Micro- and Secondary Nutrient and Pollutant Elements in Soils and Plants of ICAR at different locations of the country. The continuous cropping of rice-what-sorghum and rice-mustard-moong for 23 years at Pusa, Bihar showed that Zn could be absorbed by 13 to 14 kg ha^{-1} (Table 2.5). Such a huge uptake has led to debacle decline in DTPA available Zn as depicted in Figure 2.11. Zn uptake by rice-rice system at Hyderabad for 10 years varied from 6.28 to 7.16 kg ha^{-1} with productivity level of 5.76 to 6.0 t ha^{-1}. Three crops of sugarcane at Coimbatore could absorb 4.43 kg Zn ha^{-1}.

Table 2.5. Cumulative Zn uptake (kg ha^{-1}) by crops/ cropping sequence adopted in different parts of the country

Sl. No.	Name of the place	Number of cropping year	Cropping sequence	Average grain yield (t ha^{-1})	Cumulative Zn uptake
1.	Pusa (location 1)	23	Rice-Wheat-Sorghum	Rice (3.24) Wheat (2.79) Sorghum (5.88)	14.01
2.	Pusa (location 2)	23	Rice-Mustard-Moong	Rice (3.08) Mustard (0.80) Moong (0.83)	13.30
3.	Ludhiana (location 1)	9	Rice-Wheat	Rice (5.65) Wheat (4.92)	4.64
4.	Ludhiana (location 2)	7	Rice-Wheat	Rice (6.35) Wheat (4.98)	4.15
5.	Hyderabad (location 1)	10	Rice-Rice	Karif Rice (4.68) Rabi Rice (6.83)	6.28
6.	Hyderabad (location 2)	10	Rice-Rice	Karif Rice (5.01) Rabi Rice (7.02)	7.16
7.	Akola	7	Sorghum-Wheat	Sorghum (2.45) Wheat (2.07)	3.80
8.	Coimbatore (location 1)	3	Sugarcane-Sugarcane	Sugarcane (236) Sugarcane (230)	4.43
9.	Coimbatore (location 2)	3	Rice-Rice	Karif Rice (4.44) Rabi Rice (4.45)	1.81

Values in the parentheses indicate average yield in t ha^{-1}

Continuous cropping of rice – rice system and its monitoring over three years in Coimbatore and Erode district of Tamil Nadu revealed that, the farmers use optimal level of P, 15 to 20 per cent excess N and S and 26 per cent less K than the recommended dose of 150 : 50 : 50 : 30 kg NPKS ha^{-1}. Post harvest soil analysis for nutrient depletion and build up showed that, even with continuous addition of fertilizer inputs for each crop, no build up of all major nutrients was observed as compared to initial status. Potassium was depleted heavily (45 %) followed by N (18.8%), P (12.3 %) and S (Negligible). Among the micronutrients, Fe, Mn and Cu were sustained in all locations while Zn and

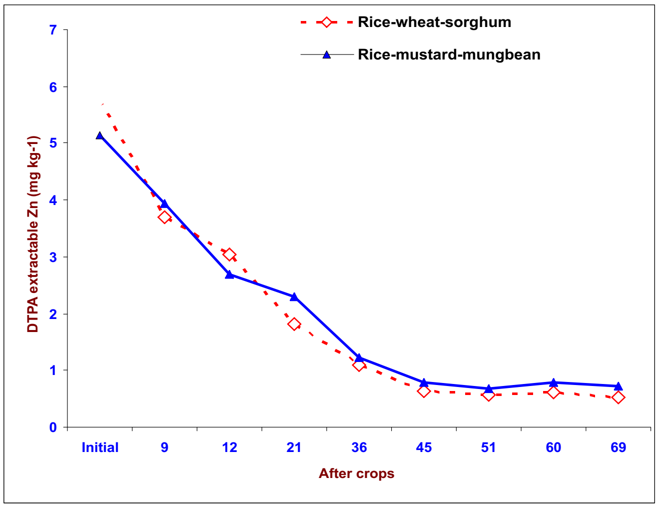


Figure 2.11 Changes in soil DTPA Zn in continuous rice based cropping systems during 23 crop cycles (69 crops)

B were depleted after three years of rice cropping. The crop removal pattern of major nutrients indicated that K was heavily depleted followed by N,P and S. The order of micronutrient removal was Fe > Mn > Zn> Cu > B. Management strategies such as addition of micronutrient mixtures and green manure incorporation enhanced the availability, plant nutrient absorption and removal of all nutrients regardless of soil types. Nutrient balance studies carried out for all 20 sites after three years of rice cropping was found negative for NPK and S regardless of soil type and management strategies adopted. Except B all other micronutrients were found in positive balance in heavy textured Anaimalai and Palladam soil series while in light textured Irugur series, Zn, Cu and B were found in negative balance. The magnitude of negative balance was greater for Zn and B thus warrants careful monitoring and management of Zn and B in soils continuously cropped with rice – rice system.

In case of continuous sugarcane- sugarcane cropping system, heavy depletion of soil nutrient reserves has been recorded. Crop removal pattern indicated that the K is heavily depleted as compared to N and P. The removal pattern of macronutrients was K > N > P. The order of removal for micronutrients was Fe > Mn > B> Zn > Cu. Due to heavy removal of Fe which necessitates the addition of Fe invariably to all fields, whether Fe deficiency is seen in plants or not, to alleviate Fe deficiency in plants or soils. From initial to final harvest of cropping period, soil Fe and Cu were in declining state whereas the potassium, sulphur and zinc were in build up state. The organic carbon content in soil was declined in all the three cropping seasons. The imbalance of nutrients was closely associated with low addition of organic manures and there is a need for continuous addition of organic manures and balanced fertilization in order to maintain a positive nutrient balance and sustain cane production. Non-addition of micronutrients has caused deficiencies of Fe, Zn and Cu in the cropping sequence.The overall data suggest that there is a necessity for the use of balanced dose of both macro and micronutrients by INM practices to enable for maintaining the crop yield and soil fertility on sustainable basis in intensive sugarcane – sugarcane cropping system

CHAPTER –III

RESPONSE OF CROPS TO MICRO AND SECONDARY NUTRIENTS APPLICATION

Fertilizer response trials on research farms or at cultivators fields were conducted to show responses of micro- and secondary nutrient application to oilseeds and pulses crops as well as to assess the likely benefits that can be accrued by the fertilization to crops which have been summarized below.

3.1 Responses of crops to multi micro nutrients at various places

Centers of AICRP on MSPE conducted various front line demonstrations to show response of various crops to multi-micronutrients applications.In Pantnagar, front line demonstrations conducted for correction of multi-nutrient deficiencies on various crops like soybean, chickpea, sesame and mustard revealed that application of 5.0 kg Zn + 40 kg S ha^{-1} increased the grain yield significantly by 17.8 per cent over control. Similarly application of 5.0 kg Zn + 40 kg S /ha increased the gram seed yield significantly by 18 to 36.9 per cent over control (Table 3.1) At another location, application of 5.0 kg Zn + 40 kg S +1.5 kg B + 0.5 kg Mo ha^{-1} increased the grain yield of soybean significantly by 16.8 per cent over control. Application of 5.0 kg Zn + 40 kg S +1.5 kg B + 2.5 kg Cu ha^{-1} increased the grain yield of soybean significantly by 15.2 per cent over control.

The Jabalpur center of AICRP on MSPE conducted field experiments on Zn and Boron deficient soils. The higher grain yield of soybean 0.06 t ha^{-1} (7.3%) with the application of 5 kg Zn ha^{-1} and 0.38 t ha^{-1} (21.3%) with the application of 5 kg Zn + 40 kg S + 1.5 g B and 0.50 kg Mo. The yield obtained at 5 kg Zn + 40 kg S ha^{-1} (1.99 t ha^{-1}) was similar with yield obtained with addition of B and Mo (2.00 and 2.02 t ha^{-1}) indicate that B and Mo has no effect on yield of soybean grain. Yield of chickpea maximum increase was recorded where B and Mo was applied in combination with Zn and S (0.33 t ha^{-1}) resulting 19.0% response. FLDs were also laid out to demonstrate the effect of Zn, S, B and Mo on Urid and pea grown in rotation at Narsinghpur district. The yield of pea was increased by 0.18 t ha^{-1} with the residual application of 5 kg Zn ha^{-1}(7.8%). The maximum increase was recorded where Zn was applied in combination with S (0.49 t ha^{-1}) resulting 21.1% response (Figure 3.1). Another site the yield of pea was (15.6%) with the application of 5 kg Zn ha^{-1}. The maximum yield was recorded where Zn was applied in combination with and S (0.52 t ha^{-1}) resulting 22.1% response.The grain yield of chickpea was increased by 0.25 tha^{-1} (12.5%) with the application of 5 kg Zn ha^{-1}. The maximum increase was recorded where B and Mo was applied in combination with Zn and S (6.2 q ha^{-1}) resulting 31.0% response (Figure 3.1). Field experiments conducted by Hyderabad centre of AICRP on MSPE revealed no significant effect in pod and haulm yields of groundnut due to Zn, Zn and Mo and Zn, Mo and B applications. The yields were at par with each other. When 40 kg S ha^{-1} was added to the combination of Zn+ Mo and B; there was significant increase in yield (1359 kg ha^{-1} pods and 1829 kg ha^{-1} haulm). Boron dose when increased from 1 to 1.5 kg ha^{-1} did not provide significantly additional yield. Pod yields varied from 1.012 to 1.390 t ha^{-1} with the variation in response from 13.53% to 37.35 depending upon the treatments. Significant effect of Zn, B and S application on seed yield of sunflower was recorded. Seed yields varied from 0.728 to 1.080 t ha^{-1}.

Table 3.1 Responses of crops to multi micro nutrients at various places

Location	Crops	Treatments (kg ha^{-1})													
		Control	5.0 kg Zn	1.5 kg B	2.5 kg Cu	0.5 kg Mo	40 Kg S	5.0 kg Zn+0.5 kg Mo	5.0 kg Zn + 40 kg S	5.0 kg Zn +1.5 kg B	5.0 kg Zn +1.0 kg B+0.5 kg Mo	5.0 kg Zn + 40 kg S +1.5 kg B	5.0 kg Zn + 40 kg S +1.5 kg B +0.5 kg Mo	5.0 kg Zn + 40 kg S +1.5 kg B +2.5 kg Cu	5.0 kg Zn + 40 kg S +1.5 kg B +2.5 kg Cu +0.5 kg Mo
		Grain/seed/tuber yield of crops (t ha^{-1})													
Pantnagar	Soybean	3.570	3.860	3.980	3.730	3.720	4.140	-	4.210	3.680	-	3.860	4.170	4.110	3.700
Pantnagar	Chickpea	1.500	1.830	1.830	1.750	1.750	1670		1.880	1.670	-	1.670	1.750	1.630	1.830
Pantnagar	Mustard	0.833	1.125	0.875	0.833	0.830	1.060	-	1.042	0.792	-	0.833	0.917	0.833	0.833
Pantnagar	Sesame	1.583	1.670	1.880	1.810	1.800	1.750	-	2.167	1.750	-	1.833	2.083	2.000	1.625
Jabalpur	Chickpea(2)	1.840	1.985	-	-	-	-	-	2.250	2.265	-	-	2.3.00	-	-
Jabalpur	Pea(4)	2.198	2.560	-	-	-	-	-	2.725	2.710	-	-	2.728	-	-
Jabalpur	Soybean	1.640	1.700	-	-	-	-	-	1.990	2.000	-	-	2.020	-	-
Jabalpur	Urd (2)	0.970	1.095	-	-	-	-	-	1.241	1.240	-	-	1.260	-	-
Hyderabad	Groundnut Pod	1.012	1.149	-	-	-	-	1.222	-	-	1.245	-	1.390	-	-
Hyderabad	Sunflower	0.728	0.844	-	-	-	-	0.862	-	-	0.913	-	1.030	-	-
Pusa	Onion	12.10	15.500	14.50	-	-	14.00	-	16.00	17.100	-	18.900	-	-	-
Pusa	Pea	0.950	1.340	1.430	-	-	1.150	-	1.390	1.480	-	1.550	-	-	-
Pusa	Black mustard	1.500	2.000	1.800	-	-	2.200	-	2.300	1.950	-	2.450		-	-
Pusa	lentil	0.910	1.240	1.110	-	-	1.140	-	1.480	1.250	-	1.570	-	-	-
Pusa	Chickpea	0.640	0.965	0.950	-	-	0.875	-	1.075	1.015	-	1.305	-	-	-
Pusa	Yellow mustard	0.810	1.140	0.960	-	-	1.250	-	1.450	1.300	-	1.580	-	-	-
Pusa	Rajma	1.000	1.250	1.380	-	-	1.250	-	1.350	1.500	-	1.750	-	-	-
Pusa	Potato	11.43	13.710	-	-	-	-	-	-	-	-	14.860	-	13.430	-
Pusa	Maize grain	0.570	0.680	-	-	-	-	-	-	-	-	0.770	-	0.730	-
Pusa	linseed	1.050	1.270	-	-	-	-	-	-	-	-	1.510	-	1.440	-

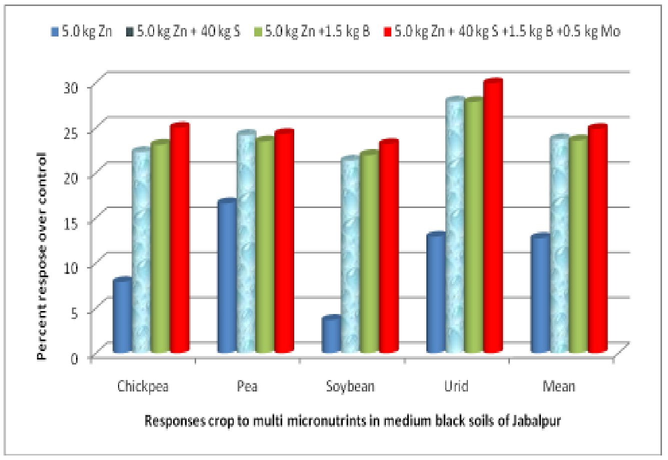


Figure 3.1. Crop responses to multi-micronutrient applications in medium black soils of Jabalpur

Pusa centre conducted four FLD cum trials at different districts of Bihar to test the response of different crops to multinutrients application. The available nutrients in initial soil were deficient in available Zn and boron. The onion bulb and dry straw yield varied from 12.1 to 18.9 and 1.42 to 3.90 t ha^{-1}, respectively (Table 3.1). The bulb yield response varied from 1.9 to 6.8 t ha^{-1}. All nutrients were able to increase the yield either applied alone or in combination. The highest response was noted at treatment Zn+B+S. The grain yield of pea varied from 0.95 to 1.55 with grain yield response of 0.20 to 0.6 t ha^{-1}. Potato tuber yield varied from 11.43 to 14.86 t ha^{-1} under different treatments. The highest yield response of 3.43 t ha^{-1} was found when Zn+B+S was added. It was noticed that Cu application along with other nutrients suppressed the tuber yield. The maize yield response varied from 2.0 to 20.0 q ha^{-1}. Zn alone was able to increase the maize grain yield to the extent of 1.10 t ha^{-1}. Zn, Cu, B and S were able to increase the linseed seed yield from 1.05 to 1.51. The highest yield response was recorded at where Zn, B and S were added in combinations.

3.1 Frontline demonstration on response of brinjal crops micronutrients and / or S applications in soils of Gujarat

Front line demonstrations conducted at two places in Gujarat revealed that brinjal crop responded well to soil application of Zn and Fe. The response in fruit yield due to different treatments ranged from 1.47 to 4.37 t ha^{-1} (Table 3.2). At both the sites, the yield was highest due to soil application of 25 kg $ZnSO_4$ ha^{-1} which was followed by yield obtained due to application of 50 kg $FeSO_4$ ha^{-1}. Response to gypsum application showed 9.5 per cent improvement in yield over control.

Table 3.2 Effect of S and micronutrients application on yield of brinjal

Treatments	Yield (t ha^{-1})	Response (t ha^{-1})
Control	15.48	-
25 kg ha^{-1} $ZnSO_4$	19.85	4.370
50 kg ha^{-1} $FeSO_4$	17.65	2.170
10 kg borax ha^{-1}	16.54	1.060
Multi-micro spray (3)	16.73	1.250
200 kg gypsum ha^{-1}	16.95	1.470

3.3 Response of wheat to Manganese application.

Two field experiments were conducted at Fatehabad district of Haryana to show response of wheat crop to manganese application. The grain and straw yield of wheat increased with both mode of Mn application i.e. soil as well as foliar application (Table 3.3). However the yield obtained with 0.5 % $MnSO_4$ foliar application and soil application of 50 kg $MnSO_4$ ha^{-1} were almost at par. Manganese application in wheat resulted a response of 19.69 and 15.08 percent under foliar and soil application, respectively. But foliar application pf manganese sulphate was found more economical as compared to soil.

Table 3.3 Yield, percent response and uptake of Mn by wheat as affected by Mn application

Treatment	Yield (q ha^{-1})		Uptake (g ha^{-1})		Percent Response
	Grain	Straw	Grain	Straw	
Control	39.10	48.875	26.10	90.91	-
0.5 % $MnSO_4$ foliar application	45.00	56.25	71.10	131.91	15.08
Soil application @ 50 kg $MnSO_4$ ha^{-1}	46.80	58.5	60.37	195.10	19.69

3.4 Response of crops to Boron application

Field experiments conducted in Hisar revealed that application of B @ 1.0 kg ha^{-1} as borax resulted an increase in yield of cotton by 2.5 q ha^{-1}, mustard by 2.0 q ha^{-1} and cauliflower by 39.0 q ha^{-1} over control, respectively (Table 3.4). There was an increase in the yield of cotton and mustard at each level of B application (Figure 3.2). Application of B @ 1.0 kg ha^{-1} through borax resulted in maximum yield response and hence it was found to be the best treatment for cotton crop. Two field experiments were conducted at Hisar district to observe the effect of B application on cauliflower. The yield of curd increased at with B application and maximum yield was recorded with 0.5 kg or 1.0 kg B application /ha. In general, application of B @ 05 kg ha^{-1} through borax resulted in maximum yield response and hence it was found to be the best treatment for cauliflower. A field experiment was conducted at Ludhiana to study the response of different levels of boron(0, 0.5 0.75,1.0,1.25, 1.50 and 2.0 kg ha^{-1}) on the bulb yield of garlic on a soil deficient in boron. The application of boron at the rate of 1.25 kg ha^{-1} resulted in the significance increase in bulb yield of garlic.

Response of paddy to Zn application at Hisar

Response of wheat crop to Zn application at Hisar

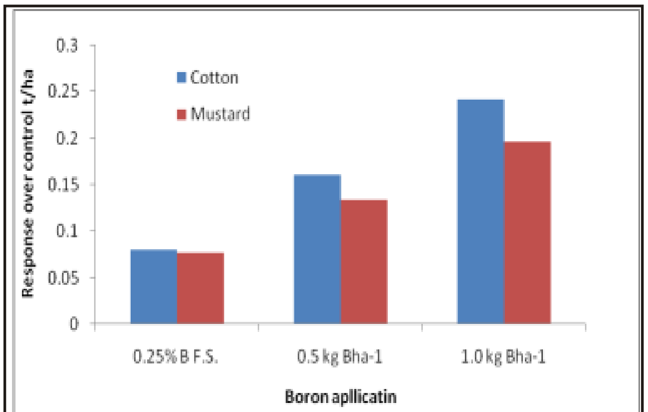
Response of wheat crop to Mn application at Hisar

Response of wheat crop to Zn application at Akola

Response of cauliflower to B application at Palampur

Table 3.4 Effect of B application on yield of different crops

Treatment	Hisar				Ludhiana
	Cotton 5 sites	Mustard 4 sites	Cauliflower 2 sites	Wheat 3 sites	Garlic 1 site
	Yield, ($t\ ha^{-1}$)	Grain Yield, ($t\ ha^{-1}$)	Yield, ($q\ ha^{-1}$)	Grain yield ($t\ ha^{-1}$)	Bulb Yield ($t\ ha^{-1}$)
Control	1.88	1.70	30.6	4.26	2.91
0.25% B foliar spray	1.96	1.78	33.8	-	
0.5 kg Bha^{-1}	2.04	1.84	34.3	4.15	2.93
1.0 kg Bha^{-1}	2.13	1.90	34.5	4.19	3.13
1.25 kg Bha^{-1}	-	-	-	-	3.47



Response of crops to boron application at sandy soils o Haryana

3.5 Response of gram crop to Sulphur application in Haryana

Field demonstrations on response of gram to Sulphur application were conducted at Chirod and Balsamand villages of Haryana during the period under report. The grain yield of gram increased with the S application @ 20 kg and 40 kg S ha^{-1} over control and maximum yield was obtained when S was applied @ 40 kg ha^{-1} through Gypsum at both the sites (Table 3.5) . The percent response in yield was also higher under 40 kg S ha^{-1} application.

Table 3.5 Effect of Sulphur application on gram yield at Hisar, Haryana

Treatment	Yield ($t\ ha^{-1}$)	Percent Response
Control	1.77	-
20 kg S ha^{-1}	2.04	13.76
40 Kg S ha^{-1}	2.235	23.85

CHAPTER –IV

AMELIORATION OF MICRO- AND SECONDARY NUTRIENT DEFICEINECIES

Balanced and integrated use of micro and secondary nutrients is essential for enhancing their use efficiency, maximizing crop productivity and sustaining fertility of the soils. Once micronutrient deficiencies are detected, it is inevitable to find out the best fertilizer sources and techniques of amelioration. The options of a corrective measure for combating micronutrient deficiency is largely determined by the nature of disorder, growth stage, condition and nutritional status of soil and plant. Centres of the AICRP on MSPE conducted several field and green house experiments to find out the best carriers, mode, rate and time of their application and develop best technique to enhance the fertilizer use efficiency for crops and cropping sequences for different soils. The summary of the works conducted during the period under report is presented here.

4.1 Frequency and rate of Zn and FYM application under paddy-wheat rotation

A field experiment was conducted by Pantnagar centre to study the effects of frequency and rate of Zn and FYM application under paddy-wheat rotation in a Typic Ustipssaments having loamy sand texture, pH 8.05, EC 0.25 dS m^{-1}, organic carbon 0.41% and DTPA-Zn was 0.58 mg kg^{-1} soil. The treatments consisted of control, 5 kg zinc sulphate per acre to paddy every year, 5 kg zinc sulphate per acre to paddy alternate year, 10 kg zinc sulphate per acre to paddy every year, 10 kg zinc sulphate per acre to paddy alternate year, 25 kg zinc sulphate per acre to paddy once only, 25 kg zinc sulphate per acre to paddy alternate year, 25 kg zinc sulphate per acre to paddy skip for three years , 5 kg zinc sulphate per acre + 5 t FYM per ha to paddy, 5 kg zinc sulphate per acre + 10 t FYM per ha to paddy , 10 kg zinc sulphate per acre + 5 t FYM per ha to paddy , 10 kg zinc sulphate per acre + 10 t FYM per ha to paddy with three replications. FYM was applied to paddy only. Zinc sulphate and FYM were mixed and allowed to incubate under field conditions for 15 days before transplanting of paddy. The residual effect of Zn and FYM applied to paddy was studied on wheat crop. Recommended basal doses of N and P were applied through urea and DAP, respectively. Paddy (cv PR 118) and wheat (PBW 343) were sown and raised to maturity.

During second year grain yield of paddy increased significantly from 5. 78 t ha^{-1} in control to 6.12 t ha^{-1} (Table 4.1) with application of 5 kg zinc sulphate per acre to both paddy crops but produced 5.84 t ha^{-1} when 5 kg zinc sulphate per acre was applied to first paddy crop only and skipped to second crop of paddy. Repeat application of 10 kg zinc sulphate per acre produced 6.27 t ha^{-1} as compared to only 5.98 t ha^{-1} when 10 kg zinc sulpahte was applied to first crop of paddy. However, application of 25 kg zinc sulpahte per acre to first crop of paddy produced a grain yield of 6.55 t ha^{-1}. A combination of 5 kg zinc sulphate $acre^{-1}$ with 5 and 10 t FYM ha^{-1} produced a grain yield of 6.14 and 5.93 t ha^{-1}, respectively whereas a combination of 10 kg zinc sulphate with 5 and 10 t FYM ha^{-1} produced a grain yield of 6.34 and 6.47 t ha^{-1} respectively. The residual effect of Zn application on grain yield of second wheat crop was not significant. The grain yield of wheat was 3.59 t ha^{-1} in control. However, with different treatments of Zn alone and in combination with FYM the yield varied between 3.54 to 3.90 t ha^{-1}.

Table 4.1 Effect of Zn and FYM application on grain yield (t ha^{-1}) of paddy and wheat

Treatment	Paddy	Wheat
Control	5.78	3.59
5 kg zinc sulphate per acre to paddy every year	6.12	3.90
5 kg zinc sulphate per acre to paddy alternate year	5.84	3.71
10 kg zinc sulphate per acre to paddy every year	6.27	38.5
10 kg zinc sulphate per acre to paddy alternate year	59.8	3.74
25 kg zinc sulphate per acre to paddy once only	6.55	3.54
25 kg zinc sulphate per acre to paddy alternate year	6.66	3.78
25 kg zinc sulphate per acre to paddy skip for three years	6.10	3.66
5 kg zinc sulphate per acre + 5 t FYM per ha to paddy	6.14	3.67
5 kg zinc sulphate per acre + 10 t FYM per ha to paddy	5.93	3.88
10 kg zinc sulphate per acre + 5 t FYM per ha to paddy	6.34	3.84
10 kg zinc sulphate per acre + 10 t FYM per ha to paddy	6.47	3.89
CD (at 5%)	4.66	NS

4.2 Effect of Boron, Zinc and Sulphur Application on Seed Yield, Nutrient Content and Uptake by Sunflower

An experiment was carried out at Hyderabad in red, sandy loam soil deficient in boron, zinc and sulphur to assess the effect of application of these nutrients on seed yield, nutrient content and uptake by sunflower crop. The initial characteristics of the soil were alkaline in reaction, normal in soluble salt content, with the initial boron status of 0.45 mg kg^{-1}, zinc status of 0.58 mg kg^{-1} and sulphur status of 9.8 mg kg^{-1}.The treatments were T1 = NPK (control), T2 = NPK +B @2 kg ha^{-1} through Granubor, T3 = T2 +2.5 kg Zn ha^{-1} through zinc sulphate, T4 = T2+5 kg Zn ha^{-1} through zinc sulphate and T5 = T3 +20 kg S ha^{-1} through sulphur bentonite pastilles. Significant effect of boron, zinc and sulphur is seen on the stalk as well as seed yield of sunflower over control (Table 4.2). Sunflower crop responded to soil application of zinc, boron and sulphur. The response was ranged from 11.26 to 28.38%. The born, zinc and sulphur contents in the index leaves also increased with the application of the respective elements and contents are above the critical levels. The uptake of zinc, boron and sulphur at harvest was also significantly higher over control.

4.3 Effect of soil amendments on yield of rice grown in iron toxic soil of Odisha

Iron toxicity occurs in hill bottom, red and laterite soils (Alfisol, Oxisol, Ultisol) under undulating and impeded drainage condition. Rice shows bronzing symptoms when iron in the soil solution ranged from 10-1680 mg kg^{-1}. It was reported that wet land rice in state of Orissa, Bihar, Chhattisgarh and W.B, were suffered since a long due to excess iron or iron toxicity. Iron toxicity has been reported to reduce rice yield by 12-100 per cent depending on the intensity of iron toxicity and tolerance of rice cultivers. In Odisha, about 0.75 lakh hectares of wet land rice suffered due to iron toxicity and yield level was as low as 0.05 t $ha^{-1.}$ Keeping this in view the field experiment was conducted at OUAT, Bhubaneswar to study the effect of different soil amendments on rice yield.

Table 4.2 Effect of boron, zinc and sulphur application on grain yield, Zn, B and S content in the index leaves and total uptake in rice

Treatments	Yield ($t\ ha^{-1}$)	Content in the index leaves			Uptake at harvest		
	Seed	Zinc	Boron	Sulphur	Zinc	Boron	Sulphur
		($mg\ kg^{-1}$)		(%)	($g\ ha^{-1}$)		($kg\ ha^{-1}$)
T1=NPK (Control)	1.420	25.21	12	0.10	83	158	3.15
T2=NPK +B @2 kg ha^{-1} through Granubor-II	1.580 (11.26)	27.26	15	0.11	85	189	3.46
T3 =T2 + 2.5 kg Zn ha^{-1} through zinc sulphate	1.648 (16.05)	45.48	15	0.12	115	192	3.52
T4=T2 + 5 kg Zn ha^{-1} through zinc sulphate	1.742 (21.26)	49.82	16	0.13	125	194	3.86
T5=T3 + 20 kg S ha^{-1} through S bentonite pastilles	1.823 (28.38)	48.96	17	0.16	132	210	5.49
CD (P= 0.05)	0.15	3.34	1.4	0.011	10	18	0.39

(Figures *in parenthesis are per cent response over control)*

The soil (Aeric Haplaquept) of experimental site was having pH 5.1, sandy loam texture, CEC 5.0 cmol (p^+) kg^{-1}, O.C. 0.62% and was low in available nitrogen (210 kg ha^{-1}) and phosphorus (7.2 kg ha^{-1}) and medium in available potassium (255 kg ha^{-1}). The soil had DTPA Fe 400 mg kg^{-1}. The treatments were control, lime @ 0.25 LR, @ 0.5 LR, fly ash @ 10t/ha, potash @ 40 kg ha^{-1}, Zn @ 5 kg/ha, Zn 10 kg/ha, FYM 10t/ha, fresh cowdung @ 5t ha^{-1}, and gypsum @ 2.5 q ha^{-1}. Results revealed that the grain yield varied from 2.60 to 3.933 t ha^{-1} under different treatments (Table 4.3). Application of different soil amendments helped in significant increase in rice grain. The highest mean grain yield was recorded with application of 5 kg Zn ha^{-1} and it was par with application of Zn @10 kg ha^{-1}. The lowest grain yield of 2.6 t ha^{-1} was recorded in control plots. From this result, it was concluded that rice yield on iron toxic soils could be improved by applying soil amendments.

Table 4.3 Effect of different amendments on rice grain yield in iron toxic soil

Treatments	Grain yield ($t\ ha^{-1}$)	Fe Conc. in grain ($mg\ kg^{-1}$)	Fe Conc. in straw ($mg\ kg^{-1}$)
Control	2.60	125	435
Lime@ 0.25 LR	3.433	111	358
Lime @ 0.5 LR	3.566	108	320
Flyash @ 10t ha^{-1}	3.133	107	400
Potash @ 40 kg ha^{-1}	3.060	105	415
Zn @ 5 kg ha^{-1}	3.933	103	313
Zn @10 kg ha^{-1}	3.633	102	409
FYM @ 10t ha^{-1}	3.300	110	355
Fresh cowdung @ 5t ha^{-1}	3.066	108	425
Gypsum @ 2.5 q ha^{-1}	3.633	110	395
C.D. (0.05)	0.35	-	-

4.4 Method, Rate, Frequency of Boron Application to Rice

Field experiment was conducted at Bhubaneswar to evaluate the method, rate and frequency of boron application to rice crop grown on a soil having pH 5.9, E.C. 0.24 dS m^{-1}, organic carbon 0.43% and CEC 4.5 [cmol (p^{+}) kg^{-1}] and hot water soluble boron 0.54 mg/kg. Twelve treatments (Table 4.4) comprising different combinations of rate and frequencies of B application including foliar spray were given. The grain yield of rice crop varied from 3.20 to 4.233 t ha^{-1} whereas straw yield varied from 3.761 to 5.959 t ha^{-1}. It was found that application of B @ 1 kg ha^{-1} to all crops gave significantly highest yield both in case of grain and straw. Total B uptake spanned from 0.183 kg ha^{-1} to 0.448 kg ha^{-1} under different treatments.

Table 4.4 Effect of treatments on Grain & Straw yield of Rice

Treatment Details	Rice Grain Yield (tha^{-1})		B uptake (kg ha^{-1})		Total
	Grain	Straw	Grain	Straw	
Control (No boron)	3.200	3.847	0.100	0.084	0.183
B @ 0.5 kg ha^{-1} to first crop	3.333	3.816	0.152	0.136	0.288
B @ 0.5 kg ha^{-1} to alternate crop	3.133	3.828	0.172	0.151	0.323
B @ 0.5 kg ha^{-1} to all crops	3.500	4.180	0.141	0.206	0.347
B @ 1.0 kg ha^{-1} to first crop	3.400	4.363	0.140	0.190	0.330
B @ 1.0 kg ha^{-1} to alternate crop	3.467	3.761	0.206	0.103	0.309
B @ 1.0 kg ha^{-1} to two crop interval	2.867	3.974	0.152	0.134	0.286
B @ 1.0 kg ha^{-1} to all crops	4.233	5.957	0.127	0.297	0.392
B @ 2.0 kg ha^{-1} to first crop	3.367	4.759	0.160	0.265	0.425
B @ 2.0 kg ha^{-1} to two crop interval	3.267	4.601	0.143	0.193	0.336
B @ 2.0 kg ha^{-1} to three crop interval	3.200	4.383	0.120	0.324	0.444
Borax @ 0.25% as Foliar Spray	3.300	3.945	0.181	0.267	0.448
CD (0.05)	0.61	1.0	-	-	-

4.5 Effect of foliar spray of micronutrients on yield of chilli and tomato

An experiment was taken up at Anand in an alkaline soil with DTPA extractable Fe, Mn, Zn and Cu were 6.3, 8.1, 0.61 and 1.2 mg kg^{-1} respectively to study the effect of different micronutrient sprays on yield of chilli (var. S-49) and tomato (var. J-Rubi) due to spray treatments. The treatments were control (water spray), 0.5% $ZnSO_4$ (Zn), 0.5 % $FeSO_4$ (Fe), 0.4 % $MnSO_4$ (Mn), 0.2 % Boric acid (B), 0.5 % (Zn +Fe) +0.4% Mn, 0.5 %(Zn +Fe) +0.2% B, Grade I (General), Grade II (Zn deficient), Grade III (Fe deficient), and Grade IV (Zn & Fe deficient). Three sprays were made for each treatment at 30, 50 and 70 days after transplanting. Grade I, II, III and IV are Government of Gujarat approved multi-micronutrient mixtures containing 2.0, 0.5, 4.0, 0.3, 0.5; 2.0,0.5, 8.0, 0.5, 0.5; 6.0, 1.0, 4.0, 0.3, 0.5 and 4.0, 1.0, 6.0, 0.5 and 0.5 % Fe, Mn, Zn, Cu and B respectively.

The results (3 years) were pooled and recommendation was brought out for both tomato and chilli (Table 4.5 and 4.6). For tomato, it was recommended to spray neutralized mixture of 0.5% $ZnSO_4$ + 0.5% $FeSO_4$ + 0.2% boric acid at 50, 70 and 90 days after transplanting of tomato to get higher yield and more net returns (CBR 1: 5.04). For chilli, it was recommended to apply micronutrient mixture equivalent to Gujarat Government notified formulation Grade IV to get higher yield and more net profit (CBR 1:2.2).

Table 4.5. Yield and economics of tomato as influenced by different treatments

Treatments	Yield (t ha^{-1})	Gross Realization (Rs. ha^{-1})	Treat, Cost * (Rs. ha^{-1})	Total, Cost (Rs ha^{-1})	Net Realization over control (Rs ha^{-1})	Cost benefit ratio
Control (Water spray)	26.953	107812	0	25000	82812	3.31
0.5% $ZnSO_4$ (Zn)	30.828	123312	525	25525	97787	3.83
0.5 % $FeSO_4$ (Fe)	38.403	153612	447	25447	128165	5.04
0.4 % $MnSO_4$ (Mn)	37.618	150472	567	25567	124905	4.89
0.2 % Boric acid (B)	37.540	150160	519	25519	124641	4.88
0.5 % (Zn +Fe)+ 0.4% Mn	37.015	148060	789	25789	122271	4.74
0.5 % (Zn +Fe) + 0.2% B	38.872	155488	741	25741	129747	5.04
Grade I (General)	34.807	139228	502.2	25502	113726	4.48
Grade II (Zn deficient)	31.748	126992	567	25567	101425	3.97
Grade III (Fe deficient)	32.647	130588	539.7	25540	105048	4.11
Grade IV (Zn &Fe def.)	34.323	137292	561	25561	111731	4.37

Table 4.6 Economics of chilli as influenced by the treatments

Treatments	Yield (t ha^{-1})	Gross Realization (Rs. ha^{-1})	Treatment Cost * (Rs. ha^{-1})	Total Cost (Rs. ha^{-1})	Net Realization (Rs. ha^{-1})	Cost benefit ratio
Control (Water spray)	10.34	51700	0	22000	29700	1.4
0.5% $ZnSO_4$ (Zn)	12.75	63750	525	22525	41225	1.8
0.5 % $FeSO_4$ (Fe)	12.50	62500	447	22447	40053	1.8
0.4 % $MnSO_4$ (Mn)	11.22	56100	567	22567	33533	1.5
0.2 % Boric acid (B)	12.52	62600	519	22519	40081	1.8
0.5% (Zn + Fe)+0.4% Mn	10.52	52600	789	22789	29811	1.3
0.5 % (Zn + Fe) +0.2% B	12.47	62350	741	22741	39609	1.7
Grade I (General)	12.36	61800	502.2	22502	39298	1.7
Grade II (Zn deficient)	14.18	70900	567	22567	48333	2.1
Grade III (Fe deficient)	11.73	58650	539.7	22540	36110	1.6
Grade IV (Zn &Fe def.)	14.43	72150	561	22561	49589	2.2

*** Treatment cost includes labour & material cost**

Prices: (I) Tomato = Rs.4000 t^{-1}. (II) Labour cost of three sprays: Rs. 375/-

Material cost (Rs.)		(Micronutrient Mixture) cost	
1) $FeSO_4$	:- 12.00/- kg	**1)** T_2 - Grade-I (Spray)	:- Rs. 127
2) $MnSO_4$	:- 40.00/- kg	2) T_3 -Grade-II (Spray)	:- Rs. 192
3) $ZnSO_4$	:- 25.00/- kg	3) T_4 -Grade-III (Spray)	:- Rs. 165
4) $CuSO_4$	:- 50.00/- kg	**4)** T_5 - Grade-IV (Spray)	:- Rs. 186
5) Boric acid	**: -** 50.00/- kg	**5)** T_6 - Grade V (SA)	:- Rs. 192

4.6 Efficacy of Multi-micronutrient Formulations in Improving Crop Production

Anand center conducted an experiment to test the efficacy of different micronutrient formulations on crop growth and yield, an experiment was in progress with different formulations containing known concentrations of different micronutrients. The experiments were conducted at the different Research Stations under the then Gujarat Agricultural University covering different important crop/s of their respective agro-eco regions. During the report period, the experiments conducted on banana (var. Robusta) at Anand and on sesame (var. Gujarat Til- 2) at Amreli were concluded and recommendations were brought out.

In the case of banana, on the basis of the economics as influenced by different treatments, application of micronutrients as per STV i.e. 20g $ZnSO_4$ and 40g $FeSO_4$ per plant besides FYM + RD of NPK in soil deficient to marginal in Zn and Fe availability was found the best treatment for getting higher banana fruits and net return (BCR- 4.32) (Table 4.7). Alternatively, farmers can also apply multi-micronutrient mixture grade V equivalent to Govt. Notified Grade V as soil application @ 20g per plant to get higher yield of banana and net return (BCR- 4.29).

Similarly, for sesame, application of mixture grade of multi-micronutrients @ 20 kg ha^{-1} as soil application equivalent to Govt. Notified general grade V for soil application was the best treatment to obtain higher sesame yield and total net return (BCR- 1.79) (Table 4.8). A common basal dose of 50kg N + 25kg P_2O_5 ha^{-1} should be applied at the time of sowing.

Table 4.7 Yield and economics of banana as influenced by different treatments of micronutrients application

Treatments	Fruit yield (q ha^{-1})	Cost of cultivation (Rs. ha^{-1})	Gross realization (Rs. ha^{-1})	Net Realization (Rs. ha^{-1})	Benefit cost ratio
Control	67.5	55,000	2,70,000	2,15,000	3.91
Water spray	68.5	55,500	2,74,000	2,18,500	3.94
LF-I (General - Foliar)	70.2	55,700	2,80,800	2,25,100	4.04
LF-II (Foliar for Zn defi.)	69.7	55,800	2,78,800	2,23,000	4.00
LF-III (Foliar for Fe defi.)	72.8	55,750	2,91,200	2,35,450	4.22
LF-IV (Foliar for Fe & Zn defi.)	67.5	55,780	2,70,000	2,14,220	3.84
LF-V (Soil application)	74.2	56,080	2,96,800	2,40,720	4.29
STV (Soil application)	76.7	57,700	3,06,800	2,49,100	4.32

Sale price of banana fruit: Rs.4/- per kg
Common operational cost: Rs. 55,000/ha
Cost of LF grade treatments (per ha)
General - Foliar - Rs. 200/-
Foliar for Zn defi - Rs. 300/-
Foliar for Fe defi - Rs. 250/-
Foliar for Fe & Zn defi - Rs.280/-
LF Soil application - Rs. 1080/-
STV (Soil application - 2700/- (STV)
Cost of 4 sprays: Rs. 500/- per ha (2.5 units /spray i.e. Rs.125/-)

Thus in Middle Gujarat Agro-climatic Zone-III (AES-II), it is recommended to apply micronutrients as per STV i.e. 20g $ZnSO_4$ and 40g $FeSO_4$ per plant besides FYM+RD of NPK in soil having deficient to marginal Zn and Fe availability for getting higher banana fruits yield and net return (BCR=4.32). Alternatively, farmers can also apply multi-micronutrients mixture grade-V (Fe-2%, Mn-0.5%, Zn-5%, Cu-0.2% and B-0.5%) equivalent to Govt. Notified Grade-V for soil application at 20 g per plant to harvest higher yield of banana and net return (BCR= 4.29).

Table 4.8 Sesame seed yield and economics as influenced by different mixture grades of multi-micronutrients

Treatments	Mean (four crops) Seed yield (kg ha^{-1})	Cost of cultivation (Rs. ha^{-1})	Gross realization (Rs. ha^{-1})	Net realization (Rs. ha^{-1})	Benefit cost ratio
T_1 Control	700	10500	24500	14000	1.33
T_2 LF-I (General)	825	11002	28875	17873	1.62
T_3 LF-II (Zn defi.)	737	11067	25795	14728	1.33
T_4 LF-III (Fe defi.)	783	11040	27405	16365	1.48
T_5LF-IV(Zn+Fe defi.)	722	11061	25270	14209	1.28
T_6 LF-V (Soil appl.)	855	10742	29925	19183	1.79
T_7 STV (Soil appl.)	813	10930	28455	17525	1.60

Sale price of sesame seed: Rs. 35/- per kg Common operational cost: Rs. 10500/ha
Cost of LF grade treatments (per ha):
General – Rs. 127/- LF-II (Zn defi.)– Rs. 192/- LF-III (Fe defi.)– Rs. 165/- LF-IV(Zn+Fe defi.)– Rs.186/- LF-V (Soil appl.)- Rs. 242/- , STV (Soil appl.)– 430/- (STV) Cost of 3 sprays: Rs. 375/- per ha (2.5 units /spray i.e. Rs.125/-)

4.7 Efficiency of Granubor II as New Boron Fertilizer

Considerable boron deficiency occurs in soils of India. A new boron fertilizer material i.e. disodium tetraborate pentahydrate carrying less water of crystallization (known as "Granubor II") was tested for its efficacy by comparing with standard source of B fertilizer i.e. disodium tetraborate decahydrate ("known as borax") in boron deficient soils of Ludhiana, Anand and Palampur. At all the places, the treatments consisted of control, soil application of three levels of B (0.75, 1.0 and 1.25 kg ha^{-1}) through both the sources. At Ludhiana, significant higher grain yield of arhar was obtained with the application of boron at the rate of 0.75 kg ha^{-1} from either of the sources (Table 4.9). The residual effect emanating from the any application rate (0.75, 1.0 and 1.25 kg ha^{-1}) of B had not caused any significant difference in the grain and straw yield of subsequent wheat crop. At Anand, seed cotton yield ranged from 36.79 to 41.60 q ha^{-1} under different treatments with response of 3.97 to 13.07% over control. Highest yield of seed cotton was obtained under application of 0.75 kg B through granubor II. Increasing response to application of graded dose of B through either source was obtained in terms of cauliflower curd yield at Palampur. It was found that higher curd yield may be obtained by application of B @ 1.25 kg ha^{-1} through either source though response to granubor II application was little higher than that of borax.

Table 4.9 Effect of levels and sources of boron on yield and response of arhar, cotton and cauliflower

Treatments	Ludhiana		Anad		Palampur	
	Arhar		Cotton		Cauliflower	
	Grain Yield ($t\ ha^{-1}$)	% response	Seed cotton yield ($t\ ha^{-1}$)	% response	Curd yield ($t\ ha^{-1}$)	% response
Control	0.920	-	3.679	-	19.830	-
0.75 kg B ha^{-1} through borax	1.120	21.74	3.825	3.97	20.510	3.43
1.0 kg B ha^{-1} through borax	1.020	10.87	3.875	5.33	21.110	6.45
1.25 kg B ha^{-1} through borax	0.930	1.09	3.882	5.52	21.510	8.47
0.75 kg B ha^{-1} through granubor II	1.160	26.09	4.160	13.07	20.910	5.45
1.00 kg B ha^{-1} through granubor II	1.030	11.96	3.817	3.75	21.610	8.98
1.25 kg B ha^{-1} through granubor II	0.960	4.35	3.965	7.77	22.050	11.21

4.8 Long term effect of varying fertility levels and cropping patterns on yield trend and micronutrient status of soil

Another long-term experiment was started during *kharif* 1985 in calcareous soil of north Bihar with four fertility levels maintained under two crop rotations viz. rice - wheat - sorghum forage and rice - mustard – moong along with one dummy plot (i.e. without crop). The fertility levels were: control ($N_0P_0K_0$), low fertility (50 % of the recommended dose of NPK), medium fertility (100 % of the recommended dose of NPK) and high fertility (150 % of the recommended dose of NPK) superimposed with10 kg Zn ha^{-1}, 10 kg Zn + 5 t FYM ha^{-1}, 10 t FYM ha^{-1}, 10 kg Zn + 10 t FYM ha^{-1} and as such (no superimposition).

The effect of varying fertility levels and cropping pattern were evaluated on crops yield, micronutrients (Zn, Cu, Fe and Mn) uptake and available micronutrients status in soil after the harvest of 63rd crop i.e. 21 complete cycles under rice-wheat-sorghum (R-W-S) and rice-mustard-moong (R-M-M) rotations. Increasing fertility levels progressively increased the crops yield and micronutrients uptake by all crops in both the rotations. Among superimposition of Zn and FYM, the maximum yields were recorded in treatment receiving 10 kg Zn + 10 t FYM ha^{-1}. The magnitude of cumulative yield response in R-W-S was higher (88 to 202%) as compared to R-M-M (75 to 187%) system (Table 4.10). Results clearly show that yield decrease over times at varying fertility levels was compensated and even increased with the application of Zn + FYM treatments. The uptake of all the four micronutrients cation by different crops in both the rotations sharply increased with rising fertility levels (Table 4.11). There was marked increase in uptake of these micronutrients due to superimposed treatments and the highest uptake was noted in the treatment receiving 10 kg Zn + 10 t FYM ha^{-1} in alternative year. The average removal of Zn, Cu, Fe and Mn by three crops of one complete rotation (21st cycle) were 290.1, 113.0, 2318 and 719 g ha^{-1}, respectively under R-W-S rotation while those values for R-M-M rotation were 202.2, 75.4, 1286 and 595 g ha^{-1}, respectively. The extent of micronutrients removal on an average by both the rotations was in the following order : Fe > Mn > Zn > Cu.The cumulative uptake of Zn, Cu, Fe and Mn up to 63rd crop at different fertility levels was found to vary from 5.59 to 13.27, 2.143 to 5.637, 44.83 to

109.24 and 10.63 to 29.86 kg ha^{-1}, respectively under rice - wheat - sorghum rotation, while the corresponding values for rice-mustard-moong rotation varied from 4.70 to 10.15, 1.683 to 4.314, 35.56 to 83.89 and 8.95 to 21.15 kg ha^{-1}, respectively. The percentage increase in micronutrients uptake over control progressively increased with rising fertility levels with its higher magnitude in former rotation than the latter one.

Table 4.10 Effect of changing cropping pattern and management practices on cumulative yield up to 63rd crop

Treatment	Cumulative yield up to 63rd crops (t ha^{-1})			Per cent increase in yield		
	Grain	Straw	Total	Grain	Straw	Total
Rice - wheat - sorghum						
Control	46.15	129.33	175.48	-	-	-
Low fertility	90.71	239.97	330.68	97	86	88
Medium fertility	122.96	318.84	441.80	166	147	152
High fertility	146.62	383.97	530.59	218	197	202
Mean	101.61	268.03	369.64	-	-	-
Rice - mustard - moong						
Control	40.87	87.44	128.31	-	-	-
Low fertility	73.16	151.74	224.90	79	74	75
Medium fertility	96.94	209.30	306.24	137	139	139
High fertility	113.23	254.80	368.03	177	191	187
Mean	81.05	175.82	256.87	-	-	-

Table 4.11 Effect of changing cropping pattern and management practices on cumulative uptake of Zn, Cu, Fe and Mn up to 63rd crop

	Cumulative uptake (kg ha^{-1})				Per cent increase in uptake over control			
Treatments	Zn	Cu	Fe	Mn	Zn	Cu	Fe	Mn
Rice - wheat - sorghum								
Control	5.59	2.14	44.83	10.63	-	-	-	-
Low fertility	9.68	3.81	75.44	20.40	73	78	68	92
Medium fertility	12.24	5.06	97.56	25.35	119	136	118	138
High fertility	13.27	5.64	109.24	29.86	137	163	144	181
Mean	10.20	4.16	81.77	21.56	-	-	-	-
Rice – mustard – moong								
Control	4.70	1.68	35.56	8.95	-	-	-	-
Low fertility	7.14	2.88	56.69	13.92	52	71	59	56
Medium fertility	8.94	3.73	72.64	18.68	90	122	104	109
High fertility	10.15	4.31	83.89	21.15	116	156	136	136
Mean	7.73	3.15	62.20	15.68	-	-	-	-

4.9 Management of B in Hybrid rice- wheat cropping system in Mollisol of *Tarai*

A field experiment was conducted in Mollisol from 2003 to 2008 at Pantnagar to examine the effect of different rates and frequency of B of application on yields of hybrid rice-wheat rotation. The treatments were as mentioned below.

T1—Control
T2—0.5 Kg B ha^{-1}
T3—1.0 Kg B ha^{-1}
T4—2.0 Kg B ha^{-1}
T5 - 4.0Kg B ha^{-1}
T6— 0.5 Kg B ha^{-1} to each crop
T7—0.5 Kg B ha^{-1} to each rice crop
T8—2.0Kg B ha^{-1} to first rice crop + 0.5 Kg B to subsequent crop
T9—1.0 Kg B ha^{-1} to each rice crop
T10—1.0 Kg B ha^{-1} to rice I year + 1.0 Kg B to wheat II year + Rice 4^{th} year + wheat 5 th year
T11—2.0 Kg B to rice I-year + 1.0 Kg B to rice in II year + 5^{th} year
T12 – 2.0 Kg B to rice I year + 0.5 Kg B to Wheat I st year + wheat II year + Wheat 3^{rd} year+ wheat 4^{th} year + wheat 5^{th} year
* Uniform application of 150 N- 60 P_2O_5- 40 K_2O in all treatments

Results revealed that the grain and straw yields of hybrid rice and subsequent wheat crop were not significantly influenced by B application in the first and second year (Table 4.12). However, the highest cumulative grain yield of rice and wheat was recorded under treatment receiving 1 kg B/ha to each rice crop (T9). Under this treatment, the grain yields of both rice and wheat showed improvement over control. The cumulative grain yields of hybrid rice and wheat obtained during five years are represented in Figure 4.1 . It is evident from the figure that the highest cumulative grain yield of hybrid rice and wheat (53.771 t ha^{-1}) was recorded in T3 (1 kg B ha^{-1}) treatment. Thus, application of 1 kg B ha^{-1} to hybrid rice crop ensures higher grain yields of both rice and wheat crop. Application of 1 kg B ha^{-1} to every hybrid rice crop in Mollisols may give still higher grain yields for hybrid rice but lowers the yield benefits for the subsequently grown of wheat crop.

4.10 Effect of Micronutrients Through Soil and Seed Treatments for Enhancing Fertilizer Use EfficiencyiIn Soybean

There are several methods of application of micronutrients like soil application, top dressing, foliar application, seed coating, soaking of the seeds before sowing. Some of these methods minimize the contact of micronutrients with soil. Therefore an experiment was carried out at Rudrur, Andhra Pradesh with soybean as test crop (variety JS-338) in clay loam soil, with slightly alkaline pH 8.3 and normal in soluble salt content and deficient in Zn, B and Mo. The experiment was conducted with thirteen treatments consisting of control, seed treatment with Zn(0.3% Zn O), Mo (0.2% Sodium molybdate), B (0.2% Borax), soil application of 25 kg Zn SO_4 ha^{-1}, 0.5 kg Mo ha^{-1}, 1.0 kg B ha^{-1}, combination of reduced rates of soil application of Zn (12.5 kg Zn SO_4 ha^{-1}), Mo (0.25 kg Mo ha^{-1}), B (0.5 kg B ha^{-1}) along with seed treatment of Zn (0.3% Zn O), Mo (0.2% sodium molybdate), B (0.2% B and three replications in a randomized block design.

Significant effect of Zn, B and Mo is seen on the pod yield of soybean by all the methods of application except seed treatment with 0.2 % sodium molybdate (Table 4.13). Pod yield varied from 1556 to 2225 kg ha^{-1}. Soil application of Zn recorded the maximum yield (2225 kg ha^{-1}) with 43 % response followed by Boron (2012 kg ha^{-1}) with 29 % and Mo (1886 kg ha^{-1}) with 21 % response. Significant effect of Zn, B and Mo is seen on the stalk yields of soybean at all levels over control except the seed treatment with B and Mo. Among the methods of application, soil application of Zn, B and Mo significantly increased the yields (2032,

Table 4.12 Effect of rates and frequency of B application on grain and straw yields of Hybrid rice – wheat sequence

Treatments	2003-04		2004-05		2005-06		2006-07		2007-08	
	Grain		Grain		Grain		Grain		Grain	
	Rice	Wheat	Rice	Wheat	Rice	Wheat	Rice	Wheat	Rice	Wheat
T1—Control	71.9	44.4	60.6	43.9	55.3	40.8	46.3	39.4	49.2	42.9
T2—0.5 Kg B / ha	69.0	45.3	63.9	43.3	58.6	43.3	56.0	38.3	54.2	45.6
T3—1.0 Kg B / ha	70.6	47.5	59.4	43.9	61.1	42.5	58.8	47.2	54.2	52.5
T4—2.0 Kg B / ha	68.5	46.9	62.8	45.6	60.3	42.2	51.5	37.5	51.7	44.2
T5 - 4.0Kg B / ha	72.5	45.3	61.1	42.2	55.6	40.0	56.3	40.3	49.2	45.4
T6— 0.5 Kg B / ha to each crop	65.6	43.3	64.4	46.7	61.1	43.9	47.5	41.7	53.3	48.3
T7—0.5 Kg B / ha to each rice crop	67.7	44.2	62.2	43.9	68.3	41.7	48.6	40.6	53.3	41.7
T8—2.0Kg B / ha to first rice crop + 0.5 Kg B to subsequent crop	69.0	42.2	64.4	46.1	60.6	43.3	56.3	42.5	53.3	45.8
T9—1.0 Kg B / ha to each rice crop	69.4	47.8	62.2	46.1	61.1	41.9	60.3	38.9	53.3	45.8
T10—1.0 Kg B / ha to rice I year + 1.0 Kg B to wheat II year + Rice 4th year + wheat 5 th year	69.2	44.7	63.9	44.4	59.2	41.4	48.2	41.4	50.0	43.8
T11—2.0 Kg B to rice I-year + 1.0 Kg B to rice in II year + 5th year	68.5	49.4	62.2	42.2	60.6	43.1	50.1	42.5	52.5	47.5
T12 – 2.0 Kg B to rice I year + 0.5 Kg B to Wheat I st year + wheat II year	68.8	46.7	57.8	46.1	62.5	42.5	55.3	36.7	55.0	47.1
S.Em.	2.5	1.9	3.5	1.7	2.1	1.5	2.0	2.1	1.5	1.5
C.D. (p = 0.05)	NS	NS	NS	NS	6.0	NS	5.9	NS	4.3	NS
C.V. (%)	6.4	7.1	9.7	6.4	5.9	6.2	6.6	9.1	5.2	5.6

1896 and 1896 kg ha^{-1}) over the seed treatments with Zn, B and Mo (1801, 1655 and 1615 kg ha^{-1}), respectively. Total Zinc uptake ranged from 79.88 to 150.54 g ha^{-1}, with the highest uptake recording (150.54 g ha^{-1}) where soil application of Zinc was applied. Boron uptake ranged from 61.31 to 136.13 g ha^{-1}. Highest Boron uptake was also recorded in the soil applied boron treatment. Seed treatments along with foliar sprays recorded higher amount of uptake compared to seed treatment alone.

4.11 Effect of combined application of boron and zinc on yield and boron and zinc uptake by sunflower

Two experiments were conducted in the farmer's field at Mettupalayam and Panayampalli villages of Coimbatore and Erode districts during 2008 – 2009 with Sunflower hybrid COSH 8063 as test crop to assess the simultaneous application of boron and zinc on yield and uptake by Sunflower crop. The experimental soil was red sandy loam in texture, neutral in pH (7.6) and low salt content (EC - 0.520dSm^{-1}). The soil of Mettupalayam village was deficient in Zn (0.92 mg kg^{-1}) and sufficient in other micronutrients such as DTPA Fe (6.25mg kg^{-1}), Mn (3.18 mg kg $^{-1}$) Cu (2.10 mg kg^{-1}), and HWS B (0.47 mg kg^{-1}). In Panayampalli, the soil was found deficient in Zn (0.76 mg kg^{-1}) and B (0.34 mg kg^{-1}). The treatment structure comprised of three levels of Zn (0, 2.50 and 5.00 kg Zn ha $^{-1}$) and four levels of B (0, 0.50, 1.00 and 2.00 kg of B ha $^{-1}$). There were totally twelve treatments replicated thrice in a randomized block design. The recommended NPK fertilizers were applied (40: 20: 20 kg NPK ha^{-1}) and the crop was grown to maturity and harvested. The grain and straw yield was recorded besides collecting soil and plant samples after the crop

Table 4.13 Effect of different methods of micronutrient application on pod and stalk yields (kg ha^{-1}) and its content in the index leaves of soyabean

Treatments	Yield (kg ha^{-1})		Contents in index leaves (mg kg^{-1})	
	Pod	Stalk	Zn	B
Control	1556	1513	24.25	34.16
ST with 0.3%ZnO	1863	1801	27.45	34.49
SA of 25 kg Zn SO 4 ha^{-1}	2225 (43%)	2032	34.81	35.06
SA of 12.5 kg Zn SO 4 ha^{-1} + ST with 0.3%ZnO	2095	1914	31.43	34.28
ST with 0.2% SM	1672	1655	25.12	32.16
SA of 0.5 kg Mo ha^{-1}	1886 (21%)	1896	24.63	33.83
SA of 0.2 5 kg Mo ha^{-1} + ST with 0.2% SM	1729	1796	24.30	34.26
ST with 0.2% Borax	1777	1655	25.38	38.49
SA of 1.0 kg Boron ha^{-1}	2012 (29%)	1896	27.26	45.16
SA of 0. 5 kg Boron ha^{-1} + ST with 0.2% Borax	1954	1775	25.32	42.79
ST with 0.3% Zn O + Two FS of 0.2% Zn SO 4	1945	1900	29.68	34.39
ST with 0.2% SM + Two FS of 0.1%SM	1749	1781	24.36	35.18
ST with 0.2% Borax + Two FS of 0.15% Borax	1824	1801	25.18	40.29
CD(0.05%)	165	149	--	

ST : seed treatment, SA : soil application, FS: foliar spray, SM: sodium molybdate

Table 4.14 Effect of combined application of B and Zn fertilizers on the yield of sunflower

Treatments	Seed yield (kg ha^{-1})	Straw yield (kg ha^{-1})
Control (Rec. NPK only)	1243	899
2.5 kg Zn ha^{-1} + Rec. NPK	1358	1040
5.0 kg Zn ha^{-1} + Rec. NPK	1502	1087
0.5 kg B ha^{-1} + Rec. NPK	1390	1114
1.0 kg B ha + Rec. NPK	1495	1174
2.0 kg B ha + Rec. NPK	1481	1170
0.5 kg B ha^{-1} + 2.5 kg Zn ha^{-1} + Rec. NPK	1554	1105
1.0 kg B ha + 2.5 kg Zn ha^{-1} + Rec. NPK	1684	1188
2.0 kg B ha + 2.5 kg Zn ha^{-1} + Rec. NPK	1677	1197
0.5 kg B ha^{-1} + 5.0 kg Zn ha^{-1} + Rec. NPK	1596	1115
1.0 kg B ha + 5.0 kg Zn ha^{-1} + Rec. NPK	1737	1194
2.0 kg B ha + 5.0 kg Zn ha^{-1} + Rec. NPK	1628	1176
SED	-	-
CD(0.05)	-	-

harvest. The samples were analyzed for various micronutrient content and the uptake was computed.

Perusal of result revealed that mean seed yield of sunflower ranged from 1243 to 1737 kg ha^{-1} (Table 4.14). The highest pooled seed yield was recorded with the addition of 5.0 kg Zn + 1.0 kg B ha^{-1} (1737 kg ha^{-1}). The increasing levels of Zn and B showed a linear increase in seed yield of sunflower however the combined application of Zn and B at varied level indicated a decline in yield at higher levels of Zn with higher level of B. Increasing the B level above 1 kg ha^{-1} though showed a lesser yield decline when applied with 2.50 kg but revealed a marked yield decline when applied with 5.0 kg Zn ha^{-1}. This result clearly showed that the interaction of Zn and B at higher levels was not positive on the yield increase of sunflower. Hence addition of Zn at 5 kg with 1.0 kg B was found optimum for sunflower. The lowest yield was recorded in Zn0 B0 control (1243 kg ha^{-1}). Increasing addition of Zn and B significantly increased the Zn and B availability and uptake in soil and plant. Interaction effect of Zn and B showed that, increasing the Zn levels showed a positive influence on B uptake however higher levels of B showed a negative effect on Zn uptake by the crop. Hence addition of Zn at 5 kg ha^{-1} and 1.0 kg B was found optimal for increasing the yield and uptake of nutrient by sunflower.

CHAPTER –V

SCREENING OF CULTIVARS OF CROPS FOR MICRONUTRIENT EFFICIENCY AND BIOFORTIFICATION

Micronutrient deficiency is a massive global problem affecting 3 billion peoples world-wide, mostly woman, infant, and children, of which one third lives in India. In India, intensive cropping over the period has accentuated extensive micronutrient deficiencies in soils and crops and so the micronutrient content in seed and fodder is declining by about 1.0 to 1.5 times in major cereal and pulse crops. Increasing micronutrient content in seed and fodders is must through better scientific understanding of mechanisms of micronutrient mobilization, absorption, translocation and retranslocation in seed under soil-plant-animal/human chain.

5.1 Identification of Micronutrient Efficient and Inefficient Cultivars of Major Food Crops in India

Under a NAIP subproject (C4/C30022), twenty cultivars of major food crops like rice, wheat, maize, pigeon pea and gram were screened by Hyderabad, Anand, Ludhiana, Pantnagar, Pusa and project coordinating unit Bhopal to identify micronutrient efficient as well as inefficient cultivars by assessing micronutrient uptake efficiency and micronutrient yield efficiency index using formulae given in this page.

The efficient cultivars can better utilize soil micronutrient under deficient condition and do not respond application of micronutrient fertilizers. Whereas inefficient cultivars respond well to external application of micronutrient fertilizers but poor in utilising native were and micronutrients from soil. The genetically micronutrient inefficient cultivars are virtually agronomically efficient for enhancing micronutrient content in seeds. Thus, the efficient cultivars may be utilized by breeders for QTL identification responsible for efficiency 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. The list of efficient and inefficient cultivars of different crops with their yield and micronutrient concentration in grain identified for further physiological study has been given in Table 5.1 and 5.2.

Formula used

$$\textit{Micronutrient uptake efficiency} = \frac{\textit{Grain micronutrient uptake in control (-micronutrient) plot}}{\textit{Grain micronutrient uptake in micronutrient treated (+micronutrient) plot}} \times 100 \text{ Grain}$$

$$\textit{Micronutrient yield efficiency index} = \frac{\textit{Grain yield in control (-micronutrient) plot}}{\textit{Grain yield in micronutrient treated (+micronutrient) plot}} \times 100 \text{ Grain}$$

Table 5.1. Yield and micronutrient concentration of genetically efficient cultivars of different crops with and without micronutrient application

Name of centre	Crop	Micronutrient	Efficient	Yield ($t ha^{-1}$)		Conc. ($mg kg^{-1}$)	
				No Zn	+Zn	No Zn	+Zn
IISS, Bhopal	Pigeon pea	Zn	ICPL 87119	1.84	1.99	27.8	41.8
			T 15-15	1.46	1.55	32.3	44.6
			Virsa Arhar 1	1.53	1.76	32.8	38.7
	Wheat		GW 322	3.86	3.92	39.0	44.3
			JW 3211	3.72	3.84	38.6	42.2
			HI 8627	4.09	4.23	39.9	48.1
ANGRAU, Hyderabad	Rice	Zn	Erramallelu	5.28	5.44	12.8	17.9
			WGL 32100	6.25	6.02	13.2	19.8
			NLR 30491	5.83	6.29	12.3	16.7
	Maize		Super 9681	4.25	4.92	27.2	26.7
			DHM 117	5.76	6.35	20.6	28.4
			DHM 111	4.92	6.19	24.1	30.6
GBPUAT, Pantnagar	Rice	Zn	Pant Dhan 18	5.30	5.30	13.2	22.2
			Pant Sugandh Dhan 17	4.50	4.70	19.1	26.3
			Pusa Sugandh 4	4.70	5.60	14.7	23.1
	Wheat		UP 2565	4.43	4.60	16.4	37.3
			UP 2628	3.82	3.90	19.6	43.4
			PBW 502	4.05	4.50	24.1	40.8
PAU, Ludhiana	Rice	Mn	PAU 201	6.98	7.23	40.6	51.9
			3047	6.70	6.85	41.5	53.4
			PR 116	6.95	6.94	41.2	51.5
	Wheat		PBW 636	5.17	5.60	26.2	35.5
			BW 8989	4.95	5.38	23.1	30.8
			PBW 550	4.97	5.39	28.4	38.2
AAU, Anand	Pigeon pea	Fe	DT 23	2.63	2.40	33.4	37.0
			AAUT 2007-4	1.82	1.74	37.6	40.6
			PKV Trombay	2.78	2.77	32.7	36.4
	Gram		GJG 506	2.60	2.66	50.3	55.2
			GG 1	3.77	3.87	63.8	64.8
			GAG 838	3.09	3.28	62.8	68.3
RAU, Pusa	Rice	Fe	RAU 759	6.33	6.58	71.1	93.0
			Sanwal Basmati	4.58	4.93	74.3	92.1
			Swarna Sub-1	5.10	5.40	47.8	70.9
	Maize		Debaki	5.64	6.06	40.1	56.5
			Hemant	5.10	5.40	46.5	62.2
			Rajendra hybrid Makka 1	5.76	6.19	53.1	77.4

5.2 Screening of Wheat Genotype for their Relative Susceptibility to Mn Deficiency

In Hisar, a pot experiment was conducted to study the influence of genotypes on Mn response in seven newly released wheat varieties by using Mn deficient, sandy loam soil of village Dhani Lamba. The pH of the soil was 7.90, EC - 0.25 dsm^{-1}, OC - 0.57 %, $CaCO_3$ 5.57% and DTPA extractable Mn - 1.69 mg kg^{-1} soil. The recommended doses of N, P, K and Zn were applied as basal and Mn was applied @ 0.0, 5.0, 10.0 mg kg^{-1} soil and 0.5% $MnSO_4$ solution sprays, respectively. The crop was grown up to maturity and yield of wheat was recorded. The soil and plant samples were collected after harvesting and analysed for their Mn concentration. The percent increase /decrease of yield was

Table 5.2. Yield and micronutrient concentration of genetically inefficient but agronomically efficient cultivars of different crops with and without micronutrient application

Name of centre	Crop	Micronutrient	Inefficient	Yield (tha^{-1})		Conc. (mg kg^{-1})	
				No Zn	+Zn	No Zn	+Zn
IISS, Bhopal	Pigeon pea	Zn	Hisar HO2-60	0.91	1.28	34.3	56.3
			Hisar Paras	0.94	1.26	33.1	51.3
			Hisar Manak	0.96	1.24	31.9	55.7
	Wheat		HW 2004	2.67	3.13	42.8	55.3
			JW 17	3.51	3.85	39.4	49.9
			C 306	2.92	3.34	41.4	51.5
ANGRAU, Hyderabad	Rice	Zn	MTU 1001	3.94	8.19	11.7	20.8
			NLR 33892	5.23	7.96	8.7	14.2
			JGL 11727	6.20	8.80	7.4	15.3
	Maize		Ashwini	3.23	5.74	23.8	31.6
			Lakshmi 4950	5.20	7.23	22.6	27.4
			NK6240	5.32	7.73	23.7	30.5
GBPUAT, Pantnagar	Rice	Zn	Jaya	4.00	7.30	8.9	14.6
			Pant Dhan 19	5.30	7.70	7.0	14.8
			Pant Sankar Dhan 1	4.70	6.80	14.3	27.3
	Wheat		UP 262	3.39	4.60	13.0	41.3
			PBW 590	3.83	4.90	14.4	46.5
			VL 804	3.03	3.80	14.7	42.4
PAU, Ludhiana	Rice	Mn	3140	4.17	4.97	28.9	38.8
			3141	3.92	4.66	26.4	40.9
			Pusa 44	5.35	6.10	31.1	44.4
	Wheat		PDW 291	3.78	4.98	18.8	31.7
			PDW 314	4.02	5.23	19.9	29.5
			BW 9022	4.65	5.34	20.3	30.6
AAU, Anand	Pigeon pea	Fe	BP 1-96	2.32	2.71	29.9	39.8
			C 11	2.37	2.82	34.8	39.6
			BSMR 853	2.79	3.06	34.5	38.6
	Gram		ICCC 4	1.99	2.61	59.3	73.7
			GAG 839	1.82	2.26	53.2	58.0
			GJG 305	3.25	3.85	55.5	70.7
RAU, Pusa	Rice	Fe	Boro 3	3.29	4.50	38.0	60.1
			Rajendra Kasturi	3.17	4.42	46.3	72.0
			Rajendra Subhashni	2.92	3.75	25.0	56.8
	Maize		Shaktiman 3	5.74	6.97	44.1	69.0
			CM 400	4.52	5.27	37.7	59.3
			Shaktiman 4	5.85	6.95	52.7	75.3

calculated as under by considering maximum yield at 0.5% $MnSO_4$ foliar application level.

Percent Increase/decrease in yield

$$= \frac{\text{Yield with Mn - Yield without Mn}}{\text{Yield with Mn}} \times 100$$

On the basis of average yield and percent increase /decrease in yield, the different genotypes of wheat were rated as (a) tolerant having percent response <10.0, (b) moderately tolerant having percent response (10 -25) and (c) susceptible/ least tolerant if the response is >25.0 percent. Out of the seven wheat varieties tested for Mn response, WH-711, WH-1021 and WH-1022 were found moderately tolerant and the varieties WH-1025, PBW-502, PBW-16 and UP-2425 were identified as least tolerant/susceptible and can not be grown under Mn stress conditions (Table 5.3).

Table 5.3. Yield of wheat genotype as affected by Mn application

Varieties	Yield (gm pot^{-1})				Variety Mean	Percent response in yield
	No Mn	5.0 mg Mn kg^{-1}	10 mg Mn kg^{-1}	0.5% $MnSO_4$ sol. Foliar spray		
WH-711	11.9	12.8	14.9	14.1	13.42	15.6
WH-1021	11.6	13.4	14.6	13.3	13.22	12.8
WH-1022	15.3	16.2	17.4	17.7	16.66	13.5
WH-1025	6.9	8.2	11.8	11.2	9.52	38.4
PBW-502	11.5	14.5	19.5	17.5	15.75	34.3
PBW-16	12.7	16.3	17.2	17.2	15.85	26.2
UP-2425	8.1	9.9	11.7	11.6	10.32	30.2

5.3 Screening Wheat Cultivrs Tolerant to Cu Stress

In Ludhiana, a pot experiment was conducted with a copper deficient soil (DTPA-Cu 0.18 mg kg^{-1} soil) for screening of eleven varieties of wheat (PBW 550, WH 542, PBW 527, PBW 509, PBW 502, PBW 343, PDW 291, PDW 274, PDW 233, TL 2098 and TL 1210) in relation to their response to Cu fertilization. Ten seeds of each variety were sown in plastic pots containing 10 kg of well processed soil. Copper was applied @ 0, 5.0 and 10.0 mg kg^{-1} soil as a solution of copper sulphate and basal applications of NPK were made as per recommendations. The crop was grown to maturity and data on grain yield per pot was recorded. Mean grain yield of wheat in control varied from 17.5 g per

Table 5.4 Variation in yield of wheat cultivars in response to Cu fertilization

Wheat cultivar	Levels of Cu (mg kg^{-1} soil)			
	0	5	10	Mean
PBW 550	30.5	29.8	30.2	30.1
WH 542	24.2	26.8	28.3	26.4
PBW 527	21.7	24.7	24.5	23.6
PBW 509	27.0	27.8	27.6	27.5
PBW 502	27.9	29.1	26.2	27.7
PBW 343	26.8	26.3	26.6	26.5
PDW 291	20.0	22.9	23.7	22.2
PDW 274	25.8	29.0	25.8	26.9
PDW 233	21.9	24.7	22.3	22.9
TL 2098	22.2	22.9	25.7	23.6
TL 1210	17.5	24.4	19.8	20.6

pot (TL 1210) to 30.5 g per pot (PBW 550) (Table 5.4). Bray's per cent yield varied from 71 for TL 1210 to 100% for PBW550 (Figure 5.1). The wheat varieties were found to bravo Cu fertilization in the order of

TL1210>PDW 1>WH 542> TL 2098> PBW 527> PDW 233> PDW 274> PBW 502> PBW 59> PBW 343> PBW 550

It was also observed that durum varieties and triticales were more responsive to copper fertilization.

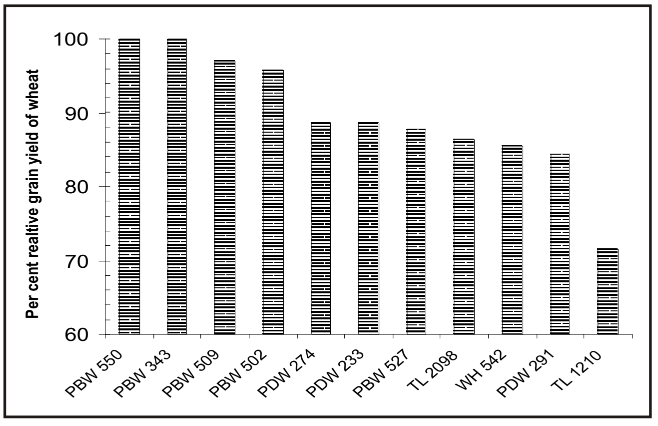


Figure 5.1 Relative grain yield of wheat cultivars

5.4 Screening of Wheat varieties for Zinc Enrichment

Seed is a store house of food and nutrients to baby plant. High micronutrient containing seed have high nutritive value for human and animal also. Thus, enriching or biofortifying the seed with micronutrients will be useful because dense seeds significantly result in better germination, good seedlings growth, better establishment of crops in early growth stages, and thus reducing seed rate (cost). Therefore, an experiment was planned in loamy textured and alkaline soil of Hisar with DTPA Zn of 1.74 mg kg^{-1} to study the effect of Zn application on yield and zinc concentration in grain of wheat varieties. The treatments consisted of Zn 0 (control), Zn1 ($ZnSO_4$ 12.5 kg ha^{-1}), Zn2 ($ZnSO_4$ 25.0 kg ha^{-1}), Zn3 ($ZnSO_4$ 37.5 kg ha^{-1} and Zn4 (0.5% $ZnSO_4$ foliar application twice). Fourteen prominent wheat varieties namely WH-1025, PBW- 502, WH-542, PBW- 550, HD- 2851, PBW- 343, WH-711, WH- 896, WH- 147, C- 306, RAJ- 3765, PBW-

Table 5.5 Effect of Zn application on grain yield of wheat varieties (q ha^{-1})

Variety	Zn Levels					
	Zn_0	Zn_1	Zn_2	Zn_3	Zn_4	Mean
WH-1025	50.90	53.70	57.40	59.20	54.60	55.20
PBW-502	42.80	46.30	47.20	50.00	45.10	46.30
WH-542	44.20	48.10	52.80	52.30	52.80	50.00
PBW-550	38.90	40.70	42.80	44.20	49.00	43.10
HD-2851	44.60	46.30	52.80	50.40	47.20	48.30
PBW-343	45.80	45.80	45.30	45.80	45.10	45.60
WH-711	38.90	39.80	45.80	43.50	41.20	41.80
WH-896	47.20	55.10	56.0	55.10	55.50	53.80
WH-147	41.20	41.60	44.40	45.80	41.20	42.90
C-306	34.20	38.90	41.20	38.90	39.60	38.60
RAJ-3765	42.90	43.50	46.30	44.40	43.50	44.10
PBW-373	40.00	40.70	44.10	46.30	45.80	43.40
WH-1021	46.50	49.10	50.40	50.00	48.10	48.80
WH-1022	45.30	45.80	47.40	47.50	48.10	46.80
Mean	43.10	45.38	48.13	48.10	46.90	
CD at 5%	Varieties=0.05	Levels= 0.03	Varieties X Levels=0.10			

373 WH-1021, WH-1022 were tested for their response. From the grain yield data (Table 5.5), it is clear that some varieties responded to application of Zn but at different amounts and at different levels of Zn application and some did not. But the grain Zn concentration increased in all the varieties with graded level of Zn application (Table 5.6). And all the varieties had higher grain Zn concentration under foliar application of Zn and it was significantly higher than grain Zn concentration obtained under other four treatments.

Table 5.6 Effect of Zn application on grain Zn concentration of wheat varieties (mg kg^{-1})

Variety	Zn Levels					
	Zn_0	Zn_1	Zn_2	Zn_3	Zn_4	Mean
WH-1025	34.00	39.00	39.50	43.00	46.50	40.40
PBW-502	34.00	36.50	41.00	43.50	50.50	41.10
WH-542	26.50	26.50	29.00	29.00	32.50	28.70
PBW-550	32.00	30.50	33.50	35.00	49.50	36.10
HD-2851	32.50	33.00	35.00	37.50	52.50	38.10
PBW-343	30.50	31.00	32.00	33.00	45.50	34.40
WH-711	33.00	33.50	35.50	38.00	46.50	37.30
WH-896	30.50	30.50	33.00	33.00	38.00	33.00
WH-147	31.50	33.00	33.00	35.50	52.00	37.00
C-306	39.00	42.50	44.00	45.00	60.00	46.10
RAJ-3765	33.50	34.00	35.50	42.00	51.00	39.20
PBW-373	32.00	32.50	36.50	36.00	38.00	35.00
WH-1021	27.00	28.00	31.50	38.00	54.50	35.80
WH-1022	34.50	35.00	37.50	39.00	47.50	38.70
Mean	32.18	33.25	35.46	37.93	47.21	
CD at 5%	Varieties=0.72	Levels= 0.43	Varieties X Levels=1.62			

5.5 Screening of Tomato cultivars to Zinc Stress

In another experiment, Lucknow centre studied with six varieties of tomato (*Lycopersicon esculentum*.L.) viz., Azad T_2, Azad T 6, KS 7, Angoorlata, Type 1, RK Heera grown in sand culture at three levels of Zn – two deficient, 0.00065 (very low), 0.0065 mg l^{-1} (moderate) and one adequate (0.065 mg Zn l^{-1}) level of Zn. The symptoms of Zn deficiency were inward curling of leaf margins and hanging of leaves from petiole, premature drying of flowers and poor fruit set. The decrease in parameters such as root volume, carbonic anhydrase activity, zinc concentration and fruit yield showed that varieties Type 1 and RK Heera to be highly susceptible while varieties Azad T2, Azad T6 and Angoorlata were moderate and KS 7 appeared relatively tolerant to Zn deficiency (Table 5.6 and Plate 5.1).

Table 5.7. Some growth parameters in six varieties of tomato in relation to Zn supply

mg Zn l^{-1}	Tomato variety					
	Azad T2	Azad T6	KS 7	Angoorlata	Type 1	RK Heera
Dry weight : (g plant^{-1}) at 30 DAS						
0.00065	5.34 (-47)	4.14 (-46)	4.51 (-40)	5.29 (-49)	3.65 (-39)	4.52 (-51)
0.0065	6.48 (-36)	5.80 (-34)	6.03(+169)	6.53 (-58)	3.76 (- 58)	5.60 (-39)
0.065	10.05	8.81	7. 47	10.31	8.94	9.14
Root length: (cm) at 30 DAS						
0.00065	9.4	9.8	9.5	8.7	8.1	7.6
0.0065	10.3	10.7	10.1	11.4	8.2	8.2
0.065	11.8	11.2	10.5	12.5	11.7	10.6

Figures in parenthesis denote % depression.

Plate 5.1 Fruit yield of different tomato varieties at different Zn supply

5.7 Screening of Gram Varieties for Tolerance to Zinc Deficiency

Ten high yielding varieties of gram (*Cicer arietinum* L.) namely HC 1, Sadabahar, JG 315, ICCV 10, BGM 413, DCP 92-3, GNG 144, PBG 1, JG130 and Vishal were grown at three levels of zinc - 0.00065 (deficient), 0.0065 (moderately deficient) and 0.065 (adequate) mg Zn l^{-1} in refined sand. A comparative study was made of visual zinc deficiency symptoms, changes in growth attributes (height, pod number), dry matter (d 65, 38 and 92), pod and seed yield (d 92) and tissue concentration (d 68 and 92) of zinc in different plant parts.

Zn deficiency appeared after d 30, as depression in growth at 0.00065 mg Zn l^{-1} supply. In the beginning (d 35) the depression in growth was most pronounced in var. JG 315 which was germinated late and whose germination percentage was very low. Visible foliar symptoms of Zn deficiency initiated at d 45 as interveinal chlorosis from the base and margins of the leaflets of middle leaves. In middle leaves the central lamina were affected first. These symptoms spread towards old leaves with prolonged deficient Zn supply. After a few days (d 50), gram plants at 0.0065 mg Zn l^{-1} also developed Zn deficiency symptoms but at low intensity. After prolonged supply of low Zn (0.00065 mg Zn l^{-1}) zinc deficient plants were stunted and turned necrotic with a very small leaf size. Zn deficiency also decreased pod and seed yield (Table 5.8).

On the basis of biomass, number of pods, pod and seed weight, height, activity of peroxidase, superoxidase dismutase, carbonic anhydrase and Zn concentration of the following varieties were identified under resistant and susceptible groups :

Highly Susceptible: BGM 413 , JG 315, PBG 1

Moderate susceptible: ICCV 10, GNG 144, Vishal

Resistant : HC 1, Sadabahar JG130, DCP 92-3.

Table 5.8 Screening of ten varieties of gram on the basis of dry matter against zinc deficiency

Varieties	mg Zn l^{-1}			
	0.00065	0.0065	0.065	Inference
	Dry weight (g $plant^{-1}$) at 35 DAS			
HC 1	0.177 (-7)	0.184 (-3)	0.19	R
Sadabahar	0.122 (+2)	0.149 (+24)	0.12	R
JG 315	0.103 (-43)	0.175 (-3)	0.18	S
ICCV 10	0.164 (-18)	0.169 (-16)	0.20	M
BGM 413	0.235 (-43)	0.180 (-56)	0.41	S
DCP 92-3	0.114 (-19)	0.142 (+1)	0.14	M
GNG 144	0.084 (-7)	0.160 (+7)	0.15	R
PBG 1	0.270 (-73)	0.295 (-71)	1.00	S
JG130	0.157 (-8)	0.120 (-29)	0.17	R
Vishal	0.158 (-19)	0.180 (-7)	0.19	M
	Number of pods $plant^{-1}$ 92 DNS			
HC 1	6	6	6	R
Sadabahar	6	5	7	R
JG 315	4	6	6	S
ICCV 10	4	4	5	M
BGM 413	2	8	9	S
DCP 92-3	4	5	6	M
GNG 144	5	6	6	R
PBG 1	3	6	10	S
JG130	5	5	6	R
Vishal	4	4	5	M
	Seed weight (g $plant^{-1}$) at 92 DAS			
HC 1	0.73 (-20)	0.77 (-15)	0.91	R
Sadabahar	0.71 (-18)	0.67 (-23)	0.87	R
JG 315	0.42 (-65)	0.75 (-37)	1.19	S
ICCV 10	0.54 (-35)	0.53 (-36)	0.83	M
BGM 413	0.25 (-75)	0.68 (-33)	1.02	S
DCP 92-3	0.61 (-24)	0.85 (-13)	0.98	M
GNG 144	2.63 (-12)	2.70 (-10)	2.99	R
PBG 1	0.38 (-57)	0.47 (-46)	0.88	S
JG130	0.69 (-17)	0.82 (-1)	0.83	R
Vishal	0.74 (-35)	0.89 (-22)	1.14	M

- / + = % decrease/ increase over control; D =deficient; C = control
S = Susceptible; M = Moderate: R = Resistant

CHAPTER - VI

BASIC AND STRATEGIC RESEARCH

6.1 Forms and Distribution of Heavy Metals in Soil

Sewage and sludge (SS) conation higher concentration of heavy metals like Co and Cd which are potentially toxic to the crops at higher concentration. Therefore, studies regarding Co and Cd adsorption-desorption as influenced by swage sludge and farm yard manure (FYM) were carried out by Anand centre.

The adsorption-desorption of Co and Cd followed the Freundlich equations. The Co adsorption maxima ranged from 5.07 μg g^{-1} (10t FYM + 2.5t SS) to 8.05 μg g^{-1} soil (control) (Table 6.1). The constant 'K' related to bonding energy varied from 0.014 (10t FYM + 2.5t SS) to 0.039 μg g^{-1} (control). The amount of sorption of Cd was found increasing with increasing Cd concentration in equilibrium solution. The Cd adsorption maxima varied from 0.893 μg g^{-1} (10t FYM + 2.5t SS) to 1.828 μg g^{-1} soil (10t FYM + 10t SS). The constant 'K' related to bonding energy ranged from 0.0042 (10t FYM + 2.5t SS) to 0.0123 μg g^{-1} (control).The adsorption of Co and Cd followed Freundlich adsorption isotherm which was modified in the soil amended with FYM, SS and FYM + SS treatments. The release pattern observed for Co and Cd indicated the soil of FYM addition to control the metals in soil solution to protect plant roots from the adverse effect of the heavy metals.

Table 6.1 Co adsorption parameters under different treatments

Treatment	Adsorption Maxima (μg g^{-1})	'K' (bonding energy)
Control	8.05	0.039
10t FYM ha^{-1}	5.36	0.017
10t FYM + 2.5t SS ha^{-1}	5.07	0.014
10t FYM + 10t SS ha^{-1}	5.58	0.016
10t SS ha^{-1}	5.87	0.021
20t SS ha^{-1}	6.06	0.024

Table 6.2 Cd adsorption parameters under different treatments

Treatment	Adsorption Maxima (μg g^{-1})	'K' (bonding energy)
Control	1.66	0.0123
10t FYM ha^{-1}	1.14	0.0067
10t FYM + 2.5t SS ha^{-1}	0.89	0.0042
10t FYM + 10t SS ha^{-1}	1.83	0.0071
10t SS ha^{-1}	1.22	0.0085
20t SS ha^{-1}	1.43	0.0106

6.2 Critical level of Cu in wheat grain

A field experiment was conducted with a copper deficient soil (DTPA-Cu 0.18 mg kg^{-1} soil) for screening of eleven varieties of wheat (PBW 550, WH 542, PBW 527, PBW 509, PBW 502, PBW 343, PDW 291, PDW 274, PDW 233, TL 2098 and TL 1210) to study the variation in their response to Cu fertilization at Ludhiana. The data on grain and straw yield was recorded and the grain samples were analyzed for Cu concentration. The data obtained on grain yield and Cu concentration in grain of different cultivars of wheat was used to estimate the critical level of Cu in wheat grain by plotting it against per cent of maximum yield by using the method of Cate and Nelson. A critical level of 4.5 μg Cu g^{-1} in wheat grain was observed to produce about 90% of the maximum grain yield (Figure 6.1). However, this critical level needs to be verified further by using a wide range of soils differing in their Cu content and physico-chemical properties.

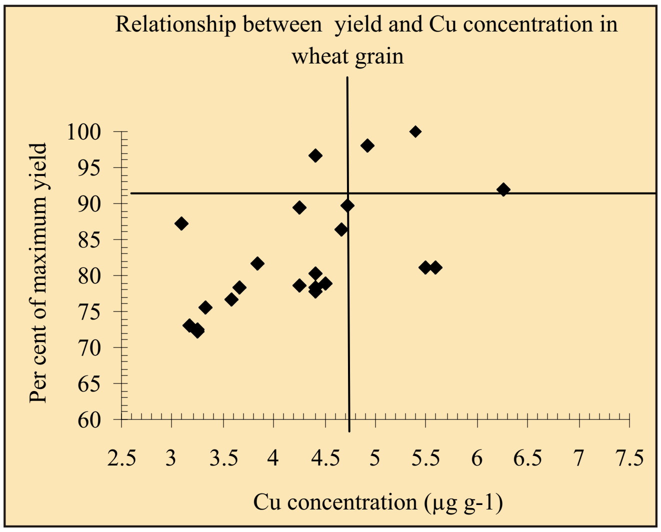


Figure 6.1 Relationship between yield and Cu concentration in wheat grain

6.3 Establishment of Critical Limit of Boron in Soil for Mustard and Moong Crop at Hisar

Establishment of critical limits of nutrient in soil is essential to categorize a soil deficient or sufficient in that particular nutrient. However, the critical limit for particular nutrient varies with soil test methods and with soil-crop-climatic conditions. Keeping above facts in view pot experiments were conducted to establish the critical limits of B in alkaline soil for mustard and moong crop at Hisar.

Eighteen different soils varying in their hot water soluble boron (HWS-B) status were collected from cultivated areas in Haryana. The soils were analyzed for their physicochemical properties and HWS-B. Accordingly, the soils were grouped in to low, medium and high HWS-B content. The mustard (var. RH-30) was used as test crop and B was applied through borax @ 0.0, 0.25, 0.50, 0.75 and 1.00 mg B kg^{-1} soil. The treatments were replicated thrice and the crop was allowed to grow up to maturity. At harvesting yield was recorded and the samples were collected for further analysis in the laboratory. Bray's percent yield was calculated. A relationship between Bray's percent yield and HWS-B was developed using Cate and Nelson technique for the establishment of critical limit (Figure 6.2). From the computation, 1.1 and 0.83 mg B kg^{-1} soil was found to be the critical limit of B for mustard and moong crop respectively.

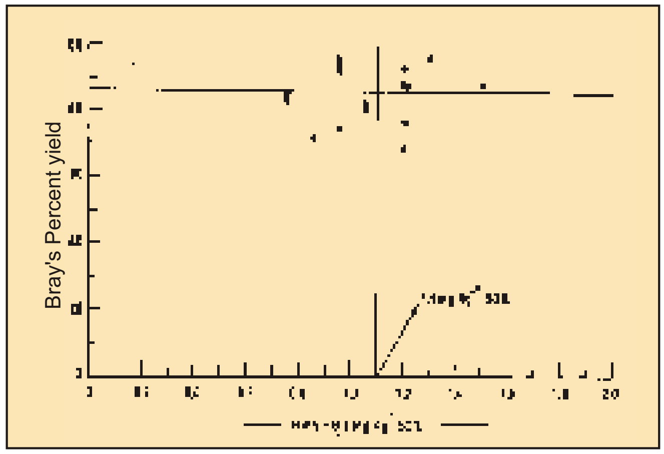


Fig.6.2 Relationship of hot water solubleboron with percent yield of raya

6.4 Effect of P and Mn Fertilization on Transformation and Availability of Cu to Wheat

A pot experiment at Ludhiana was conducted on a P deficient sandy loam soil to study the effects of P (0, 25, 50, 100, 200 and 400 mg P kg^{-1} soil as KH_2PO_4) and Mn (0, 12.5, 25 and 50 mg Mn kg^{-1} soil as $MnSO_4.H_2O$) fertilization on chemical pools of native Cu in soil. A major portion (71.4%) of total Cu resided in residual mineral fraction. MnOX-Cu increased from 2.16% to 2.25% and CRYOX-Cu increased from 14.3% to 15.0% when levels of P increased from 0 to 400 mg P kg^{-1} soil. Organically bound Cu decreased from 8.62% to 6.87% and SAD-Cu decreased from 0.33% to 0.25% with increase in P levels from 0 to 400 mg P kg^{-1} soil. Significant and positive coefficients of correlation of root dry matter yield (DMY) with MnOX-Cu (r = +0.431*), RES-Cu (r = +0.467*); of shoot DMY with RES-Cu (r = +0.504*); of root Cu concentration with DTPA-Cu (r = +0.430*), OM-

Cu (r = +0.780**); of shoot Cu concentration with DTPA-Cu (r = +0.442*), OM-Cu (r = +0.824**); of Cu uptake by root with DTPA-Cu (r = +0.613**) and Cu uptake by shoot with DTPA-Cu (r = +0.534**) indicated the importance of these pools of Cu in soil for the nutrition of wheat.

6.5 Effect of Continuous Cropping on Productivity of Crops and Distribution of Sulphur with and without FYM under *Bajra - Mustard – Cowpea* (F) Cropping Sequence

Nutrient availability in soil is governed by the dynamic equilibrium involving different forms rather than only available fraction or its total content. The present investigation was undertaken to study the effect of fertility (NP levels) with and without farmyard manure (FYM) application on yield, nutrients removal by crops and distribution of sulphur fractions in soil under *bajra* (cv. GHB-558) - mustard (cv. GM-2) - cowpea (F) (cv. EC-4216) cropping sequence. The FYM (0 and 10 t ha^{-1}) was applied once in a year to *kharif bajra* and different levels of NP fertilizers (0, 50, 100 and 150 % of RD) were applied to each crop. The experiment was conducted under factorial randomized block design keeping three replications.

The study indicated that the decline in crops productivity over the years under continuous cropping was mainly due to constant mining of nutrients like S, K and micronutrients especially in absence of FYM application at higher fertility i.e. with only NP fertilization @ 100 or 150 % of RD. The inclusion of FYM application @ 10 t ha^{-1} along with fertilizers application @ 100 % of RD and growing of leguminous crop like cowpea in the cropping system showed greater improvement in crops productivity and soil fertility. The cowpea showed beneficial effect on utilization of native nutrients more efficiently and improved fertility and crops productivity of the soil. This has emphasized the importance of balanced nutrition under intensive cropping for higher productivity of the crops on sustainable basis. Results revealed that among the S fractions, the contribution of SO_4^{-2}-S was the least while that of non-SO_4^{-2}-S was the maximum towards total- S fraction irrespective of the treatments followed by organic – S fraction. Different fractions of sulphur like organic-S, SO_4^{-2}-S, non-SO_4^{-2}-S and total-S increased due to FYM application. All the S fractions showed higher contents in surface soil (0-15 cm) and decreased lower soil depth irrespective of the treatments.

6.6 Trace Mineral Nutritional Status of Rural Pregnant Women in Mahaboob nagar and Nalgonda Districts of Andhra Pradesh

A study was conducted for assessing the selected trace mineral nutritional status of rural pregnant women and also to assess the relationship between selected trace element nutritional status and food mineral contents in Nalgonda and Mahboobnagar districts. Total of fifty pregnant women were selected from each district who were in the 2 nd trimester of their pregnancy for the study. Dietary intake of pregnant women was assessed by 24 hr recall method. Food intake data of the subjects revealed a low intake of all foods. Nutrient intake of the subjects was also not met adequately when compared with RDA values in both the districts. Mean plasma iron, zinc and magnesium levels were decreased from 158 to 98.1 µg ml^{-1}, 137 to 93 µg ml^{-1} and 2.5 meq lt^{-1} to 1.6 meq lt^{-1}, respectively as the pregnancy period advanced from 2 nd to 3 rd trimesters in Mahboobnagar district whereas, in Nalgonda district the decrease was from 89.1 to 70.3 µg ml^{-1}, 60.2to 46.2 µg ml^{-1} and 2.97 meq lt^{-1} to 2.92 meq lt^{-1}, respectively. Though the serum levels of all trace elements were with in the normal range, there was a significant decrease in the levels between 2^{nd} and 3^{rd} trimesters, there by suggesting the need for supplementation of these trace elements as the period advances during pregnancy for maintaining good health and nutrition of pregnant women.

6.7. Determination of Critical Level of Boron for Mungbean and Raya in Soils of Punjab and Haryana

The critical limit of B was fixed by Ludhiana centre following the Cate and Nelson (1965, 1971) procedures. The critical deficiency level of B in mung bean at 45 days below which response to B fertilization could be expected was found to be 55.0 $\mu g\ g^{-1}$ dry matters. This critical level gave a predictability value of 75 per cent. Similarly the Hisar centre computed the critical limit of boron for raya and moong in soil was 1.1 and 0.83 mg kg^{-1} soil.

6.8. Determination of critical level of copper for Paddy

According to the Cate and Nelson (1965, 1971) procedures, the critical deficiency level of Cu in paddy at 60 days below which response to Cu fertilization could be expected was 0.32 mg Cu kg^{-1} soil . This critical level gave a predictability value of 87.5 per cent in sandy loam soils of Punjab

6.9. Fixation of tolerance limit of Cadmium and Nickel for Amaranthus and Bhendi

Coimbatore center found that the Increasing levels of Cd addition decreased the yield and growth attributes of Bhendi and Amaranthus. Inclusion of FYM even from lower level (5 t ha^{-1}) had significant influence on crop growth and yield over control (without FYM). however the effect was marked for various levels of FYM in Amaranthus while with Bhendi the impact was insignificant among levels of FYM. Drastic reduction in growth and yield of crops were observed from 10 mg Cd kg^{-1} in Amaranthus and 40 mg Cd kg^{-1} in Bhendi.

Increasing levels of Ni increased the growth and yield of both Bhendi and Amaranthus up to 2.5 mg kg^{-1} and thereafter a decline in growth and yield was observed No significant growth and yield difference due to FYM application was observed in both the crops.

6.10. Upper Toxic Limit of Cd and Ni for Cow Pea and Onion in Loamy Sand Soils of Haryana

In Hisar the Upper toxic limits of Cd and Ni were established for cowpea and onion from two years pot experimental data. The upper toxic limits of Cd and Ni for cowpea and onion in light textured soils were found 14.0, 116.0 and 8.0, 126.0 mg kg^{-1} soil, respectively. Whereas, in case of heavy textured soils the upper toxic limit of Cd and Ni were 20.0, 160.0 mg kg^{-1} for cowpea and 11.0, 140.0 mg kg^{-1} soil for onion, respectively. Similarly, the delineation of heavy metals in sewage and non-sewage irrigated soils from Ambala, Panchkula, Jhajjar and Gurgaon districts revealed that the concentration of heavy metals were more in sewage irrigated compared to non-sewage irrigated soils. However their concentrations were below the permissible limits.

CHAPTER –VII

HEAVY METAL POLLUTION AND REMEDIATION

7.1 Distribution and Extent of Heavy Metals and Organic Pollutants and Characterization of Soil Properties in and around City Solid Waste Dumping Sites in Haryana.

The distribution and extent of toxic pollutants in some selected dumping sites (located at Rohtak, Jind and Karnal) and their relative accumulation in plants were assessed during 2009-10.

These sites varied in their waste deposits ranging from fresh deposits at Karnal to very old deposits at Rohtak. Solid waste samples from 0-1 m and 1-2 m depths were randomly collected, processed and analysed for different physico-chemical properties. The solid waste sample of 0-1 m depth constituted of 61.8 to 65.6 % soil material, 20 to 25 % rubbles, 2.62 to 5.37 % polythene, 0.78 to 1.24 % glass, 0.17 to 0.82 % iron pieces, 2.41 to 5.26 % wood and 2.23 to 4.96 % rags on dry weight basis.

Table:7.1. Physico-chemical Properties and heavy metal content of City Solid Waste collected from different dumping sites in Haryana

Property		Rohtak	Jind	Karnal	Rohtak	Jind	Karnal
		0-1 m depth			1-2 m depth		
EC (dSm^{-1})		1.12	0.78	1.23	1.92	1.39	1.67
pH		7.63	7.51	7.49	7.57	7.50	7.61
Organic Carbon (%)		3.93	4.18	3.99	3.76	4.20	4.50
Size Fractions (%)	Sand	87.00	87.59	85.59	85.59	84.79	84.79
	Silt	10.03	9.72	11.45	11.05	11.38	11.38
	Clay	2.97	2.69	3.36	3.36	3.82	3.82
Available N ($mg\ kg^{-1}$)		65	84	95	72	98	92
Available P ($mg\ kg^{-1}$)		199	168	146	236	251	153
Available K ($mg\ kg^{-1}$)		2049	1577	1748	2023	2357	2807
Available S ($mg\ kg^{-1}$)		477	409	447	735	476	706
Heavy Metals		**DTPA-extractable heavy metals ($mg\ kg^{-1}$) in solid wastes**					
Zn		9.08	8.94	9.35	9.65	9.90	10.16
Fe		23.60	28.31	31.92	19.87	22.23	31.15
Cu		10.59	13.04	15.39	15.55	14.14	27.64
Mn		3.40	5.53	6.53	5.60	6.76	7.95
Cd		0.18	0.48	0.16	0.31	1.37	0.25
Pb		11.05	8.41	11.74	12.65	9.91	14.49
Ni		1.60	0.64	0.98	0.77	0.55	0.98
Co		0.13	0.16	0.20	0.15	0.18	0.20
Cr		0.23	0.19	0.24	0.26	0.25	0.21

7.2 Background Level of Heavy Metals Pollution in Agricultural and Sewage Irrigated Soils of Haryna

In order to know the background levels of heavy metal content in tubewell/canal and sewage irrigated soils, samples were also collected from peri-urban areas of Mewat, Yamunanagar, Mohindergarh and Rewari districts of Haryana. Soil samples of both sewage and non-sewage irrigated areas were collected for the reassessment of micro and secondary nutrients status. The samples were processed and analyzed for their physico-chemical properties and soluble potentially toxic metals. The sewage irrigated soils were found to have higher pH, EC and organic carbon content. This showed that irrigation with sewage water definitely add more salts and organic load to the soils as and when it is used for irrigation. The concentration of all the heavy metals were found to be higher in all the locations irrigated with sewage waters compared to canal/tubewell waters. Moreover, the concentration of all the potentially toxic metals under study are in safe and with in the permissible limit (Table 7.2).

Table 7.2. Heavy Metal Concentration (mg kg^{-1}) in Sewage and non - sewage irrigated soils

Location	Sewage Irrigated Soils					Agricultural Soils				
	Cd	Pb	Ni	Cr	Co	Cd	Pb	Ni	Cr	Co
Yamunanagar	0.1-2.0 (0.6)	1.1-9.4 (4.5)	0.3-1.3 (0.87)	0.07-0.10 (0.10)	0.02-0.05 (0.03)	0.03-0.85 (0.52)	0.08-1.30 (0.95)	0.05-0.70 (0.37)	0.02-0.04 (0.03)	0.1-0.7 (0.53)
Mewat	1.4-2.2 (0.7)	1.6-18.8 (8.0)	0.5-3.2 (1.6)	0.07-0.10 (0.10)	0.05-0.30 (0.11)	0.03-0.07 (0.05)	0.14-2.87 (0.97)	0.18-0.46 (0.28)	0.0-0.32 (0.17)	0.18-0.82 (0.51)
Mohindergarh & Rewari	0.33-0.77 (0.47)	0.57-1.92 (0.93)	0.04-0.12 (0.070	0.04-1.47 (0.79)	0.06-0.36 (0.13)	0.01-0.63 (0.38)	0.85-8.95 (2.70)	0.07-0.10 (0.85)	0.01-0.10 (0.04)	0.02-0.10 (0.05)

*Values in the parenthesis are the mean values

7.3 Assessing the Heavy Metal Contamination in the Industrial Areas of Coimbatore District

Twenty five geo referenced soil, plant and seed samples were collected from the industrial effluent irrigated areas such as Dye factory (Telungupalayam, selvapuram), Sewer water (Selvapuram, Ukkadam, Nanjundapuram) Gold processing (Selvapuram), Casting (Kurichi,Peelamedu) Electro plating (Kurichi, Ganapathy, Avarampalayam) Foundries (Kurichi, Ganapathy, Avarampalayam, Kalapatti), textile (Ganapathy, SITRA, Singanallur), Painting (Kalapati) factory areas of Coimbatore district. The samples were processed, dried and assessed for their metal content.

The DTPA extractable metal content in soils irrigated with various industrial effluents varied widely with the type of industry. The highest metal contents were noted in soils receiving casting, painting and sewage effluents (Table 7.3). The highest DTPA Zn (26.7mg kg^{-1}) and Cu (70.97 mg kg^{-1}) content was recorded in casting industrial effluent irrigated areas, Ni in Painting industrial effluent irrigated areas (31.35mg kg^{-1}) Cd in Gold processing effluent irrigated areas (2.34 mg kg^{-1}) and Pb in sewage effluent irrigated areas soils (15.01 mg kg^{-1}). Among the metals, the order of higher availability was Cu > Zn > Ni > Pb > Cd.

Table 7.3 DTPA extractable metal status in the soils of industrial effluent irrigated areas

Contaminated site	No. of samples	DTPA Metal status (mg kg^{-1})						
		Zn	Mn	Cu	Cd	Ni	Fe	Pb
Dye	4	15.6	9.3	17.8	0.53	2.16	250	3.98
Gold processing	2	10.7	18.0	16.8	2.34	2.17	238	5.28
Sewage	7	21.6	9.3	28.3	1.90	6.69	216	15.01
Foundry	4	17.4	17.4	32.7	0.43	19.83	270	2.87
Electro plating	3	16.0	19.1	59.3	0.37	2.93	221	3.61
Textile	3	20.8	12.9	10.8	0.48	2.57	56	2.29
Painting	1	15.6	2.2	8.3	0.11	31.35	216	4.98
Casting	1	26.7	19.6	70.9	0.46	1.28	207	2.68
Mean	25	18.0±4.9	13.5±6.2	30.6±23.0	0.83±0.82	8.62±11.0	209±65.0	5.09±4.2
		Total Metal status (mg kg^{-1})						
Dye	4	139	143	75	4.55	153	762	113
Gold processing	2	226	360	255	5.00	167	1055	354
Sewage	7	633	357	225	9.81	280	1259	344
Foundry	4	120	104	73.3	8.63	80.6	3708	171
Electro plating	3	113	123	256	8.31	317	688	196
Textile	3	250	166	119	3.60	119	730	179
Painting	1	136	720	88.6	11.00	128	1260	122
Casting	1	122	280	114	7.20	158	640	180
Mean	25	217	282	151	7	175	1263	207

Among the total metal content in the soils Pb content was noticed highest in soils irrigated with Gold processing and Sewage effluents (354 and 344 mg kg^{-1}), Zn in sewage irrigated soils (633 mg kg^{-1}), Cu in Electro plating and Gold processing areas (256 mg kg^{-1}), Cd in Painting (11 mg kg^{-1}) and Sewage irrigated areas (9.81 mg kg^{-1}), Ni in Electro plating (317 mg kg^{-1}) and Fe in Foundry effluent irrigated areas (3708 mg kg^{-1}).

Heavy metal content in the plants

The heavy metal content of the plant samples grown in different effluent water irrigated areas were quantified and presented in (Table 7.4) . The metal content varied with plant sp. and locations which may be due to differential level of contamination and absorption capacity of the plants. Among the various plants collected from the contaminated soils, the mean metal content from various industrial areas showed higher Zn content in painting effluent irrigated areas (351 mg kg^{-1}), Cu in gold processing effluent (226 mg kg^{-1}), Cd in Sewage irrigated areas (35.6 mg kg^{-1}), Ni in Foundries (512 mg kg^{-1}) and Electro plating areas (475 mg kg^{-1}), and Pb in textile (500 mg kg^{-1}), Dye (498 mg kg^{-1}) and sewage effluent irrigated areas (469 mg kg^{-1}).

Among the various greens grown in the sewage irrigated areas, the highest Zn (391 mg kg^{-1}) and Cu (229 mg kg^{-1}) was recorded in Senkeerai (*Amaranthus sp*), Fe (1893 mg kg^{-1}) and Cd (87 mg kg^{-1}) in Green Amaranthus, Mn (1415 mg kg^{-1}), and Pb 712 mg kg^{-1} in Sukuti (*Amaranthus sp,* Ni) in sirukeerai (*Amaranthus sp,*). The average tissue metal content in the plant samples collected from 12 locations showed that, the highest absorption is in the order of Pb (468.9 mg kg^{-1}) > Ni (214.8 mg kg^{-1}) > Zn (183.1 mg kg^{-1}) > Cu (130.3 mg kg^{-1}) > Cd (35.6 mg kg^{-1}). This reveal that the plants grown in sewage irrigated areas predominantly contain Pb followed by Ni and Zn. Mostly weed and grass species were found in the dye effluent contaminated areas. Among the plant samples collected from gold processing effluent irrigated areas the weed sp Parthenium contained highest Zn (159 mg kg^{-1}) and Cd (28 mg kg^{-1}) while the highest Ni was observed in Grass sp (336 mg kg^{-1}) and Pb in Citrus leaves (544 mg kg^{-1}). The plants collected from textile effluent irrigated areas contain very high concentration of Pb (500 mg kg^{-1}) followed by Zn (170 mg kg^{-1}) = Ni (169 mg kg^{-1}) > Cu > Cd. Among the various crops grown in foundry effluent irrigated, the highest Zn (507 mg kg^{-1}), and Cd (28 mg kg^{-1}) were recorded in Amaranthus sp. The highest Cu (113 -115 mg kg^{-1}) and Fe (2473 to 3000 mg kg^{-1}) were observed in grass sp. The highest Pb and Mn content were noted with Castor sp. The predominant contaminants found in this areas were in the order of : Ni > Pb > Zn >Cu >Cd.

The heavy metal content in the plants grown in different industrial contaminated soils showed the highest metal content of : Pb > Zn > Ni > Cu > Cd in all the areas except in foundries and electro plating industrial areas where Ni content was higher followed by Pb, Zn, Cu and Cd. Among the plant species collected, Amaranthus was found to accumulate almost all the metals in sewage irrigated areas, Castor contained higher metal content in foundry, electro plating and painting industrial areas, weed species (Parthenium and Abutilon sp.) contained higher metal status in casting and dye effluent irrigated areas.

Plate 7.1a View of sewage effluent

Table 7.4 Mean heavy metal content in plant samples collected from industrial effluent irrigated areas

Nature of contaminated site	No. of samples	Trace metal content (mg / kg)						
		Zn	Fe	Mn	Cu	Cd	Ni	Pb
Dye	5	205±124	1072±411	273±111	1339±6	17±11.4	202±127	498±188
Gold Processing	3	210±145	1970±622	668±227	226±140	28±0.58	232±91	462±84
Sewage	12	183±95	1169±57	473±411	130±84	35.6±24	215±191	469±146
Foundry	4	281±187	1816±1112	402±194	92±25	17±11	512±284	471±202
Electro plating	3	126±35	1250±883	784±260	136±74	16.3±6.4	391±98	475±142
Textile	5	170±23.5	1501±1078	605±450	57.1±20	18.4±10	168±82	500±153
Painting	2	351±272	1386±955	180±66	169±27	34±8	288±245	323±11
Casting	2	105±129	1543±1278	665±474	124±107	25±21	83.5±66	281±9.2

Textile effluents

City sewage water

Gold processing industrial effluent

Casting effluents

Foundry effluents

Dye factory effluent

Plates 7.1 b View of various industrial effluent irrigated areas

7.4 Screening Food and Non Food Crops for Heavy Metal Hyper Accumulation Potentials

The food crops and non food crops were screened for hyper accumulation of heavy metals to identify the best accumulators, which could be grown in heavy metal polluted areas for remediation. The fresh biomass of seventeen food crops recorded after 45 days was the highest in Amaranthus sp (35.3 g pot^{-1}) followed by Lab lab (30.8 g pot^{-1}), Palak and Cauliflower (27.4 g pot^{-1}). The lowest biomass yield was recorded with Sunflower (13.1 g pot^{-1}) and Beans (13.3 g pot^{-1}).

Significant variation in the available metal status was noticed with plant species tested in sewage irrigated soil. The dominance of extractability was in the order of Pb> Ni> Zn >Cu> Cd. The highest Pb availability was recorded in the soil grown with Sorghum (16.46 mg kg^{-1}) followed by Palak (15.3 mg kg^{-1}). The lowest Pb availability was noted in soil after Amaranthus (7.38 mg kg^{-1}) which might be due to the higher removal by the crop. The Cd availability was ranged from 0.34 to 0.71 mg kg^{-1} and highest extractability was recorded in the soil after Cluster bean. With regard to Ni, the values varied from 3.47 to 8.71 mg kg^{-1} and the highest extractability was noticed after radish. The soils tested after mustard recorded the higher Zn extractability (9.55 mg kg^{-1}) followed by Amaranthus (9.35 mg kg^{-1}). The Cu availability ranged between 3.50 to 7.70 mg kg^{-1}.

The highest heavy metal contents such as Pb (498 mg kg^{-1}), Ni (442 mg kg^{-1}), Zn (516 mg kg^{-1}), Cu (193 mg kg^{-1}) measured in plant tissues and were recorded highest in Mustard crop followed by Amaranthus and maize. The lowest tissue concentration of Pb was noted with Brinjal (124 mg kg^{-1}), Cd and Ni in Tomato (7.9 and 135 mg kg^{-1} respectively), Zn in Beans (74 mg kg^{-1}) and Cu in Lab lab (25.9 mg kg^{-1}). To screen the crops for hyper accumulation the metal accumulation ratio was calculated by using total soil metal status and plant tissue concentration. The crops having a metal accumulation ratio of more than 1 were taken as hyper accumulators and the details are furnished below:

Heavy metals	Hyper accumulators	Poor accumulators
Pb	Mustard, Amaranthus , Maize, Cluster bean, Fodder cowpea	Brinjal , Cauliflower, Beans
Cd	Radish, Cluster bean, Cauliflower, Brinjal, Amaranthus, Sorghum, Sesbania	Tomato, Sunflower
Ni	Amaranthus, Mustard, Palak, Maize, Cowpea, Sunflower	Toamto, Bhendi
Zn	Mustard, Amaranthus, Maize	Radish, Beans
Cu	Mustard, Amaranthus, Maize	Lab lab

Based on this, for Pb contaminated areas Mustard, Maize and Amaranthus can be recommended for remediation.

Among the non food crops, Castor and Marigold can be recommended as hyper accumulators . The details is furnished below :

Heavy metals	Hyper accumulators	Poor accumulators
Pb	Castor, Marigold	Zinnia, Cockscomb
Cd	Castor, Marigold, Aster, Globe amaranth, Zinnia, Balsam	Cockscomb
Ni	Castor, Marigold, Globe Amaranth, Zinnia	Balsam, Cockscomb
Zn	Marigold	Zinnia
Cu	Castor, Aster, Globe amaranth	Balsam, Marigold

In gist, of the twenty five foods and non food crops tested, Mustard, Amaranthus, Maize in food crops and Castor, Marigold under non food crops are found to possess higher accumulation potentials for remediation of Pb polluted soils (Table 7.5). Since food crops can not be used effectively, the non food crops can be recommended to remediate the Pb polluted soils.

7.5 Developing Management Strategies for Phyto Remediation of Pb Contaminated Soils

In order to develop suitable management strategies, three food crops viz., Amaranthus (Co5), Fodder cowpea (Pusa Basrathi) and Cluster bean (Pusa Navapop) and three non food crops viz, Marigold (African tall), Castor hybrid TMVCH 1 and native Castor (wild sp) having hyper accumulation potentials were evaluated under different management options in pot culture study. The crops were tested with and without organic manure (No manure, FYM at 5 t ha^{-1}, Green leaf manure 5 t ha^{-1} and Microbial inouculam at 2 kg ha^{-1}) under different doses of EDTA (0, 50 and 100 mg kg^{-1}) Table 7.6 & 7.7

Increasing levels of EDTA addibility increased the extractability of Pb and the percent increase was marked in Amaranthus (48.0%) followed by Fodder cowpea (26.0%) > Cluster bean (22 %) and Mary gold (19.6%). EDTA and organic addition significantly increased the Pb content and its translocation from root to shoot. Application of 100 mg EDTA kg^{-1} along with either 5 t FYM or Green leaf manure ha^{-1} was found to be the best in increasing the availability of Pb and its absorption by crops. EDTA and organics addition significantly increased the Pb content and its translocation from root to shoot. Higher translocation coefficient values were observed with Cluster bean> Mary gold > Fodder cowpea > Amaranthus. Among the hyper accumulators, Amaranthus, Cluster bean and Mary gold were found superior in removing higher Pb with better phyto remediation potentials. However based on the higher biomass production and being the non food crop, Mary gold can be recommended to contaminated soils along with 100 mg kg^{-1} EDTA and 5 t FYM or GLM ha^{-1}.

Higher translocation coefficient values were observed with Cluster bean> Mary gold > Fodder cowpea > Amaranthus. Among the hyper accumulators, Amaranthus, Cluster bean and Mary gold were found superior in removing higher Pb with better phyto remediation potentials. However based on the higher biomass production and being the non food crop, Mary gold can be recommended to contaminated soils along with 100 mg kg^{-1} EDTA and 5 t FYM or GLM ha^{-1}.

Table 7.5 Yield and heavy metal accumulation in food and non food crops

S.No.	Plant sp.	Fresh biomass yield (g/pot)	Heavy metal in soil after harvesting food crops					Heavy metal concentration in the food crops				
			Pb	Cd	Ni	Zn	Cu	Pb	Cd	Ni	Zn	Cu
	Food crops											
1	Maize	23.5	14.65	0.633	7.23	9.15	4.45	381	10.5	342	470	174
2	Sunflower	13.1	12.44	0.338	4.42	7.15	3.90	161	8.0	189	110	101
3	Tomato	19.8	14.86	0.410	5.31	5.35	4.05	165	7.9	135	142	79.0
4	Bhendi	16.9	14.42	0.290	3.47	5.40	5.60	189	8.7	139	205	74.2
5	Amaranthus	26.7	7.38	0.365	5.04	9.35	7.45	484	8.9	390	350	174
6	Musatrd	22.0	12.52	0.639	8.42	9.55	7.70	498	8.7	442	516	193
7	Palak	27.3	15.29	0.695	8.30	7.85	5.90	186	10.3	294	305	136
8	Beans	13.3	13.34	0.473	6.68	6.95	4.75	138	11.5	146	74	76.9
9	Cluster bean	20.3	14.29	0.706	8.59	5.80	4.55	211	13.1	136	112	77.0
10	Cauliflower	27.3	13.62	0.251	6.91	6.00	4.00	131	12.4	140	142	102
11	Radish	14.8	11.33	0.570	8.71	7.10	4.25	141	26.6	142	74	88.7
12	Brinjal	17.9	13.62	0.446	7.07	5.20	3.25	124	13.7	152	91	82.6
13	Thandukeerai	35.3	11.94	0.434	6.49	9.30	7.20	384	12.0	397	249	174
14	Avarai	30.8	12.58	0.665	6.56	6.60	4.70	155	11.3	182	91	25.9
15	Sorghum	14.1	16.46	0.535	4.94	7.25	4.25	161	14.3	153	113	102
16	Agathi	17.0	14.57	0.465	6.95	8.25	5.70	149	12.9	140	118	74.7
17	Fodder Cowpea	24.8	11.00	0.341	5.71	7.40	5.65	203	11.0	189	82	56.5
	Non food crops											
1	Castor variety	14.35	15.38	0.686	7.57	13.35	5.05	252	11.4	237	250	139
2	Castor wild sp	22.90	21.05	0.926	9.01	15.40	6.40	440	12.3	294	288	223
3	Marigold	10.66	16.66	0.749	6.85	10.10	6.05	370	13.3	300	434	140
4	Cockscomb	27.35	16.24	0.528	6.34	8.00	3.90	151	10.9	141	197	121
5	Aster	12.85	14.26	0.604	5.46	5.90	5.40	206	12.9	157	63	164
6	Balsam	22.50	16.61	0.680	6.37	4.95	4.70	170	12.2	148	219	116
7	Zinnia	8.08	18.12	0.585	6.54	8.30	4.15	156	12.2	206	137	128
8	Globe amaranth	22.10	14.63	0.678	4.92	9.05	5.45	160	12.9	202	161	164

Mary gold

Fodder cowpea

Cluster bean

Castor

Plate 7.2 View of the pot culture experiments

Table 7.6 Effect of levels of EDTA on the fresh biomass yield, DTPA-Pb and its content in the plants

EDTA levels	Fresh biomass				DTPA Pb			
	Amara nthus	Fodder cowpea	Cluster bean	Mary gold	Amara nthus	Fodder cowpea	Cluster bean	Mary gold
0	34.7	68.0	55.0	217	14.7	14.8	9.7	10.2
50	49.0	64.8	63.3	249	18.7	16.5	11.0	11.3
100	38.9	56.6	54.1	269	21.8	18.7	11.8	12.2
Mean	40.8	63.1	57.5	245	18.4	16.7	10.8	11.2
CD (P = 0.05)	7.70	NS	7.40	48.0	4.10	1.50	NS	NS
EDTA levels	Total Pb content				Translocation co efficient			
0	267	324	217	166	1.72	2.02	4.29	2.61
50	339	376	249	196	1.96	2.07	4.39	2.66
100	376	420	279	221	1.92	2.11	4.43	2.74
Mean	328	373	249	194	1.87	2.07	4.37	2.67
CD (P = 0.05)	42.0	51.0	41.0	22.0	-	-	-	-

7.6 Pollution Studies on Paper and Pulp and Sugar Industries in Uttarakhand:

The properties of industrial effluents of Paper & Pulp industries, Sugar Mill and also a typical regional tube well water and its effect on soil properties was studied. The effect of lateral seepage of effluent on soil properties adjoining the main effluent drain of Century Paper Mill (Lalkuan), Cheema Paper Mill (Bajpur) was also studied. Plant samples were also collected to study the changes in elemental composition of plants, due to effluent irrigation in farmer's fields. The paper mill effluent was collected from four locations downstream the main drain of Century Paper Mill, Lalkuan. The samples were collected at a distance of about 0.5 Km of mills. Plant samples were also collected to study the changes in elemental composition of plants, due to effluent irrigation in farmer's fields. There was a considerable decrease in the concentration of solids and soluble nutrients in the effluents during the course of its flow downstream. The effluent characteristics particularly, the total solids, BOD, COD and content of Mn were higher than ISI prescribed limits. Lateral seepage with paper mill effluent in farmer's fields increased the EC in the soil. Higher C content in soil was noted with the lateral seepage of effluent of Cheema Paper Mill, Bajpur. An increase in EC of soil was due to the enrichment of soil with the soluble salts present in the effluents. The contents of P, K and micronutrient cations in plants decreased with the increasing distance from the point of discharge of the effluent. The concentration of toxic heavy metals in soil or plant samples was not alarming. Higher concentration of Na and chlorides in the effluent especially, at relatively smaller distances from the discharge point are injurious to soil and crops (Table 7.8).

Table. 7.7 Effect of sources of organics on the fresh biomass yield, DTPA Pb and its content in the plants

Treatments	Fresh biomass				DTPA Pb			
	Amaranthus	**Fodder cowpea**	**Cluster bean**	**Mary gold**	**Amaran thus**	**Fodder cowpea**	**Cluster bean**	**Mary gold**
No organics	40.6	49.5	58.4	170	18.5	12.4	7.8	9.0
FYM 5 t ha^{-1}	51.5	69.7	67.7	293	17.0	18.1	13.1	13.4
Green leaf manure 5 t ha^{-1}	37.0	72.8	47.7	304	20.8	20.6	12.1	12.2
Microbial innoculam 2 kg ha^{-1}	34.3	60.5	43.6	212	17.2	15.6	9.7	10.3
Mean	40.8	63.1	52.8	245	18.4	16.7	10.8	11.2
CD (P = 0.05)	15.3	14.1	NS	32.0	1.80	1.40	1.47	1.12
Treatments	**Total Pb content**				**Translocation co efficient**			
No organics	229	228	135	120	1.57	1.62	3.57	2.30
FYM 5 t ha^{-1}	469	534	344	275	1.97	2.37	4.87	2.87
Green leaf manure 5 t ha^{-1}	392	413	300	215	1.95	2.31	4.83	2.77
Microbial innoculam 2 kg ha^{-1}	301	319	216	167	1.68	1.97	4.20	2.72
Mean	348	373	249	194	1.87	2.07	4.37	2.67
CD (P = 0.05)	38.1	38.3	44.4	35.2	-	-	-	-

Table: 7.8 Characteristics of paper mill effluent at different locations downstream in the main drain.

Character	Century Paper & Pulp Mill, Lalkuan		Cheema paper mill ,Bajpur		Sugar mill,Bajpur		Tube well water	
pH	7.32	7.38	7.46	7.65	7.48	7.56	6.72	7.58
EC(ds/m)	1.29	1.74	1.48	0.79	1.1	1.3	1.4	0.4
BOD(mg/l)	306	408	306	306	306	408	612	51
COD(mg/l)	4357	3983	1736	647	1532	1123	4119	238
TSS(mg/l)	460	240	200	80	480	340	160	traces
TDS(mg/l)	1380	1120	1000	480	700	760	1360	160
TS (mg/l)	1840	1360	1200	560	1180	1100	1520	160
Bicarbonate(mg/l)	440	408	396	352	440	515	503	201
Chloride (mg/l)	347.6	268.0	195.5	43.5	57.9	72.4	36.2	7.2
Ammonical nitrogen (mg l^{-1})	7.92	6.48	5.04	0.72	1.44	0.72	0.72	0
Nirtrate nitrogen (mg l^{-1})	2.48	4.96	4.96	42.16	12.4	4.96	4.96	2.48
Phosphorus(mg/l)	0.98	0.46	0.58	0.8	0.22	0.26	0.24	0.08
Sulphur(mg/l)	0.27	0.36	0.15	0.17	0.26	0.48	0.33	0.07
Calcium (mg/l)	2346	2080	2195	1614	1954	2261	2057	1336
Magnesium (mg/l)	51	51	51	50	68	88	53	41
Sodium (mg/l)	826	807	817	347	450	758	820	128
Potassium (mg/l)	334	270	240	128	111	166	292	62
Iron (mg/l)	0.73	0.33	0.45	0.17	0.32	1.04	0.95	0.33
Copper (mg/l)	0.0060	0.0005	0.0005	0.0003	0.0020	0.0010	0.0050	0.0010
Manganese (mg/l)	0.25	0.23	0.14	0.07	0.17	0.23	0.32	0.001
Zinc (mg/l)	0.04	0.006	0.01	0.012	0.02	0.029	0.023	0.03
Cobalt (mg/l)	0.021	0.007	0.011	0.004	0.012	0.008	0.007	ND
Cadmium (mg/l)	0.004	ND	ND	ND	ND	ND	ND	ND
Lead (mg/l)	0.081	0.045	0.067	0.05	0.06	0.071	0.069	0.053

7.7 Phyto-extraction Ability of Raya, Broccoli and Hyolla for Lead in the Presence and Absence of EDTA

A green house experiment was conducted at Ludhiana centre to asses the phyto-remedial potential of Brassica species namely Raya, Broccoli and Hyolla with eight levels of Pb (0, 40, 80, 160, 240, 320, 480 and 640 mg kg^{-1} soil) and two levels of EDTA (0 and 1 g kg^{-1} soil) in a factorial RBD on a sandy loam soil. The mean lead content in all the crops increased successively as the rate of Pb application to soil increased. The mean Pb content in hyolla shoot increased from 2.05 without Pb to 160µg g^{-1} dry matter with 640mg Pb kg^{-1} soil application. The rate of Pb application resulted in significant increase in Pb content of crops although it was dependent on the crops. The application rate of 40 mg Pb kg^{-1} soil significantly increased the Pb content in all the crops. Comparing the content of Pb in the shoots of various crop, it was found that raya contained highest content of Pb in shoots followed by broccoli and hyolla. Lead contents in roots were invariably higher as compared to their values in shoots of all the crops at all levels of added lead. It implied that the decrease in dry matter yield was the consequence of the phytotoxic effect of Pb in all the crops emanating from the increased availability of Pb in soil and plants as a result of its application. The rate of Pb at which significant decline in dry matter yield occurred was 160 mg Pb kg^{-1} soil for all the crops. Raya accumulated the highest content of Pb in its shoot and roots, thus showing its highest phyto-remedial potential among other brassica species. The yield reduction at 160 mg Pb kg^{-1} soil was 15.7, 14.2 and 19.4 percent in the shoots of raya, broccoli and hyolla respectively indicating that the extent and magnitude of decrease varied with crop species at different Pb levels Application of EDTA in general decreased the dry matter yield of the shoots of all the crops irrespective of Pb levels. The percent decrease in dry matter yield depended upon the crops. It was 8.6, 9.9 and 9.5 percent in the shoots of raya, broccoli and hyolla respectively. The reduction in yield may be attributed to the increase in Pb content with the addition of EDTA. Dry matter yield of root also followed the same trend.

A peculiar kind of Pb uptake pattern was observed in shoots and roots of all the crops. It was a consequence of both reduction in yield due to Pb toxicity and increased uptake of Pb at higher rates as reduction in yield was compensated by higher Pb absorption. If the uptake of Pb for raya, broccoli and hyolla were compared, it was seen that there was higher Pb uptake in raya followed by broccoli, and hyolla indicating high capability of raya to extract metal from the contaminated soils.(Table7.9)

7.8 Monitoring of Pollution in Untreated and Treated Sewage Water for its use in Agriculture

Ludhiana centre studied the quality of both untreated and treated sewage water from the sewage treatment plants (STPs) were tested in terms of different parameters such as BOD=Biological oxygen demand; COD=Chemical oxygen demand; TS=Total solids; TDS=Total dissolved solids: TSS=Total suspended solids; RSC=Residual sodium carbonates; SAR=Sodium adsorption ratio, arsenic, cadmium, chromium, nickel, lead, barium, boron, sodium, zinc, copper, iron, manganese, carbon, nitrogen, phosphorus, potassium, calcium, magnesium and sulpur.

Biological oxygen demand and chemical oxygen demand were in permissible limit as per standards set by Punjab Pollution Control Board. Total dissolved solids in treated water of Bhatian were in the permissible limits but not that of

Jamalur. Suspended solids in treated water in both of the STPS surpassed safe limits. Treated water of STP Bhattian can be used for irrigation without any risk of salinity and sodicity for all type of soils as EC, SAR and RSC of these water samples were in safe limits. Treated sewage water of STP Jamalpur had EC and RSC in marginal range. This water can be used for irrigation by mixing with good quality water on light textured soils as it has higher salinity. These waters contained substantial amount of plant nutrients. Toxic metals such as arsenic, cadmium, chromium, nickel, and lead were in safe limits.

Table 7.9 Effect of Pb and EDTA levels on dry matter yield (g pot^{-1}) of shoots of different crop

	Pb levels (mg kg^{-1} soil)								
EDTA levels (g kg^{-1} soil)	0	40	80	160	240	320	480	640	Mean
Raya									
0	15.50	15.50	15.07	13.44	12.11	10.98	9.24	6.09	12.24
1	15.08	14.65	14.33	12.33	10.84	9.25	7.88	5.13	11.19
Mean	15.29	15.07	14.70	12.89	11.47	10.11	8.56	5.61	-
Broccoli									
0	17.79	17.76	17.25	15.12	13.73	12.30	10.28	6.71	13.87
1	16.75	16.38	15.95	14.53	12.35	11.26	7.74	4.98	12.49
Mean	17.27	17.07	16.60	14.82	13.04	11.78	9.01	5.84	-
Hyolla									
0	14.75	14.71	14.17	11.91	10.96	9.09	7.58	4.96	11.02
1	14.03	13.20	13.32	11.28	9.66	8.04	5.75	4.51	9.97
Mean	14.39	13.95	13.74	11.60	10.31	8.57	6.66	4.73	-

CD (5%)	Raya		Broccoli		Hyolla	
For	EDTA levels	= 0.39	EDTA levels	= 0.51	EDTA levels	= 0.55
	Pb levels	= 0.78	Pb levels	= 1.02	Pb levels	= 1.10
	EDTA x Pb	= NS	EDTA x Pb	= NS	EDTA x Pb	= NS

Table 7.10 Composition of untreated and treated sewage water of Sewage Treatment Plant (STP) Bhattian from April 2008 to March 2009

Pollutant elements	Untreated				Treated			
	Min	Max	Mean (n=12)	SD	Min	Max	Mean (n=12)	SD
pH	7.21	8.15	7.66	0.30	7.22	8.14	7.65	0.27
EC (dS m^{-1})	1.24	1.79	1.51	0.18	1.08	1.86	1.46	0.26
BOD (mg L^{-1})	120	204	148	29	22	56	37	9.04
COD (mg L^{-1})	350	744	505	124	80	252	153	61
T S (mg L^{-1})	860	5000	1803	1102	760	1860	999	356
T DS (mg L^{-1})	580	4680	1448	1090	535	1800	862	369
T SS (mg L^{-1})	200	530	355	91	40	342	135	90
CO_3^{-2} (meq L^{-1})	1.2	2.8	2.3	0.5	0.8	2.4	2.0	0.6
HCO_3^{-2} (meq L^{-1})	4.3	11.0	6.7	1.9	3.6	10.0	5.8	2.1
Ca + Mg (meq L^{-1})	4.5	5.7	5.2	0.3	4.3	6.0	5.3	0.5
RSC (meq L^{-1})	0.8	9.3	3.4	2.2	0.7	6.5	2.2	1.7
SAR	1.5	6.2	3.8	1.2	1.7	5.7	3.3	1.1
Chloride (meq L^{-1})	4.0	9.3	6.9	1.4	3.5	9.6	7.0	1.8
Sodium (mg L^{-1})	56.8	237.0	145.5	44.1	63.3	226.0	128.0	45.2
E. coli (MPN $(100ml)^{-1}$)	1100	>2400	Mode 1100		150	460	Mode 290	
Plate count (Cfu ml^{-1})	8.0×10^3	21.9×10^3	14.9×10^3	5.1×10^3	1.4×10^3	11×10^3	6.9×10^3	3.2×10^3

BOD=Biological oxygen demand; COD=Chemical oxygen demand; TS=Total solids; TDS=Total dissolved solids: TSS=Total suspended solids; RSC=Residual sodium carbonates; SAR=Sodium adsorption ratio

7.9 Impact of Sewage Irrigation on Chemical forms of nickel in soils

Sequential fractionation was carried out by Ludhiana centre to partition Ni in to fractions such as Exchangeable and water soluble, organic bound, carbonate bound, Mn oxides bound, amorphous Fe oxides, crystalline Fe oxides bound and residual in the tube-well and sewage irrigated soils of four industrial towns of Punjab, Ludhiana namely Jalandhar, Mandi, Gobindgarh and Amritsar. Sequential fractionation indicated that every extracted fraction exhibited increase in Ni content with sewage irrigation with most prominent increases occurring in the organic and oxide fractions in all the towns. The lowest amount of Ni in exchangeable and water soluble and the highest in residual pools testify that plants grown on these soils may not suffer from Ni toxicity and therefore exhibiting no symptoms of Ni toxicity.

7.10 Effect of Musi water pollution on paddy seed production in Hyderabad

Survey was carried out by Hyderabad centre from all along the Musi River belt to know the impact of this water on seed production and a total of eight-bench mark sites were fixed. Water and soil samples were collected first at the beginning of the crop season. Paddy is grown in these sites. At the end of the crop season, again soil, water and plant samples (whole plant and grain) were collected from the same spots. Four varieties of paddy grains were collected. Nurseries were raised for all the four varieties in a non-polluted soil irrigated with non-polluted water.

The heavy metal and micronutrient content of the water samples collected during the initial and harvest stages of the crop season were in the normal range (Table 7.11 & 7.12).The heavy metal and micro nutrient contents of all the soil samples collected were also in the normal range except Pb in the samples collected at the end of the crop season (Table 7.12). Micronutrient and heavy metal contents of all the plant samples are in the higher range except Cd and Co. The contents were higher in the grain samples also except Ni and Cd. The micronutrients and heavy metal content in the plant and grain samples of the non polluted environment is comparatively lower than the polluted environment. The reduction is more in the grain samples but still the contents weree found to be more than the permissible limits (Table 7.13).

Table 7.11. Micronutrient and heavy metal contents in water samples collected at harvest stage of the crop season

Water source	heavy metal contents mg l^{-1}								
	Cr	Cu	Mn	Fe	Co	Ni	Cd	Pb	Zn
Karremula canal	0.028	0.01	0.0227	0.058	0.033	0.027	0.009	0.10	0.002
Well water	0.23	0.32	0.0208	0.018	0.041	0.021	0.009	0.08	0.042
Edulabad canal	0.004	0.024	0.0196	0.015	0.032	t	0.006	0.11	0.025
Edulabad cheruvu	0.001	0.021	0.0137	0.018	0.035	0.013	0.009	0.10	0.016

Table. 7.12. Micronutrient and heavy metal contents in soil samples collected at initial stage of the crop season

Water source	heavy metal contents mg l^{-1}								
	Cr	Cu	Mn	Fe	Co	Ni	Cd	Pb	Zn
Karremula canal	0.014	2.174	3.38	33.56	0.076	0.502	0.016	0.98	1.908
Well water	0.050	2.25	6.62	34.56	0.140	0.678	0.078	2.24	5.610
Edulabad canal	0.078	3.63	8.76	32.58	0.134	0.658	0.124	2.60	9.14
Edulabad cheruvu	0.056	1.10	5.78	32.34	0.092	0.210	0.002	0.90	1.470

7.11 Assessing and Mapping of Pollutant Element Status in Soils of Non- industrial Areas of Andhra Pradesh

Survey was carried out in all the districts of Andhra pradesh and non-polluted soils were collected. Twenty-five soil samples were collected from the non-polluted areas in each district of Andhra Pradesh. The collected soil samples were analyzed for all the micronutrients and heavy metals so as to arrive the reference level for the non-polluted soils. The mean heavy metal contents present in the non polluted soil 1.63 mg kg^{-1} for copper, 25.36 mg kg^{-1} for manganese, 12.61 mg kg^{-1}

Table 7.13. Micro and heavy metal status (mg kg^{-1}) of plant and grain samples collected at harvest in non-polluted soils

Element	Normal	Plant		Grain	
		Range	Mean	Range	Mean
Cr	1.0	0.81-22.73	1.41 (-38.9%)	3.32-7.27	6.84 (-2.14%)
Cu	4.0	5.05-8.45	6.16 (-38.02%)	4.7-5.95	5.24 (-96.38%)
Mn	50	56.0-236.0	128.0 (-8.57%)	11.83-17.35	14.51 (-89.56%)
Fe	60	188.0-280.0	241.0 (-42.75%)	19-276	18.8 (-93.3%)
Co	0.1	4.3-4.72	4.51 (-12.2%)	0.3-0.36	0.34 (-19.0%)
Ni	1.0	3.9-5.17	4.66 (-8.62%)	0.039-0.048	0.43 (-36.76%)
Cd	0.5	0.52-0.65	0.60 (-7.69%)	0.35-0.4	0.375 (-9.75%)
Pb	2.0	4.75-8.5	6.31 (-62.88%)	3-6.2	4.62 (-95.1%)
Zn	10	14.4-27.2	20.67 (-14.02 %)	12.9-16.85	15.46 (-63.27 %)

- denotes decrease in Percentage

for Iron, 0.289 mg kg^{-1} for Cobalt, 0.39 5mg kg^{-1} for Nickel 0.0399 mg kg^{-1} for Cd, 0.978 mg kg^{-1} for Pb and 0.94 mg kg^{-1} for Zn. Cr content is in traces in the normal non polluted soil.

7.12 Industrial Effluents contaminated and Bioremedial soils- Effect on heavy metal content in edible crops and human health in Andhra Pradesh

A study was conducted in Ranga Reddy and Medak districts which are surrounded by highly polluted industries. The farmers in these districts used industrial effluent contaminated water for irrigating the crops. The soil, water, food and blood samples collected from the Cherlapalli (Uppal mandal), Patancheru and Ramachandrapuram (Ramachandrapuram Mandal) and Munagala (Munagala mandal) were analysed for heavy metals.

Soil and water analysis showed to contain heavy metal contents on the upper side of safe limits and the crops grown in these fields found to have significantly higher contents of heavy metals. A short duration green leafy vegetable-Fenugreek was grown in the polluted soil using four yeast strains- *Saccharomyces cerevisiae NCYC 1190* and three locally available yeast cultures namely AMB111,112 and 113 in liquid form with FYM and varied concentration of sugar. Crop was harvested after ten days of sowing for analysis of heavy metals. Yeast culture AMB 113 with FYM and 3 % sugar concentration was found to be effective in remediation of heavy metals and micronutrients in soil and fenugreek samples. Thus the study signifies the usefull ness of microbial processes to clean up metallic contaminants, which in turn reduce the entry of toxic heavy metals into the human food chain

7.13 Assessment of Nature and Extent of Pollution in Soils and Plants through Sewage Water in Nagpur and Nashik

The survey was conducted to identify the farmers who are using the city sewage effluent for irrigating the field and vegetable crops in the peri urban areas in Nagpur and Nashik district. The sewage effluent samples were collected from city nala/river flowing out of the city to assess the extent of heavy metal and nutrient content. The pH and electrical conductivity of sewage effluent ranged from 6.73 to 7.25 and 0.42 to 1.64 dS m^{-1} at both the location. The mean pH was recorded lower in soil irrigated with sewage effluent water (7.42) as compared to soil irrigated with well water (7.82) which showed reduction in pH. The electrical conductivity of soil irrigated with sewage effluent water was found higher (1.30 dS m^{-1}) as compared to soil irrigated with well water (0.34 dS m^{-1}). The organic carbon content in the soils was found to be higher (15.20 g kg^{-1}) in the soils where it was continuously irrigated with sewage water as compared to soil irrigated with well water (5.09 g kg^{-1}).

Average DTPA extractable micronutrients, sulphur and heavy metals were also found higher in the soils irrigated with sewage water. The mean Zn, Fe, Mn, Cu, S, Co and Cd were found to be 4.54, 16.40, 15.21, 7.05, 41.32, 0.553, and 0.131 mg kg^{-1} respectively, while in well water irrigated area it was found to be 0.91, 8.09, 11.23, 1.28, 19.67, 0.017, and 0.010 mg kg^{-1} respectively (Table 7.14).

Table 7.14. Micronutrients and heavy metal status of soil irrigated with sewage effluent and well water in peri-urban area of major cities in Maharashtra

Location of sampling sites	DTPA-Micronutrients & Heavy metals (mg kg^{-1})					
	Zn	**Fe**	**Mn**	**Cu**	**Co**	**Cd**
Soils irrigated with sewage effluents	4.54	16.40	15.21	7.05	0.553	0.131
Soils irrigated with well water	0.98	8.09	11.23	1.28	0.017	0.010

The organic carbon content in the soil irrigated with sewage effluent irrigated soil showed significantly high and positive correlation with Cd (r = 0.84**), Zn (r = 0.81**) and medium positive correlation with Cu (r = 0.65**), S (r = 0.56*), Fe (r = 0.55*), Mn (r = 0.51*) and Co (r = 0.51*).

The georeferenced profile soil samples were collected from the fields where the sewage effluent is used for irrigating the vegetable crops, cereals, forage etc. and the fields where the well water used in Nagpur and Nashik district. The soil samples were analysed for pH, electrical conductivity, $CaCO_3$ and organic carbon content. In case of $CaCO_3$ it ranged from 3.18 to 8.18 % (Nagpur) and 5.38 to 10.75 % (Nashik) and found to be increased with depth. The organic carbon content ranged from 11.6 to 14.8 hg kg^{-1} (Nagpur) and 12.4 to 16.3 g kg^{-1} (Nashik) and decreased with the depth. At location where the soil were irrigated with well water , pH ranged from 7.60 to 8.24, electrical conductivity ranged from 0.362 to 0.612 dS m^{-1}, $CaCO_3$ varied from 3.75 to 8.18 % and organic carbon ranged 2.14 to 6.16 g kg^{-1}. The mean DTPA extractable micronutrients Zn (5.17), Fe (23.50), Mn (21.07) Cu (8.46) and heavy metals Co (0.665) and Cd (0.164) were also recorded higher in the soil irrigated with sewage effluent water as compared to soils irrigated with well water Zn (1.21), Fe (13.76), Mn (12.34) Cu (1.56) and heavy metals Co (0.011) and Cd (0.006).

The content of S, micronutrients (Zn, Fe, Mn, Cu) and heavy metals (Co, Cd) were more concentrated in the upper soil horizon and their concentration was recorded to be reduced with the depth of soil (Table 7.150).

Table 7.15. Micronutrients and heavy metal status of soil collected from profile from the area irrigated with sewage water and well water in peri-urban areas Nagpur and Nashik districts (average 5 sites)

Location	DTPA-Micronutrients & Heavy metals ($mgkg^{-1}$)					
	Zn	Fe	Mn	Cu	Co	Cd
Soil Irrigated with Sewage water						
0 – 20 cm	5.17	23.50	21.07	8.46	0.665	0.164
20 – 40 cm	2.42	18.51	13.68	5.94	0.555	0.155
40 – 60 cm	0.85	9.47	10.17	1.30	0.340	0.065
Soil Irrigated with well water						
0 – 20 cm	1.21	13.76	12.34	1.56	0.011	0.006
20 – 40 cm	1.12	13.14	10.78	1.36	0.008	0.002
40 – 60 cm	0.9	9.62	7.97	1.22	0.005	0.001

In another comparative study, Akola center found that the content of various elements were higher in the sewage cum effluent of Kalyan as compared to the less industrialized city of Nasik and Nagpur. The concentration of metals such as Zn, Fe, Cu, Mn, Cd, Ni, Co and Pb was higher in Kalyan 6.2, 26.4, 2.54, 11.8, 5.7, 11.8, 0.036, 24.2 mgL^{-1} medium in Nagpur 5.4, 14.8, 2.0, 9.4, 4.6, 8.4, 0.024, 20.6 mgL^{-1} and lowest in Nasik 4.8, 9.12, 1.75, 8.6, 3.2, 6.4, 0.018, 12.8 mgL^{-1} respectively . This high concentration in metals of Kalyan is due to the presence of large number of industries of all types. The average higher values of 164 mgL^{-1} at Kalyan and 126 MgL^{-1} at Nagpur. Biological oxygen demand (BOD) which indicate higher pollution potential of waste water. The values of BOD of sewage effluent of Kalyan and Nagpur were above the maximum limit of 100 mg L^{-1} proposed by FAO for irrigation. Therefore sewage water of Kalyan and Nagpur can only be used safely for irrigation after proper dilution.

The soil under study were neutral to slightly alkaline in reaction (7.3 to 7.8), electrical conductivity ranged from 1.24 to 2.10 dSm^{-1} which may be due to high amount of soluble salts in irrigation water such as chlorides, sulphates and bicarbonates due to the contamination. Organic carbon content was 1.12 to 36% and these higher values may be due to higher content of organic matter in the sewage water. Soils irrigated with sewage effluent were highly polluted with all heavy metals The soils irrigated with sewage effluent had higher contents of micronutrients and heavy metals as compared to the corresponding ground water irrigated soils.

7.14 Phytoextraction of Heavy Metals by Different Plant Species to Evaluate Their Suitability for Phytoremediation.

Anand centre studied the quality of effluent and tube well water in both contaminated and non-contaminated area of *Khari* canal and ECPL channel could be referred as 'poor' for irrigation purpose as the water contained higher soluble salts besides appreciable quantity of heavy metals.

In general, seed and root dry matter yield was significantly depressed under contamination soil condition. However, the total biomass yield of castor and tobacco was enhanced due to irrigation with effluent water.

In general, the content of trace and heavy metals as well as their uptake by root, stem, leaf and seed of different crops were higher under effluent irrigated and The overall findings of the present study indicated that the castor could remove more quantity of total heavy metals (Cd + Ni + Cr + Co + Pb) from contaminated soil in one cropping season than other crops viz., cotton, tobacco and sunflower. However, the extraction efficiency of tobacco for total heavy metals was higher than the other crops for production of unit biomass per unit time; and followed the ascending order tobacco > sunflower > cotton > castor. Therefore, the suitable crop needs to be selected for bioremediation of contaminated site depending on the factors like availability of time and economic importance of the crop.

Table 7.16. Effect of different irrigation water on yield of seed of crops under different soil conditions

Soil (S) and Crops (C)		Seed (g plot^{-1})						
		Irrigation water (I)						
		I_1 (Effluent)		I_2 (1:1)		I_3 (TW)		Mean (SxC)
S_1 (Contaminated)	SF	315		169		152		212
	CT	259		214		369		281
	CS	6207		5205		4683		5365
Mean (S x I)		2260		1863		1735		1952 (S_1)
S_2 (Non-contaminated)	SF	195		188		142		175
	CT	279		223		324		276
	CS	5760		5977		6497		6078
Mean (S x I)		2078		2129		2321		2176 (S_2)
Mean (I)		2169		1996		2028		
Mean (C)		SF		CT		CS		
		193		278		5721		
		S	C	I	S x C	S x I	C x I	S x C x I
S.Em. ±		71.57	87.65	87.65	123.96	123.96	151.82	214.71
CD @ 5%		206	253	NS	358	358	NS	619

The absolute quantity of total heavy metals (Cd + Co + Cr + Pb + Ni) removal was higher in castor followed by cotton, which was about 10 times higher than other crops. The removal of the total metals (Cd + Ni + Cr + Co + Pb) was comparatively higher under effluent irrigation than tube well irrigation. However, the percent reduction in total heavy metals from the soil was more due to tube well irrigation than effluent water (data not shown).

Although, the castor could remove maximum amount of heavy metals in a season, its efficiency of phytoextraction on the basis of unit biomass production (mg kg^{-1}) per unit time (mg kg^{-1} day^{-1}) was the least, while tobacco and sunflower were superior with almost equal efficiency in this respect. The same was further confirmed by higher accumulation factors values in tobacco and minimum with castor.

The mobility index values were computed to evaluate the translocation behavior of different heavy metals at different growth stages. The absorption of the metals from soil to root was faster in sunflower than other crops, but the translocation of these metals was least from seed to oil except Pb. The mobility values of Cr were higher in cotton; Ni and Co in castor and Pb in sunflower.

The soil pH, EC, OC and DTPA-heavy metals and micronutrients were higher under contaminated soil than non-contaminated soil; however, the overall pH tended towards neutrality under both the soil conditions. The increase in EC was more after tobacco and soil OC also increased after harvest of the crops over initial value under both the soil conditions. The soil status of DTPA-extractable Mn and Cu were improved after harvest of the different crops; whereas DTPA-Fe and Zn showed reverse trend over the initial value. In general, the DTPA-micronutrients were higher under effluent irrigated soil than tube well water irrigated soil at or after harvest of the crops.

The contents of all the DTPA-heavy metals were higher under contaminated soil condition than non-contaminated soil. Also there was an increase in DTPA-heavy metals of soil over their corresponding values after harvest of the crops under both the soil conditions. The cotton and sunflower reduced the DTPA-Cr and Cd followed by castor more effectively than tobacco under effluent irrigated soil condition. The total heavy metals (Cd, Ni, Cr, Co and Pb) were reduced from the soil under both the soil conditions and different irrigation water due to growing of the crops. However, total heavy metals reduction was higher due to castor than tobacco and sunflower followed by cotton.

The phytoextraction efficiency for total heavy metals removal based on unit biomass production in a unit time followed the order as tobacco > sunflower > cotton > castor. However, the computed approximate time required to bring most limiting elements (Cr and Cd) below the permissible limit was minimum (about two to three years) with castor which indicated its superiority for phytoremediation of such contaminated soils.

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	02.01.1997	Continue
Dr. M.V. Singh	Past Project Coordinator	28.04.1988	31.3.2011
	ANGRAU, HYDERABAD, Andhra Pradesh		
Dr. G. Bhupal Raj	Senior Soil Chemist (Officer Incharge)	01.09.1991	12.05.2010
Dr. P. Suredndra Babu	Present Officer Incharge	13.05.2010	Continue
Mrs. M.C. Patnaik	Asstt. Research Officer	26.041988	Continue
Mr. K.M. Khadke	Senior Scientist	04.11.2001	Continue
Sr. Research Associate	Sr. Research Associate	12.08.1998	Continue
	RAU, PUSA, Bihar		
Dr. A.P. Singh	Officer Incharge	23.06.1998	27.07.2008
Dr. S.K. Singh	Senior Scientist	16.07.2007	Continue
Dr. Vipin Kumar	Jr. Scientist	31.03.2008	Continue
	AAU, ANAND, Gujarat		
Dr. K.P. Patel	Senior Soil Scientist (Officer Incharge)	29.09.1994	Continue
Mrs. V. George	Senior Scientist	26.11.1975	Continue
Mr. V.P. Ramani	Senior Scientist	01.12.1990	Continue
	CCSHAU, HISAR, Haryana		
Dr. Ramkala	Senior Soil Scientist (Officer Incharge)	01-06-2009	continue
Dr. Sukhbir Singh	Senior Scientist	01.08.2009	continue
Dr. R.S. Malik	Asstt. Soil Scientist	20.02.2002	continue
Dr. R. R. Dahiya	Research Associate	01.09.1995	Continue

JNKVV, JABALPUR, Madhya Pradesh

Dr. P.S. Kulhare	Officer Incharge	29.03.2010	Continue
Dr. B.L. Sharma	Senior Scientist	8.09.1996	28.03.2010

PAU, LUDHIANA, Punjab

Dr. U.S. Sadana	Officer Incharge	06-11-2007	Continue
Dr. M.P. Khurana	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. V. Velu	Senior Soil Chemist	03.04.2006	04.05.2008
Dr. P Stain	Officer Incharge	09.05.2008	Continue
Dr. D.Muthumanickam	Asstt. Professor	19.09.2006	Continue
Dr. T. Chitdeshwari	Asstt. Professor	11.05.2007	Continue

LUCKNOW UNIV, LUCKNOW, Uttar Pradesh

Dr. (Mrs.) N. Khurana	Asstt. Soil Scientist	26.03.1981	31.12.2009
Dr. B.K. Dube	Asstt. Plant Physiologist	10.03.1989	31.03.2009
Dr. (Miss) P. Sinha	Sr. Research Asstt.	10.3.1989	Continue
Dr. Sunil Gupta	Sr. Research Asstt.	04.9.1984	30.06.2010

GBPUAT, PANTNAGAR, Uttarakhand

Dr. P.C. Srivastava	Officer Incharge	01.11.1997	Continue

OUAT, BHUBNESWAR, Orissa

Dr. M.R. Patnaik	Professor	26.06.2002	01.06.2009
Dr. A. K. Pal	Professor & OIC	01.06.2009	Continue
Dr. S.C. Nayak	Asstt. Professor	06.12.1996	Continue

	PDKV, AKOLA, Maharashtra		
Dr. D.B. Patil	Asstt. Soil Scientist	20.05.1998	04.08.2009
Dr. R.N. Katker	Officer Incharge	04.08.2009	Continue
Dr. G. S. Laharia	Jr. Res. Scientist	18.01.2010	Continue

COOPRATIVE CENTERS

	AAU, JORHAT, Assam		
Dr. K. Borkakati	Professor	01.04.2009	11.07.2011
Dr. (Mrs.) Anjali Brahma	Officer Incharge	12.07.2011	Continue
	B.A.U Ranchi, Jharkhand		
Dr. R.P. Singh	Professor	01.04.2009	31.12.2011
Dr. Arvind Kumar	Officer Incharge	01.01.2012	Continue
Mrs. Gayatri Goswami	Research Associat	22.10.2009	Continue
	B.C.K.V Mohanpur, Nadia, W.B		
Dr. G.C. Hazra	Officer Incharge	01.04.2009	Continue
Mr. Bhola Nath Sahu	Research Associate	15.09.2009	Continue
	C.S.K. HPKV Palampur H.P.		
Dr. S.P. Sharma	Professor	01.04.2009	31.08.2011
Dr. S.K. Sharma	Officer Incharge	01.09.2011	Continue
	CSAUA&T Kanpur U.P.		
Dr. D.D. Tiwari	Officer Incharge	01.04.2009	Continue
Mr. Manoj Kumar	Sr. Res. Fellow	01.11.2009	Continue
Mr. Ravindra Kumar	Sr. Res. Fellow	01.11.2009	Continue

List of Publication

PCM UNIT, BHOPAL

Research papers

Behera, S.K. and Singh, D. (2010). Fractions of iron in soil under a long-term experiment and their contribution to iron availability and uptake by maize -wheat cropping sequence. *Communications in Soil Science and Plant Analysis (USA)* 41 (13): 1538-1550.

Behera, S.K. and Singh, D. (2010). Impact of continuous fertilizer use on fractions of manganese in soil and their contribution to availability and its uptake by maize (Zea mays)-wheat (Triticum aestivum) cropping system. *Indian Journal of Agricultural Sciences* 80 (**4**): 316-320.

Behera, S.K., Singh, D. and Dwivedi, B.S. (2009). Changes in fractions of iron, manganese, copper and zinc in soil under continuous cropping for more than three decades. *Communications in Soil Science and Plant Analysis* (USA) 40 (9& 10): 1380-1407.

Behera, S.K., Singh, D., Dwivedi, B.S. and Bhadraray, S. (2009). Fractions of copper in soil under long-term experiment and their contribution to Copper availability and uptake by maize-wheat cropping sequence. Journal of Plant Nutrition (USA) 32 (**7**):1092-1107.

Behera, S. K. and Singh, D. (2009). Effect of 31 years of continuous cropping and fertilizer use on soil properties and uptake of micronutrients by maize (Zea mays)-wheat (Triticum aestivum) system. Indian Journal of Agricultural Sciences 79 (**4**): 264-267.

Behera, S.K., Singh, D., Dwivedi, B.S., Singh, S., Kumar, K. and Rana, D.S. (2008). Distribution of fractions of zinc and their contribution towards availability and plant uptake of zinc under long-term maize (Zea mays L.)-wheat (Triticum aestivum L.) cropping on an Inceptisol. *Australian Journal of Soil Reaserch 46* (**1**): 83-89.

Popular article

Behera, S. K., Singh, M. V. and Lakaria, B. L. (2009). Micronutrients deficiencies in Indian soils and their amelioration through fertilization. Indian Farming (May, Volume 59, No. 2): 28-31.

Brij Lal, Panwar, N. R. and Behera, S.K.(2008). Mrida Parikshyana: Bidhi abam upoyagita. Mera Gaon Mera Desh (10-16 March) : 8.

Technical bulletin/book chapter/any other

Singh, M. V. and Behera, S. K. (2010). Biofortification – A new paradigm for Agriculture in Improving Human Health. In: Souvenir, 75th Annual Convention of Indian Society of Soil Science organized by IISS, Bhopal from 14 to 17 November: pp 111-120.

Singh, M. V. and Behera, S. K. (2009). Information Brochure of NAIP sub-project "Understanding the mechanism of variation in status of a few nutritionally important micronutrients in some important food crops and the mechanism of micronutrient enrichment in plant parts". Indian Institute of Soil Science, Bhopal. pp 1-6.

Singh, M. V. and Behera, S. K. (2009). Project document of NAIP sub-project "Understanding the mechanism of variation in status of a few nutritionally important micronutrients in some important food crops and the mechanism of micronutrient enrichment in plant parts". Indian Institute of Soil Science, Bhopal. pp 1-126.

Behera, S. K. (2009). Soil test for micronutrients. In: Proceedings of winter school on "Farmers' resource based site specific integrated nutrient management and on-line fertilizer recommendations using GIS and GPS tools" organized by IISS, Bhopal on 3-23 January: pp 397-404.

Singh, M. V., Behera, S. K. and Patel, K. P. (Editors) (2008). Extended Summaries: National Seminar on Micro and Secondary Nutrients for Balanced Fertilization and Food Security. Indian Institute of Soil Science, Bhopal, India. pp 215.

COIMBATORE CENTRE

Velu,V., Usha Mathew and A.Bhaskar. (2008). "Scenario of Micro and Secondary nutrient deficiencies in the states of Tamil Nadu, Kerela and Pondicherry and amelioration practices for increasing crop production and ensuing food security". Proc. of National seminar on 'Micro and Secondary Nutrients for Balanced Fertilization and Food Security" held at Anand Agricultural University, Anand, 11- 12th March. pp 29-30.

Muthumanickam,D, Subramaniam, K.S, Duraisamy, V.P and Velu, V. (2008). "Nutrient dynamics in intensive Sugarcane - sugarcane cropping systems" Proc. of National seminar on 'Micro and Secondary Nutrients for Balanced Fertilization and Food

Muthumanickam D., S.Natarajan, R. Sivasamy, R. Kumaraperumal and K.P.Ragunath.(2006). Drought assessment and monitoring through Remote sensing and GIS in kangayem taluk of Tamil Nadu Proceedings of International Conference on" Geoinformatics for Rural Development – Achieving Synergy between technical & Social Systems" held at Hyderabad

Stalin, P.and K.Natarajan 2008. Leaf colour chart based N management for irrigated rice in Tamil Nadu. *Indian Fertlizer Scene Annual Vol*. 21, p.67-72.

Stalin, P.S. Ramanathan, K.Natarajan, B.Chandrasekaran and R. Buresh (2008). Performance of site specific and real time N management strategies in irrigated rice . *J. Indian Soc.Soil Sci. vol.*56(2*) : 215-221.*

Stalin, P., T.Chiteshwari and D. Muthumanickam, (2008). Micronutrient deficiency in soils and their management, *Valarum Velanmai Vol*.35 (1) :14-20. (Tamil)

Muthumanickam, D., P. Stalin, and V.Velu. (2009). Fixing tolerance limit for Ni in soil and its bioavailability to *Amaranthus* sp *L.* In. National seminar on Recent Advances in Soil Health and Crop Management for Sustainable Agriculture held at Faculty of Agriculture, Annamalai University, Annamalainagar during February 26th to 27th, 2009.

Muthumanickam,D, Subramaniam, K, Duraisamy, V.P and Velu, V. (2008). Nutrient dynamics in intensive Sugarcane - sugarcane cropping systems**.** In National seminar on developments of Soil Science held at University of Agricultural Sciences, Bangalore during 26th to 28th November 2008.

LUDHIANA CENTRE

Research papers

Bansal RL and Khurana MPS (2007) Effectiveness of manganese carriers for the correction of its deficiency in wheat (*Triticum aestivum*). *Indian J. Ecology* 34 : 58-59.

Dhaliwal, S.S. and Manchanda, J.S. (2008) Different chemical pools of manganese as influenced by submergence, green manure and soil applied manganese under rice-wheat system. *Asian J Soil Sci.* 3(**1**): 166-172

Khurana M.P.S,. Bansal RL and Setia R.K. (2008) Yield and metal composition of Brinjal (*Solanum melongena*) and Pig- weed (*Amaranthus tricolor*) as influenced by lead contaminated soils. .*Agrochimica* LII-n.2 : 60-69.

Khurana M.P.S., Sadana U.S. and Chibba I.M. (2008) Manganese use Efficiency of Wheat (*Triticum aestivum L.*) and Raya (*Brassica juncea L.*) grown on Mn-deficient Soils. *Environment and Ecology* 26 : 575-578

Manchanda, J.S. and Bansal R.L. (2006) Yield and sulphur nutrition of soybean (*glycine max* l) and gobhi sarson (*brassica napus* l) as influenced by sources and levels of suulphur fertilization. J. Plant Sci. Res. 22: (3-4) 229-233.

Dhaliwal, S. S., Manchanda, J. S. and Tiwana U. S. 2009. Seed production of Egyptian clover(*Trifolium alexandrium* L) as influenced by foliar application of Zn, Mn, Mo and B on loamy sand soil. *Asian J Soil Sci*. 3(**2**):257-260

Khurana M P S and Bansal R L (2008) Impact of sewage irrigation on speciation of Nickel and its accumulation in crops of industrial towns of Punjab. *J Environ Biol* 29: 793-798

Manchanda, J. S., Dhaliwal, S S and Chhibba I M. 2008. Genotypic variations of Egyptian clover (*Trifolium alexandrium* L) to manganese deficiency in a typic haplustept. I*ndian J. Ecol*. 35 (**1**): 16-21.

Sayyari Zahan, M.H., Sadana U.S., Steingrobe, B. and Claassen, N. (2009) Manganese efficiency and Mn uptake kinetics of raya (Brassica juncea L.), wheat (Triticum aestivum L.) and oat (Avena sativa L.) grown in nutrient solution and soil culture. *J. Plant Nutr. Soil Sci. (Germany)* 172 (**3**): 425-434.

Singh, C. J., Thind H. S., Manchanda, J. S. and Kansal, B.D. (2009). Effect of coal fly ash on crop yield and soil health under cotton- wheat cropping sequence. *Environ and Ecol*. 27(**2**): 519-523.

Verma V K, Setia R K, Sharma P K, Khurana M P S and Kang G S (2007) Pedospheric distribution of micronutrient cations in soils developed on various land forms in north east Punjab. *J. Indian Soc Soil Sci* 55 : 515-520.

Popular articles

Bhatti, DS and Manchnada, JS (2007) *Narme ate Kapah Which Khuraki Tatan di Ghat ate Purti*. *In*: *Cotton Bulletin, Society for Sustainable Cotton Production*. 2 (**2**): 1-3.

Bhatti, D.S. and Manchnada, JS (2007) *Jamin Di Upjau shakti kiwen Barkrar Rahe.* Daily Ajit. 27.11.2007.

Chhibba I.M. , RL Bansal and SS Dhaliwal (2007) Manage Micronutrient Deficiencies in Rice .

Progressive Farming (5) :11-12.

Chhibba I.M., Bansal R.L. and Khurana M.P.S. (2006**)** Kanak atey berseem vitch manganese de ghat adan poori karo. Changi Kheti (Oct) 16-17.

Chhibba I.M., Bansal R.L. and Khurana M.P.S. (2006) Managing manganese deficiency in wheat, berseem. *Progressive Farming*. (Oct) 25-26

Chhibba I. M. , R L Bansal and S S Dhaliwal (2007) Jhone Vich Laghu Tattan Di Ghaat Aedan Puri Karo *Changi Kheti* .2007 (**5**) :14-15

Chhibba, IM and Sadana, US (2008) Micronutrient management for sustainable crop production. In: Chhibba, IM and SS Kukal (eds.) Irrigation water and soil fertility management in *Punjab. Tech. Bul*l. II, Niche Area of Excellence, Department of Soils, PAU, Ludhiana pp. 41-50.Dhaliwal SS and SS Walia (2007)

Integrated nutrient management for better soil health. *Progressive Farming*. (6):

Bhatti, D. S. and Manchnada, J. S**.** (2008). *Sauni dian faslan which chhote tatan di ghat ate purti*. August 2008. 23-24.

Bhatti, D. S. and Manchnada, J. S. (2008). Kanak ate berseem which chhote tatan dig hat di pehchan ate ilaj. Modern kheti. December 2008, 22-23.

Bhatti, D. S. and Manchnada, J. S.(2009). *Miti parakh rahi khadandi santulat warton karo.Changi kheti,* May 2009, 7-8

Bhatti, D. S. and Manchnada, J. S. (2009). *Wadh jhar lai jhone whichchotte tatan di ghat puri karo*. *Changi kheti*, June 2009. 16

Chibba I M, Khurana M P S and Sodhi G P S (2008) Kanak vitch manganese di ghat the poorti. Daily Ajit Jalandhar, Jan 10, 2008 (III)

Khurana, M P S, Ghuman, B.S and Sandhu K S (2009) Pardusit ate marey panian nu Khetiwitch vartan thay tarkey. *Changi Kheti* : Feb , pp16

Manchnada, J. S and Bhatti, D. S.(2009). *Correcting micronutrient deficiencies in paddy. Progressive Farming, May 2009, 16 & 22*

Book Chapter

Khurana, MPS, Sadana, US and Bijay-Singh (2008)

Sulfur nutrition of crops in the Indo-Gangetic plains of South Asia. In: Sulfur: A missing link between Soils, Crops and Nutrition. Agronomy Monograph 50. *American Soc. Agrorn.,Crop Sci. Soc. America and Soil Sci. Soc. America, Madison*, WI 53711, USA. Pp. 11-24

Manchanda, JS and Aulakh, MS (2007) Importance of interactions of nitrogen with primary, secondary and micronutrients in crop production and environmental safety – Indian Perspectives. *In*: *Agricultural Nitrogen Use: Environmental Implications.* Abrol Y.P., N. Raghuram and M.S. Sachdev (Ed.). *IK International Publishers, New Delhi.* pp 227-247.

Conference papers

Dhaliwal, SS and Manchanda, JS (2008) Critical level of B in soil for predicting response of green gram (*Phaseolus aureus* L.)to boron application. Paper presented at National Seminar on *Policy Intervention for Promotion of Balanced Fertilization Integrated Nutrient Management –A key to sustain Soil quality and crop productivity* organized by Department of Soil Science, CSK, HPKV, Palampur from April 10-11, 2008.

Khurana M.P.S. and Bansal R.L. (2007) Performance of some customized fertilizers containing zinc and manganese vis a conventional fertilizers in crop grown under field conditions. In Proc National Seminar on " Standards and technology of value added/fortified/customized fertilizers as a source of plant nutrients" sponsored by Ministry of Agriculture, Govt. of India, New Delhi-110001 at Bhopal from Sept 26-27, 2007 pp 54-55.

Khurana M.P.S. and Sadana US (2008) Response of Oilseed and Pulse crops to sulphur application on Alluvium derived soils of Punjab under field conditions. In Proc National Seminar on "Micro and Secondary nutrients for balanced fertilization and food security" sponsored by Ministry of Agriculture, Govt of India, New Delhi, held at Anand from March 11-12, 2008 pp 93-94.

Manchanda, JS. and Dhaliwal, S.S. 2008. Transformation of iron and its availability to wheat in a *Typic Haplustept* as influenced by phosphorus and manganese fertilization. Paper presented at National Seminar on *Policy Intervention for Promotion of Balanced Fertilization Integrated Nutrient Management –A key to sustain Soil quality and crop productivity* organized by Department of Soil Science, CSK, HPKV, Palampur from April 10-11, 2008.

Invited papers/lectures

Sadana, U.S. (2007) Efficient management of micronutrient deficiencies in rice-wheat cropping systems. Invited paper presented at Plant Nutrition Colloquium held at University of Goettingen, Germany on October 12, 2007.

Sadana, U.S. (2007) Micronutrients disorders – challenge to sustain food grain production in Punjab, India. Lead paper presented at International Seminar on Food Security, Biomass Energy and Livelihood Strategies held at University of Göttingen, Germany from 18-20 November, 2007

Sadana, U.S. (2008) Scenario of micro and secondary nutrient deficiencies in Punjab and amelioration practices for increasing crop production and ensuring food security. Invited paper-presented at National Seminar on "Micro and Secondary Nutrients for Balanced Fertilization and Food Security" held at Anand Agricultural University, Anand from March 11-12, 2008.

Sadana, U.S. (2008) Genetic variation in micronutrient use efficiency in crops. Invited paper- presented at Workshop on "Harnessing the Benefits of Biotechnology" held under the Indo-US Agricultural Knowledge Initiative (AKI) at the National Agricultural Science Centre, New Delhi from March 27-29, 2008

Sadana, U.S. (2008) Latest trends in nutrition supplementation practices. Invited lecture delivered at National Agribusiness Conference on "Making Balanced Crop Nutrition a National Imperative" held at CII, Chandigarh on 30.05.2008.

Technical Reports

Nayyar, V.K., Bansal, RL, Manchanda, JS, Khurana, MPS., Dhaliwal, SS and Sadana, US (2008) Research achievements of ICAR All India Co-ordinated Research Project on Micro-and Secondary Nutrients and Pollutant Elements in Soils and Plants-QRT report from 2002-2007.pp 1-85.

ANAND CENTRE

Ramani, V. P. Patel, B. K. Patel, K. P. and Patel, K. C. (2007)Effect of Ni and FYM on spinach and different forms of Ni in Fluventic Ustrochrepts of middle Gujarat. *Journal of Industrial Pollution Control.* 23**(2)** 327-335

Ramani, V. P; Patel, K. P.; Patel, K. C.; Patel, B. K. and George, V. (2008) Effect of Ni and FYM on yield and chemical composition of spinach grown on effluent irrigatived Fluventic Ustrochrepts of middle Gujarat. *Ecology Environment and Conservation*. 14 **(2-3)** 1-8).

Patel K. P. and M. V. Singh (2008)Scenario of Micro- and Secondary – Nutrients deficiency and their management in soils and crops of arid and semi- arid regions of Gujarat. Singh, M. V., Behera, S. K. and Patel K. P. (Eds.) 2008. Extended Summaries: National Seminar on Micro and Secondary Nutrients for Balanced Fertilization and Food Security, Indian Institute of Soil Science, Bhopal, India, pp 215

Patel, P. C., K. P. Patel, A. V. Kotecha and A. G. Sukhadia (2008) Reponse of Zinc and Boron nutrition on seed yield of LucerneSingh, M. V., Behera, S. K. and Patel K. P. (Eds.) Extended Summaries: National Seminar on Micro and Secondary Nutrients for Balanced Fertilization and Food Security, Indian Institute of Soil Science, Bhopal, India, pp 215.

Rathod D. D., K. P. Patel and K. C. Patel(2008) Enrichment technique of Zn- A promising tool to increase Zinc use efficiency and crop yields under Wheat- Maize (Fooder) cropping sequence. (2008). Singh, M. V., Behera, S. K. and Patel K. P. (Eds.) Extended Summaries: National Seminar on Micro and Secondary Nutrients for Balanced Fertilization and Food Security, Indian Institute of Soil Science, Bhopal, India, pp 215.

Mevada K. D., J. J. Patel and K. P. Patel (2008) Response of Micronutrients to Urdean (*Vigna Mungo* (L.) Hepper) . Singh, M. V., Behera, S. K. and Patel K. P. (Eds.) 2008. Extended Summaries: National Seminar on Micro and Secondary Nutrients for Balanced Fertilization and Food Security, Indian Institute of Soil Science, Bhopal, India, pp 215.

Janaki Singh N and K. P. Patel (2008).Effect of FYM and pressmud on yield of maize (Zea mays L.) and soil properties in shallow medium black soils of Vadodara district in Gujarat. Singh, M. V., Behera, S. K. and Patel K. P. (Eds.) 2008. Extended Summaries: National Seminar on Micro and Secondary Nutrients for Balanced Fertilization and Food Security, Indian Institute of Soil Science, Bhopal, India, pp 215.

Ramani V. P., M. V. Singh, K. P. Patel and K. C. Patel (2008). Effect of B application on crops yield and soil properties under Groundnut - Wheat sequence. Singh, M. V., Behera, S. K. and Patel K. P. (Eds.) 2008. Extended Summaries: National Seminar on Micro and Secondary Nutrients for Balanced Fertilization and Food Security, Indian Institute of Soil Science, Bhopal, India, p p 215

Patel K. P., G. N. Patel, B. T. Patel, D. R. Vaghasia and S. B. Patel (2008).Efficacy of customized fertilizers in correcting micronutrient deficiencies and enhancing yields and uptake of micronutrients by oilseeds in soils of Gujarat. Singh, M. V., Behera, S. K. and Patel K. P. (Eds.) 2008. Extended Summaries: National Seminar on Micro and Secondary Nutrients for Balanced Fertilization and Food Security, Indian Institute of Soil Science, Bhopal, India, pp 215

M. K. Dabhi, J. J. Patel, K. P. Patel and J. C. Shroff (2008).Response of Sulphur application on yeld and quality of Mustard (Brassica Juncea (L.) Czer and Coss) under middle Gujarat conditions.Singh, M. V., Behera, S. K. and Patel K. P. (Eds.) 2008. Extended Summaries: National Seminar on Micro and Secondary Nutrients for Balanced Fertilization and Food Security, Indian Institute of Soil Science, Bhopal, India, pp 215

K. C. Patel, M. V. Sing, K. P. Patel, V. P. Ramani and V. George (2008) Efficacy of Bentonite – Sulphur on crops yield and uptake of nutrients under Maize-Mustard cropping sequence in soils of middle Gujarat. Singh, M. V., Behera, S. K. and Patel K. P. (Eds.) 2008. Extended Summaries: National Seminar on Micro and Secondary Nutrients for Balanced Fertilization and Food Security, Indian Institute of Soil Science, Bhopal, India, pp 215.

Meena M.C. and K. P. Patel (2008) Long-term effect of sewage sludge and FYM on crops yield and availability of micronutrients under Pearlmillet-Mustard cropping sequence.Singh, M. V., Behera, S. K. and Patel K. P. (Eds.) 2008. Extended Summaries: National Seminar on Micro and Secondary Nutrients for Balanced Fertilization and Food Security, Indian Institute of Soil Science, Bhopal, India, pp 215

Patel, K. C., Ramani, V. P. and Patel, J. C (2008)Trace and heavy metals composition in crops grown in sewage irrigated *peri* urban area of Vadodara *Asian Jr. of Environ. Sci.,* 3(**1**): 39-45 (2008)

Patel, K. C., Patel, K.P., Ramani, V. P. and Patel J. C. (2008) Effect of Pb and FYM application on spinach yield, Pb uptake and different fractions of Pb in sewage irrigated *Fluventic ustochrepts* soils of *peri* urban area of Vadodara *An Asia Jr. of Soil Sci*., 3(**2**): 227-230 (2008).

Patel, K.C., Patel, K. P., Kandoria, K. L., Jetani, K. L. and Ramani, V. P (2008). Yield and uptake of micronutrients by groundnut (*Arachis hypogea* (L.)) as influenced by foliar application of seaweed liquid fertilizer under rainfed condition of Jamkhambhaliaya, Saurashtra region. An *Asia Jr. of Soil Sci*., 3(**2**): 252-257 (2008).

PUSA CENTRE

Research Publication

Kumar, Ajay; Singh, C. and Singh A.P. (2007). Response of age and reproductive stage on plasma cobalt concentration with and without feeding mineral mixture. *Indian Journal of Animal Sciences* 77 (7) pp 68-69.

Kumar, Ajay; Singh, C. and Singh A.P. (2007). Effect of mineral mixture on plasma iron concentration in heifers and cycling lactating cows. *Indian Journal of Animal Physiology,* January, Vol-2, pp 18-21.

R. Laik, Koushlendra Kumar and D. K. Das (2007) soil organic carbon and nutrient buildup in calciorthents soil. Forest, *Trees and Livelyhood* Vol.19.

R. Laik and A. P. Gupta (2008) Periodic mineralization of N in long term FYM amended soils, *Journal of Research, BAU*, 19(2) 2007 : 149-158.

S. B. Mittal, R. Anlauf, R. Laik, A. P. Gupta, A. K. Kapoor, S. S. Dahiya (2007) Modelling nitrate leaching and organic-C build up under semi-arid copping conditions of northern *India, Journal of Plant Nutrition and Soil Science, Vol* 170(4) pp 506-513.

Popular Article

R. Laik, R. R. Singh and K. Kumar (2007) Carbon sequestration by conservation agriculture, *Souvenir, Agri-Fest*, pp 69-70.

R. Laik, M. Kumar, R.R.Singh (2008) Agricultural technologies for soil carbon sequestration in Bihar, Proceeding of eastern region soil testing workshop on Balance and integrated use of fertilizers, pp 46-53.

M. Kumar, R. Laik and R. R. Singh (2008) Soil physics in relation to soil health, Proceeding of eastern region soil testing workshop on Balance and integrated use of fertilizers, pp 54-56.

Papers presented in symposia

Singh, A. P., Choudhary, K., Prasad, J. and Mishra, G. K.

(2007). Zinc nutrition to maize-rice through zincated superphosphate. (Communicated National Seminar on customized fertilizers) at Bhopal.

Singh, A. P. and Singh, M.V. (2007). Scenario of Micro- and Secondary nutrient deficiencies in the state of Bihar and amelioration practices for increasing crop production and insuring food security. Paper presented in National Seminar on " Scenario of Micro- and Secondary nutrient deficiencies and amelioration practices for increasing crop production and insuring food security" at Bhopal.

Praveen Kumar, D. K. Das, and R. Laik Nitrogen supplementation by leguminous tree leaves for rice cultivation, Proceeding of national symposium on Soil and Water Management for agricultural transformation in eastern India. Held at BAU, Ranchi, Nov.2-5, 2007 pp. 120.

Research Publication

Vipin Kumar and Prasad, R. K. (2008) Integrated effect of mineral fertilizers and green manuring on crop yield and nutrient availability under rice-wheat cropping system in calciorthents. *Journal of the Indian Society of Soil Science,* 56 : pp 209-214.

Prasad, R. K., Vipin Kumar and Choudhary, S. N. (2008) Effect of pyrite and organic manures on iron nutrition of sorghum in calcareous soil. *Environment and Ecology*, 26 (46) : pp 2268-2272.

Prasad, R. K., Vipin Kumar and Choudhary, S. N. (2008) Residual effect of pyrite and organic manures on iron nutrition of sorghum forage and yellow mustard. *Environment and Ecology*, 26 (46) : pp 2280-2284.

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* (Communicated).

Prasad, R. K., Vipin Kumar, Prasad, B. and Singh, A. P. (2009). Decomposition of wheat straw and mineralization of carbon and nitrogen in zinc treated rice field in calcareous soil. *Journal of the Indian Society of Soil Science* (Communicated).

Pandey, A. K., Singh, S. K., Prasad, R. (2008). Long term influence of organic & inorganic fertilizer on nutrient uptake by rice and wheat in calcareous soil. *Journal Environment & Ecology* (Accepted).

Pandey, A. K., Singh, S. K., Prasad, R. (2008). Long term influence of organic & inorganic fertilizer on yield of rice and wheat in calcareous soil. *Journal Environment & Ecology* (Accepted).

Papers presented in symposia

Singh, A. P. and Choudhary, B.C. (2008). Nutrient mining from soils of Bihar. Paper presented in National Seminar organized by FAI at Patna.

Singh, A. P. (2008). Balanced fertilization through micronutrient application. Paper presented in National Seminar organized by NAII-YI (*National Association of Indian Industries-Young Indians*) at Chandigarh on 30.05.2008.

Singh, A. P., Singh S. K., Kumar Vipin and Choudhary, K. (2008) "Role of micronutrient in potassium availability" paper presented by Vipin Kumar in the seminar on "Importance of potassium in Bihar agriculture" on 11th December, 2008 at RAU, Pusa, Samastipur.

Vipin Kumar, Singh, A. P., Prasad, R. K. and Suman, S. N. (2008). Long term effect of organic and inorganic fertilizer on yield, nutrient uptake and fertility buildup under rice-wheat cropping system in calcirothents. In proceeding of 73rd Annual Convention of Indian Society of Soil Science and National Seminar on "Development in Soil Science", 2008 at UAS, Bangalore.

Suman, S. N., Thakur, S. K., Laik, R., Vipin Kumar and Singh, R. R. (2008) Effect of temperature on cadmium sorption in sludge treated calcareous soil. In proceeding of 73rd Annaul Convention of Indian Society of Soil Science and National Seminar on "Development in Soil Science", 2008 at UAS, Bangalore.

Books

Singh, S. P., Singh, A. P. and Singh, R.R. (2008). अधिक फसलोत्पादन के लिए गंधक का उपयोग Department of Soil Science, RAU, Pusa, Bihar.

Articles

Singh, A.P. and Kumar, Vipin (2008). Biahr ki mittiyon men jasta ka asttar ewam uska prabandhan. (बिहार की मिट्टियों में जस्ता का स्तर एवं उसका प्रबन्धन). *Adhunik Kisan* (2008)

Singh, S. P. and Singh, A.P.(2008). Adhunik krishi men gandhak ka mahatwa ewam prabandhan. (आधुनिक कृषि में गंधक का महत्व एवं प्रबंधन). *Adhunik Kisan* (Accepted)

Vipin Kumar and Singh, A.P. (2009). Biahr ki mittiyon men boron ka asttar ewam uska nidan. (**बिहार की** मिट्टियों में बोरन का स्तर एवं उसका निदान). *Adhunik Kisan* (March-April, 2009).

Singh, A. P., Singh, S. K., Choudhary, K. and Kumar Vipin (2009) Micronutrient management in soils and crops of Bihar. Souvenir on crop production, I.A.R.I., Regional Station, Pusa, Samastipur.

Singh, A. P., Vipin Kumar, Singh, R.R. (2009). Bihar ki mitti men sukshm ewam gaun poshak tatvon ki kami ewam sudhar ke tarike. *Adhunik Kisan*, (March-April, 2009)

HISAR CENTRE

Research Paper

Daleep Kumar, R.S. Malik and R.P. Narwal (2007). Chemical fractionation of Cadmium, Lead, Nickel and Chromium. *Environment & Ecology vol*. 255 (**3A**): 895-898.

Malik, R.S., Ramkala, Gupta, S.P., Dahiya, R.R. and S.S. Dahiya (2007). Pollutant metal contents of crops irrigated with sewage water. *Agricultural Science Digest vol*. 27(**4**): 255-257.

Malik, R.S. and Narwal, R.P. (2007) Diagnosis and management of nutritional deficiency symptoms in crops. ICAR sponsored winter school on Integrated Nutrient Management. pp. 69-75.

Malik, R.S. and Ramkala (2007) Soil analysis for DTPA extractable micronutrients and its interpretations. ICAR sponsored winter school on Integrated Nutrient Management. pp 193-195.

Narwal, R.P. and Dahiya, R.R. (2007) Status of nutrients in Haryana soils and crop response. ICAR sponsored winter school on Integrated Nutrient Management. pp 15-21.

Narwal, R.P and Singh Balwan (2007) INM in Pearl-millet-wheat cropping system. ICAR sponsored winter school on Integrated Nutrient Management. pp 22-27.

Malik, R.S., Narwal, R.P., Ramkala, Singh, M.V. and Dahiya R.R. (2008) Secondary and micronutrient status and response to crops in soils of Haryana. *Indian Journal of Fertilizers vol*. 4(**2**): pp 53-57.

Sidhu, A.S. and Narwal, R.P. (2008). Effect of lead and varying organic materials on micronutrient concentration of miaze (*Zea mays* L.). *Indian J. Res*. (In press).

Antil, R.S., Narwal, R.P. and Sangwan. O.P.,(2007). Micro-Nutrients. pp. 125 - 132. In: Research Methods in Plant Sciences: Allelopathy. Volume 4 Plant Analysis: S.S. Narwal, O.P. Sangwan and O.P. Dhankar (Eds.). *Scientific Publishers Jodhpur* (India).

Narwal, R.P., Antil, R.S., Singh, Balwan, Shanwal, A.V. and Dahiya, D.S. (2007). Toxic Metals. pp. 133 - 136. In: Research Methods in Plant Sciences: Allelopathy, Vol. 4. Plant Analysis: S.S. Narwal, O.P. Sangwan and O.P. Dhankar (Eds.). *Scientific Publishers, Jodhpur* (India).

Dahiya, D.J., Kumar, Ravi, Phogat V. and Narwal, R.P. (2007). Role of neem in increasing nitrogen use efficiency. In: Neem Tree – A *Treatise. I.K.*

international Publishing House, New Delhi, India (In press).

Daleep Kumar, Malik, R.S., Narwal, R.P. (2008). Pollution Potential of Sewer Waters of South-Western Cities of Haryana. *Environment and ecology*, Vol. 26 (**3**): pp. 1276-1278.

Malik, R.S., Narwal, R.P. and Dahiya, R.R. (2008). Toxic Metal Content of Crops Irrigated with Sewer Water. In Wasteland Development in Himalayas. *The Shiwaliks*, pp. 231-235.

Narwal, R.P. and Malik, R.S. (2008). Use of Industrial Effluents and Solid Waste in Amelioration of Wasteland. In Wasteland Development in Himalayas. *The Shiwaliks*, pp. 221-230.

Malik, R.S., Ramkala, Dahiya, R.R., Dahiya, S.S. and Singh Dalel (2008). Evaluation of NPZn (10:50:1.5Zn) complex fertilizer in rice-wheat cropping system. *Indian J. Agric. Res*. 42(**4**): 235-243.

Malik, R.S., Narwal, R.P., Ramkala, Singh, M.V. and Dahiya R.R. (2008) Secondary and micronutrient status and response to crops in soils of Haryana. *Indian Journal of Fertilizers vol*. 4**(2):** 53-57.

Sidhu, A.S. and Narwal, R.P. (2008). Effect of lead and varying organic materials on micronutrient concentration of maize (*Zea mays* L.). *Indian J. Res*. (In press).

PANT NAGAR CENTRE

Srvastava, P.C.; Megh Naresh and Srivastava, P. (2008). Apparaisal of some soil tests for zinc availability to late-sown wheat in mollisols. Commun. *Soil Science & Plant Anal*. 39: pp. 440-449

Srivastava, P., Srivastava, P.C.; Srivastava, U. and Singh, U.S. (2008). Effect of sample preparation methods on analytical values of some micro- and secondary nutrients in plant tissues. Commun. *Soil Science & Plant Anal.* 39: 2046-2052.

Kar, D.; Ghosh, D.; Srivastava, P.C. (2007). Efficacy evaluation of different zinc-organo complexes in supplying zinc to maize (*Zea mays* L.) plant. *J. Indian Soc. Soil Sci*. 55 (**1**): 67-72.

Chaube, A.K.; Ruhella, R.; Chakraborty, R.; Gangwar, M.S.; Srivastava, P.C. and Singh, S.K. (2007). Management of zinc fertilizer under Pearl millet-Wheat cropping system in a Typic Ustipsamment **.** *J. Indian Soc. Soil Sci*. 55 (**2**): 196-202.

Sachan, S.; Singh, S.K. and **Srivastava, P.C.** (2007). Buildup of heavy metals in soil- water-plant continuum by irrigation with contaminated effluents. *J. Environ. Sci. & Engg*. 49 (**4**) : 293-296.

Mishra, P., Singh, S.K and Srivastava, P.C. (2007). Vertical distribution of DTPA-extractable Zn, Cu, Mn and Fe in some profiles of *Tarai* and *Rohilkhand* plains in relation to soil properties. *Pantnagar J. Res*. 5(**1**): 92-98.

Sahai, P.; Srivastava, P.C. ; Singh, S.K. and Singh, A.P. (2006). Evaluation of organics incubated with zinc sulphate as Zn source for rice-wheat rotation. *J. Ecofriendly Agric*. 1 (**2**): 120-125.

Siddiqui, A., Srivastava, P.C. ; Singh, A.P. and Singh, S.K. (2006). Effect of multi micronutrients and press mud compost application on yields and nutrient uptake of sugarcane- ratoon sequence. *Indian Sugar*. pp.33-42.

Singh, A. P., Srivastava, P.C. and Singh, S.K. (2007). Seasonal variations in water quality of natural lakes of Nainital, *India Ecol. Env. & Cons*. 13: pp. 137-141.

Sachan, S. Singh, S.K and Srivastava, P.C. (2006). Effect of continuous irrigation with metals rich effluents on accumulation and distribution of trace elements in soil profiles.Abstract 8th Agril scientists and farmers Congress,Feb.21-22,2006,B.H.U., Varansip156

HYDERABAD CENTER

Bhupal Raj, G., Patnaik, M.C., Surendra Babu, P., Kalakumar, P., Singh, M.V. and Shylaja, J. 2006, Heavy metal contaminants in water-soil -plant- animal ontinuum due to pollution of Musi river around Hyderabad in India., *Journal of Animal Sciences***,** 76 (**2**), 131-133

Bhupal Raj, G., Patnaik, M.C., Shailaja, J . and Khadke, K.M. 2006, Extent of Variations in Micronutrient status of soils of Andhra Pradesh over the period of time, *The Journal of Research ANGRAU,* 34(**4**)

Venkata Sridhar,T., Jeevan Rao, K. and Bhupal Raj, G. 2006, Risk Assesment of Metals in Sewage Sludge of Hyderabad *,The Journal of Research ANGRAU,* 34(**2**) pp 105-108

Venkata Sridhar,T., Jeevan Rao, K. and Bhupal Raj, G. 2006, Integtated use of Sewage Sludge and Chemical Fertilizers on Uptake of Major and Micronutrients by Maize, *The Journal of Research ANGRAU,* 34(**2**):37-43

Patnaik,M.C., A. Sreenivasa Raju and Bhupal Raj, G. 2006, Direct, residual and cumulative effects of applied zinc in rice- sunflower system *,J. Oilseeds Research,23* **(2)***: 230-233*

Bhupal Raj, G., Surendra Babu, P., Shailaja, J. Khadke, K.M. and Patnaik, M.C., 2006, Effect of different Nutrient Management Practices on Seed Yield and Oil output in Castor under Rainfed Conditions*, Journal of Oilseed Research.*

BhupalRaj.G and Patnaik, M.C. (2008) Boron deficiency in coconut orchards of East Godavari district in Andhra Pradesh..*Indian Coconut Journal*: 3 : 17-21.

Sandhya Rani, K., Uma Devi,M., Chandini Patnaik,M and Raj Kumar, M.(2008) Integrated nutrient management on medicinal coleus and soil nutient status. *Crop research* 36 : 341-348.

Patnaik,M.C. , Srinivasa Raju, A and Bhupal Raj, G. (2008) Effect of soil moisture regimes on Zinc availability in a red sandy loam soil of Andhra Pradesh. *Journal of the Indian Society of Soil Science* 56 :452-453

Bhupal Raj ,G., Patnaik, M.C and Khadke, K. M. (2008) Effect of Nickel on fresh matter yield and its content in Amaranthus *National seminar on Developments in Soil Science- 73 rd Annual convention , Indian Society of Soil Science held at Banglore during Nov. 27-30.*

Patnaik, M. C., G. Bhupal Raj and K.M. Khadke.(2008) Effect of cadmium on fresh matter yield and its content in Amaranthus. - *National seminar on Developments in Soil Science- 73 rd Annual convention , Indian Society of Soil Science held at Banglore during Nov. 27-30.*

Popular Articles

Bhupal Raj, G (2006) Scientists profile, *Rhytu Nestam*, January.

Shylaja, J., Bhupal Raj, G., Patnaik, M.C. and Khadke, K.M. (2006) Adika DigubadikiYivanni Kavali (All these required for higher production), *Rytanna Monthly Magagine,* May.

Shylaja, J., Bhupal Raj, G. , Patnaik, M.C. and Khadke .K.M . (2006) Natrajani viniyoga samartyanni penche amsaalu(Steps for increasing the use efficiency of nitrogenous fertilizers), *Annadata Monthly Magagine*, October.

Shylaja, J., Bhupal Raj, G. , Patnaik, M.C. and Khadke .K.M. (2006) Pradana pantallo zinc lopa kshanalu - savarana(Zinc deficiency symptoms in important field crops and its rectification), *Annadata monthly Magagine*, December.

Bhupal Raj, G. and Shylaja, J. (2006) Adika digubadulaku, labha sati vyavasayaniki ryutulu patinchavalasina mukyamaina paddatulu – (Tips to the farmers for getting the higher yields and profitable farming), *Padipantalu Monthly Magagine*, February.

Patnaik, M.C., Bhupal Raj, G. and K. M. Khadke (2007) Samasyatmaka bhoomulu-Bhoosaara rakshana Problamatic soils - soil fertility management), *Padipantalu Monthly Magagine*, February.

BhupalRaj.G and Patnaik, M.C. (2008) Boron deficiency in coconut orchards of East Godavari district in Andhra Pradesh..*Indian Coconut Journal*: 3 : 17-21.

Sandhya Rani, K., Uma Devi, M., Chandini Patnaik,M and Raj Kumar, M.(2008) Integrated nutrient management on medicinal coleus and soil nutient status. *Crop research* 36 : 341-348.

Patnaik,M.C. , Srinivasa Raju, A and Bhupal Raj, G.

(2008) Effect of soil moisture regimes on Zinc availability in a red sandy loam soil of Andhra Pradesh. *Journal of the Indian Society of Soil Science* 56 :452-453

Bhupal Raj ,G., Patnaik, M.C and Khadke, K. M. (2008) Effect of Nickel on freshmatter yield and its content in Amaranthus *National seminar on Developments in Soil Science- 73 rd Annual convention , Indian Society of Soil Science held at Banglore during Nov. 27-30.*

Patnaik, M. C., G. Bhupal Raj and K.M. Khadke.(2008) Effect of cadmium on fresh matter yield and its content in Amaranthus. - *National seminar on Developments in Soil Science- 73 rd Annual convention , Indian Society of Soil Science held at Banglore during Nov. 27-30.*

BHUBNESWAR CENTRE

Nayak,S.C., Sahu, S. K., Rout, D. P. and Nayak, P.K. (2008). Suitable rice varieties for iron toxic soils of Orissa. *Oryza*,45**(2)** : 163-165

Jena, D. Nayak, S. C., Dash, A. K. and Mohanty, B.(2008). Effect of soil amendment on grain and iron content of rice in iron oxic soil. *An Asian journal of soil science*,3 **(2)**: 264-268

Nandi, A and Nayak, S. C.(2008). Performance of hybrid cabbage(Brassica oleracea var. capitata) os influence d by foliar micronutrient spray. *Vegetable science*,35**(1)** : 45-48

Pany, B.K., Pattnaik, M.R. and Das, D.(2008). Suitability of sewage waste water of bhubaneswar municipalticity as a source of irrigation to vegetable crops. Abstract presented in XXXVII Annual convention Bhubaneswar Chapter .ISSS held on 15th Nov,2008 at Pratap nagari, Cuttack

Nayak, S.C. and Pattnaik, M. R.(2008). Micro & secondary nutrient status of soil based on nutrient index .Abstract presented in XXXVII Annual convention Bhubaneswar Chapter .ISSS held on 15th Nov,2008 at Pratap nagari, Cuttack

Nayak,S.C,Sarangi,D.,Sahu,S.K.,Das, N(2008). Chromium contamination in soil and water in chromite mining areas of Kaliapani ,Orissa. Abstract presented in 73rd Annual convention,ISSS held at University of Agriculture Sciences, Bangalore from 27th - 31st Nov,2008

Jena, D, Pattnaik, M. R, Mohanty, B, Jena, B & Mukhi, S.K.(2008) Effect of lime on change in soil pH,exchangeable acidity,exchangeable H of red & laterite soil. Abstract presented in XXXVII Annual convention Bhubaneswar Chapter .ISSS held on 15th Nov,2008 at

LUCKNOW CENTRE

Rajeev Gopal , Vivek Giri and N. Nautiyal 2008. Excess copper and manganese alters the growth and vigor of maize seedlings. *Indian Journal of Plant Physiology*, 13**(1)**: 44-49.

Geetanjali Bhakuni, B.K. Dube and C. Chatterjee 2008. Manganese deficiency affects the growth, metabolism and yield of chickpea. *Indian Journal of Plant Physiology,* 13**(2)**:198-202.

K.K. Tiwari, B.K. Dube, C. Chatterjee and. Pratima Sinha 2008. Phytotoxic effects of high Cr on oxidative stress and metabolic changes in *Citrullus vulgaris. Indian Journal of Horticulture, 66: 171-175.*

Rajni Shukla, Rajeev Gopal and C. Chatterjee 2008. Altered levels of metabolized under the influence of nickel in green gram. *Indian Journal of Plant Physiology*, 13**(2)**: 203-207.

Neena Khurana and C. Chatterjee 2007. Changes in metabolism, root quality and nutritive character of carrot under copper stress. *Indian Journal of Horticulture* 64: 335-339.

Neena Khurana and C. Chatterjee 2007. Zinc stress induced changes in biochemical parameters and oil content of mustard. *Communication of Soil and Plant Analysis* 38: 751.761.

Sunil Gupta, Rajeev Gopal and M.V. Singh 2007. Variable Ca affects growth and metabolism of bittergourd grown in sand culture. *Journal of Plant Nutrition* 30: 109-114.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