वार्षिक प्रतिवेदन
ANNUAL REPORT
2020-21

All India Coordinated Research Project on

Long Term Fertilizer Experiments to Study Changes in Soil Quality, Crop Productivity and Sustainability (AICRP LTFE)

भाकृअनुप – भारतीय मृदा विज्ञान संस्थान

ICAR - Indian Institute of Soil Science

Nabibagh, Berasia Road, Bhopal-462 038 (M.P.)

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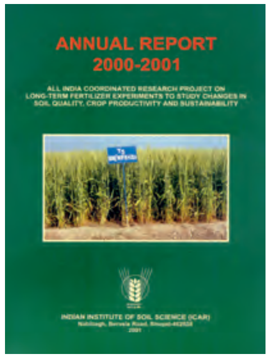

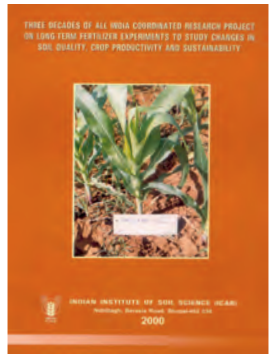

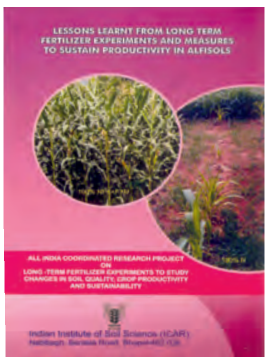

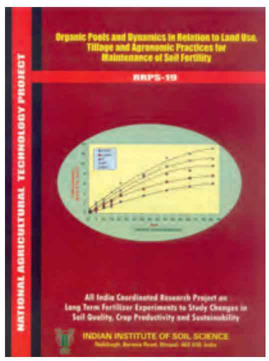

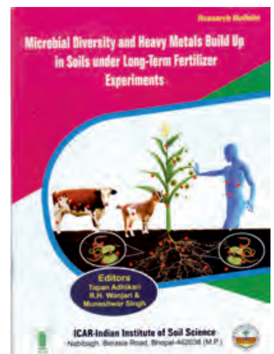

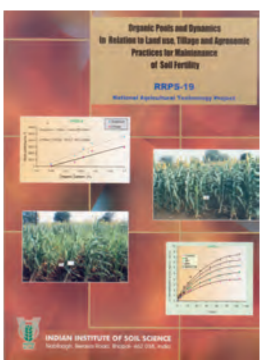

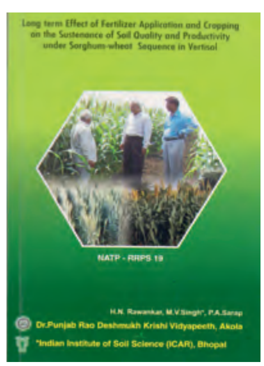

With Best Compliments

(Ashok K. Patra)

Director

ICAR - Indian Institute of Soil Science

Nabibagh, Berasia Road, Bhopal

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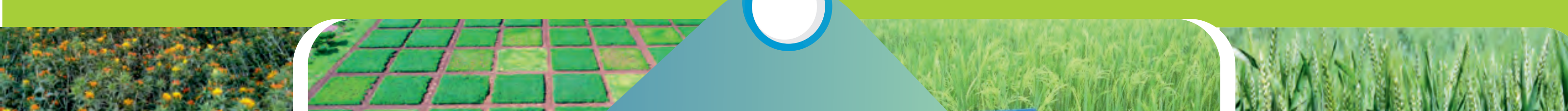

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Director
ICAR-Indian Institute of Soil Science
Nabibagh, Berasia Road, Bhopal-462 038, Madhya Pradesh
Tel: 0755-2730970, 2730946; Fax: +91-755-2733310
E-mail : director.iiss@icar.gov.in
Website : www.iiss.icar.gov.in

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Preface

SOIL HEALTH is a vital component for boosting crop productivity and sustainability. The soil health has been a prime focus of long term fertilizer trials. It has been observed that the proper maintenance and improvement of carbon in soil is key for optimal nutrient supply. Worldwide, long term experiments demonstrated the need for balanced/integrated nutrient application for higher productivity and sustainability. On the other hand, indiscriminate use of fertilizers without scientific basis may have adverse effect on soil quality, crop productivity and sustainability. Therefore, it is necessary to have a proper monitoring on soil sustainability. Changes in soil fertility, as a result of imbalanced fertilizer use and improper management practices have led to deterioration in soil quality and crop productivity which takes many years to revive. Thus, there is an urgent need to preserve and restore natural resources for posterity. Long term experiments in India have generated enormous information, which could be used for sustainability of high input intensive agriculture. In the present report, an attempt has been made to highlight the comprehensive view of achievements of the project. I strongly believe that the results of these long-term experiments would immensely benefit scientists, extension workers, policy makers and other personnel related to natural resource management for developing strategies for sustained agricultural production and cleaner environment.

The research findings reported herein is a combined effort of the Cooperating Centres and Project Coordinating Cell of the AICRP on Long Term Fertilizer Experiments (LTFE). I take this opportunity to express my sincere gratitude to Vice Chancellors of SAUs and Directors of ICAR Institutes for their constant support, help in providing infrastructure and facilities during the experimentation and overall conduct of research. I profusely thank all the scientists' and students (MSc & PhD)/Research Scholars who worked/ working in the project at different centres including voluntary centre at ICAR-IASRI, New Delhi, for their valuable contribution and cooperation in the execution of the project.

I express a deep sense of gratitude and respect to Dr Trilochan Mohapatra, Secretary, DARE and Director General, ICAR for his constant guidance and support for the overall growth and development of the AICRP LTFE. I am highly grateful to Dr SK Chaudhari, Deputy Director General (NRM) and Dr Adlul Islam, Assistant Director General (SWM) for their constructive suggestions, active co-operation and support in carrying out various research and development activities for the overall progress of the AICRP LTFE.

My thanks are also due to all the Project Coordinators (Micronutrients, Soil Test Crop Response), Network Coordinator (Soil Biodiversity-Biofertilizers) and Head of Divisions (Soil Chemistry & Fertility, Soil Biology, Soil Physics and Environmental Soil Science) for the facilities extended to coordinating cell in execution of the research programme of the project.

I sincerely thank Dr RH Wanjari, Pr Scientist, PC LTFE Unit for his excellent support in execution and monitoring programme and help rendered by him in compilation and editing of the report. Thanks also to Dr Dhiraj Kumar, Scientist and Dr M Vassanda Coumar, Sr Scientist for their help in compilation and editing of the document. The help extended by Mrs Geeta Yadav, Private Secretary for her secretarial assistance not only in preparation of manuscript but also in day-to-day work of PC (LTFE) Unit is duly acknowledged. The help rendered by Mr Sunny Kumar, PA and Mr Jagannath Gour (SSS) for assisting in day-to-day work is also appreciable.

Bhopal
22nd July 2022

(Ashok K Patra)
Director
ICAR-Indian Institute of Soil Science

Foreword

भारतीय कृषि अनुसंधान परिषद
कक्ष क्र. 101, कृषि अनुसंधान भवन–II, नई दिल्ली – 110 012, भारत
INDIAN COUNCIL OF AGRICULTURAL RESEARCH
Room No. 101, Krishi Anusandhan Bhavan-II, Pusa, New Delhi-110012, India

डॉ. सुरेश कुमार चौधरी
उप महानिदेशक (प्राकृतिक संसाधन प्रबंधन)
Dr. Suresh Kumar Chaudhari
Deputy Director General (Natural Resource Management)

SUSTAINING SOIL HEALTH is crucial for achieving / fulfilling food and nutritional security. In this respect, long term fertilizer experiments (LTFEs) are widely known for its importance and necessity for taking decision on sustainable soil management in the country. One such worldwide example is the 'Rothamsted Classical Experiments' initiated by JB Lawes and JH Gilbert, in United Kingdom in 1843. In a similar fashion, Indian Council of Agricultural Research (ICAR) initiated All India Coordinated Research Project on Long Term Fertilizer Experiments to study changes in soil quality, crop productivity and sustainability in 1970 i.e. just after the beginning of green revolution. These experiments spread across 11 agro-ecological regions covering 9 major cropping systems under 4 dominant soil types across the length and breadth of the country. Information generated over last 50 years has been recognized as cornerstone to monitor soil health on long term basis and to formulate policies and strategies on soil health management at national level.

I appreciate the sincere and dedicated efforts of the team of scientists from ICAR Institutes and State Agricultural Universities (SAUs) in generating the information on long term impact of fertilizer and manure on crop productivity, soil quality and sustainability. The Information would be extremely helpful for researcher, planners and other stakeholders to facilitate balanced and integrated nutrient management in the country.

My best wishes and compliments to the entire team of AICRP (LTFE).

13th July 2022

(SK Chaudhari)

EXECUTIVE SUMMARY

THE LONG–TERM FERTILIZER EXPERIMENTS conducted across the country clearly brought out that balanced and integrated nutrient management sustained the crop productivity, soil quality and overall soil health. The findings emanated from AICRP LTFE are highlighted hereunder :

- The crop yield trends in the long term fertilizer experiments (LTFEs) are in the order of 100% NPK+FYM>150% NPK>100% NPK+Zn/lime>100% NPK>50% NPK>100% NP>100% N>Control at most of the LTFE locations. The balanced fertilizer use sustained the crop productivity across almost all the locations. The integrated nutrient management (100% NPK+FYM) further improved the crop productivity and soil quality under LTFEs.
- Balanced fertilizer use as well as integrated nutrient management (100% NPK+FYM) improved physical, chemical and biological state of soil.
- Crop yield data for Alfisols of Palampur, Ranchi and Bangalore indicated that soil amended with FYM found to be superior to lime as far as crop productivity is concerned. Application of organic manure helps in moderating soil condition in addition to supply nutrients whereas lime merely increases soil pH.
- Balance application of nutrients (fertilizers and manure) resulted in increase of the population of soil microorganisms. Increase in application of nutrient from 100 to 150% also had positive effect on soil microbial count and also enzymatic activities.
- In Vertisols of Raipur, yield can be sustained with balance application of fertilizer nutrients as well as integrated nutrient management (INM) in rice and wheat.
- In Vertisols of Akola, results indicated that exclusive application of nutrients through organic manure (FYM) even after 34 years could not keep the pace with 100% recommended NPK. It is advised that there is need to increase the dose of organic manure (FYM) to optimize the yield and to keep the pace with inorganic nutrient application.
- In Alfisols, results indicated that application of urea alone (i.e. 100% N alone) had deleterious effect on crop productivity of maize and wheat at Palampur, soybean and wheat at Ranchi, finger millet and maize at Bangalore. This is due to decline in soil pH which reduces the availability of P and K to a large extent.
- Irrespective of soil and crop, incorporation of farm yard manure (FYM) or green manure not only resulted in increase in productivity but also increase microbial count and enzymatic activities.
- Application of FYM along with balanced fertilizers found to decrease soil bulk density, compared to imbalance and unmanured treatments. Similarly, hydraulic conductivity, mean weight diameter, water stable aggregates, infiltration etc. got remarkably improved under balance and INM (100% NPK+FYM) practices under LTFEs.
- Soil biological parameters such as microbial count, dehydrogenase activity, biomass C and N, urease activity, phosphatase enzymes found to be encouraged with balanced and INM (100% NPK+FYM) nutrient options across soil types under LTFEs.

- The nutrient dynamics studies carried out at LTFEs suggests both macro and micronutrient fractions found to be highest in 100% NPK+FYM. The forms of potassium i.e. water soluble, exchangeable and non-exchangeable K were recorded higher in balance and INM treatments at most of the LTFEs.
- Imbalance nutrient application resulted in low yield of major crops in LTFEs. On the contrary, balance nutrient application sustains crop productivity as well as nutrient uptake. The 100% NPK+FYM further improved nutrient uptake.
- Results revealed that decline in P dose to half in the plots/fields, wherein P accumulated as in case of soils of Ludhiana (Punjab), Bangalore (Karnataka) and Jabalpur (Madhya Pradesh) did not have any adverse effect on crop productivity. Thus, it can be inferred that P accumulated over the years can be reutilized in these areas.
- Application of balanced use of fertilizer catalyzed the enzymatic activity such as dehydrogenase activity in soil which resulted in evolution of more CO_2. Thus, observations clearly demonstrated that balance application of fertilizer is essential for not only sustaining the crop productivity but also to maintain or enhance microbial population in soil.
- Rice yield at Pantnagar (Mollisols) indicated that combined application of Zn and S had additive effect. Thus, Zn and S need to be supplied simultaneously for enhancing/maintaining crop productivity in Mollisols of Uttarakhand.
- The increase in productivity on use of balanced fertilizer resulted increase in carbon and microbial population in soil and thus ruled out the assumption that chemical fertilizer deteriorate soil carbon and adversely affects the growth of microorganisms.
- The Carbon Management Index (CMI) was maximum with 100% NPK+FYM. Soils with higher CMI values are considered as better managed soil. The CMI significantly enhanced by 100% NPK+FYM compared to balanced or imbalanced nutrient application.
- The technology demonstration on farmers' field under Tribal sub plan (TSP) and Scheduled Caste Sub Plan (SCSP) clearly demonstrated the yield advantage and also monetary gain on adoption of balanced and integrated nutrient management (INM) doses of nutrients over imbalance and farmers' practice.

कार्यकारी सारांश

देश भर में किए गए दीर्घकालीन उर्वरक परीक्षण प्रयोगों से यह स्पष्ट हुआ है कि संतुलित और एकीकृत पोषक तत्व प्रबंधन फसल उत्पादकता, मिट्टी की गुणवत्ता और मिट्टी के स्वास्थ्य को बनाए रखने में कारगर साबित हुए । एआईसीआरपी एलटीएफई में किये गये अनुसंधान कार्य को निम्नलिखित प्रमुख बिन्दुओं में दर्शाया गया हैं।

- दीर्घकालीन उर्वरक परीक्षण प्रयोगों (एलटीएफई) में फसलोत्पादन क्रमशः 100% नत्रजन, स्फुर, पोटाश (एन पी के) + गोबर खाद> 150 % एन पी के>100% एन पी के + जस्ता या चूना>100% एन पी के>50% एन पी के>100% नत्रजन, स्फुर>100%नत्रजन> उर्वरक रहित, अधिकांश दीर्घकालीन उर्वरक परीक्षण प्रयोग स्थलों पर इस क्रम में पायी गयी। उर्वरकों के संतुलित प्रयोग से लगभग सभी प्रयोग स्थलों पर अच्छी फसल उत्पादकता पायी गयी है। इस तरह एलटीएफई के अन्तर्गत एकीकृत पोषक तत्व प्रबंधन (100% एन पी के + गोबर खाद) से भी फसल उत्पादकता और मिट्टी की गुणवत्ता में सुधार पाया गया।
- संतुलित उर्वरक उपयोग के साथ-साथ एकीकृत पोषक तत्व प्रबंधन (100% एन पी के + गोबर खाद) से मिट्टी की भौतिक, रासायनिक और जैविक स्थिति में सुधार देखा गया है।
- अल्फिसोल्स में पालमपुर, रांची और बैंगलोर के फसल उपज आकड़ो से यह ज्ञात होता है कि गोबर खाद (जैविक खाद) से फसल उत्पादकता में मृदा सुधारक चूने की तुलना में बेहतर पाई गई। जैविक खाद का उपयोग पोषक तत्वों की आपूर्ति के अलावा मृदा स्वस्थ्य बनाये रखने में मदद करता है जबकि चूना केवल मिट्टी के पीएच मान को बढ़ाता है।
- संतुलित पोषक तत्वों (उर्वरक और खाद) के उपयोग के परिणाम स्वरूप मृदा सूक्ष्मजीवों की संख्या में वृद्धि पायी गयी। पोषक तत्वों की मात्रा में 100 से 150% तक की वृद्धि करने से भी मिट्टी में सूक्ष्म जीवाणुओं की संख्या और एंजाइम गतिविधियों पर सकारात्मक प्रभाव पड़ा।
- काली मिट्टी (रायपुर) में चावल और गेहूँ में उर्वरक पोषक तत्वों के साथ-साथ एकीकृत पोषक तत्व प्रबंधन (आईएनएम) तथा संतुलित पोषक तत्त्व उपयोग से उपज में बढ़ोत्तरी पायी गयी।
- काली मिट्टी (अकोला) के परिणाम दर्शाते हैं कि जैविक खाद (केवल गोबर खाद) के माध्यम से पोषक तत्वों का अनुप्रयोग 34 वर्षों के बाद भी 100% अनुशंसित एनपीके के साथ प्रभाव नहीं रख पा रहा है। यह सलाह दी जाती है कि उपज को अनुकूलित करने और अकार्बनिक पोषक तत्वों के अनुप्रयोग के साथ गति बनाए रखने के लिए जैविक खाद (गोबर खाद) की मात्रा बढ़ाने की आवश्यकता है।
- अल्फिसोल्स में, परिणामों ने संकेत दिया है कि केवल यूरिया के प्रयोग (अर्थात् 100% नत्रजन) का पालमपुर में मक्का और गेहूँ, रांची में सोयाबीन और गेहूँ, बैंगलोर में रागी और मक्का की फसल उत्पादकता पर हानिकारक प्रभाव पड़ा। यह मिट्टी के पीएच मान में गिरावट के कारण होता है जो फॉस्फोरस और पोटाश की उपलब्धता को काफी कम कर देता है।
- मिट्टी और फसल के बावजूद, गोबर खाद या हरी खाद को सम्मिलित करने से न केवल उत्पादकता में वृद्धि हुई बल्कि सूक्ष्मजीवों की संख्या और उनकी एंजाइमैटिक गतिविधियों में भी वृद्धि पायी गयी।
- संतुलित उर्वरकों के साथ लगातार गोबर खाद के प्रयोग से असंतुलित और असंतृप्त उपचारों की तुलना में मिट्टी के घनत्व

में कमी पाई गई। एलटीएफई के अन्तर्गत संतुलित और एकीकृत पोषक तत्व प्रबंधन (100% एनपीके + गोबर खाद) के तहत हाइड्रोलिक चालकता (Hydraulic Conductivity), औसत वजन व्यास (MWD), पानी स्थिर समुच्चय, इन्फिल्ट्रेशन आदि में उल्लेखनीय रुप से सुधार हुआ है।

- दीर्घकालीन उर्वरक परीक्षणों से यह ज्ञात होता है कि मिट्टी के जैविक मापदंडों जैसे सूक्ष्मजीवों की संख्या, डिहाइड्रोजनेज गतिविधि, बायोमास कार्बन और नत्रजन, युरियेज गतिविधि, फॉस्फेट एंजाइम विकल्पों में बढ़ोत्तरी हुयी है।
- दीर्घकालीन उर्वरक परीक्षण स्थलों पर किए गए पोषक तत्व अध्ययन से पता चलता है कि प्रमुख पोषक तत्व तथा सूक्ष्म पोषक तत्व दोनों 100% एनपीके + गोबर खाद में उच्चतम पाए गए। पानी में घुलनशील, विनिमेय और गैर-विनिमेय पोटाश को एलटीएफई के अधिकांश स्थानों पर संतुलित और एकीकृत पोषक तत्व प्रबंधन में बढ़ोत्तरी दर्ज की गयी।
- असंतुलित पोषक तत्व अनुप्रयोग के परिणामस्वरूप दीर्घकालीन प्रयोगो में प्रमुख फसलों की उपज कम हुई। इसके विपरीत, संतुलित पोषक तत्व अनुप्रयोग फसल उत्पादकता के साथ-साथ पोषक तत्वों के अवशोषण को भी बनाए रखता है। 100% एनपीके + गोबर खाद से पोषक तत्वों के अवशोषण में बढ़ोत्तरी हुयी है।
- परिणामों से पता चला है कि फॉस्फोरस की मात्रा घटाकर आधी करने से फॉस्फोरस संचित हुआ, जैसे लुधियाना (पंजाब), बंगलौर (कर्नाटक) और जबलपुर (मध्य प्रदेश) की मिट्टी में जहाँ फॉस्फोरस संचित हुआ वहाँ फसल उत्पादकता पर कोई प्रतिकूल प्रभाव नहीं पड़ा। इस प्रकार, यह अनुमान लगाया जा सकता है कि वर्षों से संचित फॉस्फोरस का इन क्षेत्रों में पुर्नउपयोग किया जा सकता है।
- उर्वरक के संतुलित उपयोग से मिट्टी में एंजाइमिक गतिविधि जैसे डिहाइड्रोजीनेज उत्प्रेरित हुयी है इसके परिणाम स्वरूप कार्बन डाई ऑक्साइड की मात्रा में वृद्धि हुई। इस प्रकार, अवलोकनों से स्पष्ट रूप से प्रदर्शित हुआ कि उर्वरक का संतुलित अनुप्रयोग न केवल फसल उत्पादकता को बनाए रखता है बल्कि मिट्टी में सूक्ष्म जीवों की संख्या को भी बढ़ाने के लिए आवश्यक है।
- मोलीसोल्स (पंतनगर) में धान की पैदावार पर जस्ता और गंधक के संयुक्त उपयोग का योगात्मक प्रभाव देखा गया। इस प्रकार, उत्तराखंड के मोलीसोल्स में फसल उत्पादकता बढ़ाने तथा बनाए रखने के लिए जस्ता और गंधक दोनों की आपूर्ति करने की आवश्यकता है।
- संतुलित उर्वरक के उपयोग से उत्पादकता में वृद्धि के परिणाम स्वरूप मिट्टी में कार्बन और सूक्ष्मजीवों की संख्या में वृद्धि हुई और इस तरह इस धारणा को खारिज कर दिया कि रासायनिक उर्वरक मिट्टी के कार्बन को कम करते हैं और सूक्ष्मजीवों के विकास पर प्रतिकूल प्रभाव डालते हैं।
- कार्बन मैनेजमेंट इंडेक्स (सीएमआई) 100% NPK + गोबर खाद के साथ अधिकतम पाया गया । उच्च कार्बन मैनेजमेंट इंडेक्स मान वाली मिट्टी को बेहतर प्रबंधित मिट्टी माना जाता है। संतुलित एवं असंतुलित पोषक अनुप्रयोग की तुलना में 100% NPK + गोबर खाद द्वारा (सीएमआई) उल्लेखनीय रूप से बढ़ गया।
- जनजातीय उप योजना (टीएसपी) और अनुसूचित जाति उप योजना (एससीएसपी) के तहत किसानों के खेत पर प्रौद्योगिकी प्रदर्शन से स्पष्ट रूप से यह पाया गया है कि संतुलित और एकीकृत पोषक प्रबंधन (आईएनएम) को अपनाने पर असंतुलित मात्रा में पोषक तत्व डालने की तुलना में उपज में बढ़ोत्तरी तथा मौद्रिक लाभ हुआ है।

1. INTRODUCTION

1.1 Historical background of Long Term Experiments

J. B. LAWES AND J. H. GILBERT started nine long-term experiments between 1843 and 1856, one of these was discontinued in 1878. Even after the death of Lawes in 1900, the eight remaining experiments were continued more or less as, originally planned; these are called the 'Rothamsted Classical Experiments'. Their main objective was to measure the effects of inorganic compounds containing nitrogen, phosphorus, potassium, sodium and magnesium elements known to occur in considerable amounts in crops and farmyard manure on crop yields but their separate actions as plant foods had not been studied systematically. The effects of these inorganic fertilizers alone and in various combinations were compared with those of FYM and rape cake in most of the experiments. These experiments are continued for more than 175 years continuously and yielded most valuable information, used to develop an efficient approach for managing the crops and cropping systems. Growing of the same crop year after year on the same land was considered bad farming in the nineteenth century, but it has now become an established practice for cereal growing continuously due to some compulsion. It has added emphasis on the urgency and priority of these experiments, as the information emerging from these studies has led to many timely interventions in agronomic practices. From 1957 several classical experiments were modified to evaluate the residual effects of the annually repeated dressings of different combinations of nutrients. These experiments are continuously providing the valuable information for refining the strategy and policy to enhance productivity without adverse effect on environment.

In India also a series of long-term fertilizer experiments were established at different locations in the country in the beginning of 20th century. These were at Kanpur, Uttar Pradesh (1905); Pusa, Bihar (1908); and at Coimbatore, Tamil Nadu (1909). Later on more long term fertilizer experiments were established with more heavily fertilized crop such as sugarcane at Shahjahanpur (Uttar Pradesh) 1935; Padegaon (Maharashtra) 1939; Indore (Madhya Pradesh) 1947; Muzaffarnagar (Uttar Pradesh) 1949; and at Anaka Palle (Andhra Pradesh) 1950 and on cereal based cropping system at Ranchi (Jharkhand) 1956. Unfortunately, some of these experiments were either discontinued or seriously altered, as they were found inadequate in respect of the statistical requirement pertaining to the design of experiments or suffered from some management problems. However, the experiments at Coimbatore and Ranchi are still being continued.

During late sixties high yielding varieties (HYVs) were introduced which later on proved to be the main pillar of Green Revolution. Intensification of agriculture under irrigated condition resulted in acceleration of nutrient mining from soil to harness the potential of the HYVs for long term. Under this situation, it has become imperative to maintain supply of the nutrient in sufficient quantity without external use of fertilizers. To sustain the productivity a need of interventions in soil fertility maintenance programme was felt.

1.2 Brief about AICRP on Long Term Fertilizer Experiments

Since fertilizer has become a key factor for increasing agricultural production, its consumption in agriculture is also increasing rapidly, hence, a need is felt for studying the impact of fertilizers not only on the crop yields and quality but also on the soil and environment under intensive cropping systems. This gave a call for a long term studies at fixed sites for monitoring the nutrient dynamics in soil with the objectives of developing strategies for sustained productivity by incorporating the intervention. In view of these emerging compulsions the Indian Council of Agricultural Research decided to launch the "All India Coordinated Research Project on Long-Term Fertilizer Experiments (AICRP-LTFE)" in September 1970 at 11 centres **(Figure 2.1** & **Table 2.1).**

The work carried out at different centers of LTFE was reviewed by Quinquennial Review Team (QRT) during 1997 and recommended to enlarge the mandate and objectives of the project and changed its title as AICRP on "Long-term fertilizer experiments to study changes in soil quality, crop productivity and sustainability". The purpose of conducting long term fertilizer experiments at fixed sites in different agroecological zones (AEZ) with important cropping systems was not only to monitor the changes in soil properties, yield responses and soil environment due to continuous application of plant nutrient inputs through fertilizers and organic sources, but also to help in synthesizing the strategies and policies for rational use and management of fertilizers to improve soil quality and to minimize environment degradation. Thus, the thrust of AICRP-LTFE is on productivity, sustainability and environment safety.

1.3 Mission

Soil Fertility Management through Integrated Plant Nutrient Supply for Enhancing and Sustaining Crop Production and Maintaining Soil Quality

1.4 Mandate

- To conduct coordinated long term fertilizer experiments in different soil types under diversified cropping system and
- To collate information on long term soil fertility trials

1.5 Objectives

- To study the effect of continuous application of plant nutrients, singly and in combination, in organic and inorganic forms including secondary and micronutrient elements (as per the need) on crop yield, nutrient composition and uptake in multiple cropping systems;
- To study the effect of application of secondary and micronutrients (as per the need) on crop yield and also on the assessment of the need for these elements under an intensive cropping programme;
- To work out the amount of nutrient removal by the crops;
- To monitor the changes in soil properties as a result of continuous manuring and cropping with respect to the physical, chemical and microbiological characteristics of the soil in relation to its productivity;
- To investigate the effect of intensive use of biocidal chemicals (weedicides and pesticides) on the build up of residues and soil productivity;
- To make an assessment of the incidence of soil borne diseases and changes in pests and pathogens under the proposed manuring and cropping programme.

2. TECHNICAL PROGRAMME

ALL INDIA COORDINATED RESEARCH PROJECT on Long Term Fertilizer Experiments (AICRP-LTFE) was started at 11 centres in irrigated and intensively cultivated areas representing different agroclimatic regions **(Figure 2.1)**. Five of these are located at ICAR-CRIJAF Barrackpore (West Bengal); TNAU Coimbatore

Figure 2.1 Map showing locations of cooperating centres of All India Coordinated Research Project on Long Term Fertilizer Experiments (AICRP-LTFE)

(Tamil Nadu); ICAR-IARI, New Delhi; PJTSAU Hyderabad (Telangana) and PAU Ludhiana (Punjab) on Inceptisols. Four experiments were established on Alfisols at CSKHPKV Palampur (Himachal Pradesh); BAU Ranchi (Jharkhand) and UAS GKVK Bangalore (Karnataka); OUAT Bhubaneswar (Odisha); one each on Vertisols at JNKVV Jabalpur (Madhya Pradesh) and Mollisols at GBPUA&T Pantnagar (Uttarakhand).

2.1 Treatment Details

Cropping system and soil type followed under AICRP-LTFE are given in **Table 2.1**. There are **10 treatments** in each experiment. These are: $\mathbf{T_1}$ 50% optimal NPK dose; $\mathbf{T_2}$ 100% optimal NPK dose; $\mathbf{T_3}$ 150% optimal NPK dose; $\mathbf{T_4}$ 100% optimal NPK dose + hand weeding; $\mathbf{T_5}$ 100% optimal NPK dose + Zinc or lime; $\mathbf{T_6}$ 100% optimal NP; $\mathbf{T_7}$ 100% optimal N; $\mathbf{T_8}$ 100% optimal NPK + FYM; $\mathbf{T_9}$ 100% optimal NPK (Sulphur free/sulphur source); $\mathbf{T_{10}}$ Unmanured (Control) with a provision of one or two additional treatments that may be of local or regional interest. The treatments are replicated four times in a randomized block design. The unit plot size varied from 100 to 300 m^2 except at Palampur centre where it was only 15 m^2 because of non-availability of large sized plots in the hilly areas.

After realizing the importance of the information generated from LTFE centres, The Indian Council of Agricultural Research (ICAR) sanctioned six new centres to cover more agro-climatic zones and soils during 1996-97. They are at MPKV Parbhani (Maharashtra), Dr PDKV Akola (Maharashtra), KAU Agricultural Regional Station Pattambi (Kerala), RAU Udaipur (Rajasthan), JAU Junagadh (Gujarat) and IGKVV Raipur (Chhattisgarh) during 1996-97. The centre at OUAT Bhubaneswar (Odisha) had to be shifted from the original site during 1996-97 because of acquisition of land by Airport Authority of India. Due to shortage of water the centre at ANGRAU, Hyderabad was shifted to its Regional Station at Jagtial and was initiated during 2000-01.

AICRP LTFE Experimental site on rice at Jagtial (Hyderabad)

Aerial view of LTFE on soybean at VNMKV Parbhani

Table 2.1 Details with soil type, cropping system and Agroecological region of different centres of AICRP on LTFE

S. No.	Location (State)	Soil Type	Year of start	Taxonomic Class	Cropping system	Agro-eco region	AE Sub-region
1	ICAR-CRIJAF Barrackpore (West Bengal)	Inceptisols	1971	Typic Eutrochrept	Rice-wheat-jute fibre	15	15.1
2	PAU Ludhiana (Punjab)	Inceptisols	1971	Typic Ustochrept	Maize-wheat-cowpea fodder (Cowpea discontinued since 1999)	4	4.1
3	ICAR-IARI New Delhi (Delhi)	Inceptisols	1971	Typic Ustochrept	Pearlmillet-wheat-cowpea fodder (till 1981-82) ; Maize-wheat-cowpea fodder (since 1982-83); Maize-Wheat (since 2001-02)	4	4.1
4	TNAU Coimbatore (Tamil Nadu)	Inceptisols	1971	Vertic Ustopept	Fingermillet-maize-cowpea fodder (Cowpea discontinued w.e.f. 2000-01)	8	8.1
5	JNKVV Jabalpur (Madhya Pradesh)	Vertisols	1972	Typic Chromustert	Soybean-wheat-maize fodder (Maize fodder discontinued w.e.f. 1994-95)	10	10.1
6	GKVK Bangalore (Karnataka)	Alfisols	1972	Kandic Paleustalf	Fingermillet-maize-cowpea-fodder (Cowpea discontinued w.e.f. 1994)	8	8.1
7	PJTSAU RRS Jagtial (Telangana)	Inceptisols	2000	Typic Tropaquept	Rice-rice [Earlier expt. continued till 1996 (at Hyderabad,1971-96)]	7	7.2
8	OUAT Bhubaneswar (Orissa)	Inceptisols	2002	Aeric Haplaquept	Rice - rice (Expt. continued till 2001) Rice - rice (new Expt. started w.e.f. 2002)	12	12.2
9	BAU Ranchi (Jharkhand)	Alfisols	1972	Typic Haplustalf	Soybean-potato-wheat (till 1984) Soybean-wheat (since 1985)	12	12.3
10	CSKHPKV Palampur (Himachal Pradesh)	Alfisols	1972	Typic Hapludalf	Maize-potato-wheat (till 1977-78) Maize-wheat (since 1978-79)	14	14.3
11	GBPUA&T Pantnagar (Uttarakhand)	Mollisols	1971	Typic Hapludoll	Rice-wheat	14	14.1
12	JAU Junagadh (Gujarat)	Vertisols	1996	Vertic Ustochrept	Groundnut-wheat	2	2.4
13	Dr PDKV Akola (Maharashtra)	Vertisols	1996	Typic Haplustert	Sorghum-wheat	6	6.2
14	KAU Pattambi (Kerala)	Alfisols	1996	Typic Haplustalf	Rice-rice	19	19.2
15	IGKV Raipur(Chhattisgarh)	Vertisols	1996	Typic Haplusterts	Rice-wheat	11	11.0
16	MPUA&T Udaipur (Rajasthan)	Inceptisols	1996	Typic Ustochrept	Maize-wheat	4	4.2
17	MPKV Parbhani (Maharashtra)	Vertisols	1996	Typic Chromustert	Soybean -safflower	6	6.2
B. Voluntary centre							
18	ICAR-IASRI New Delhi (Delhi)	-	1972	-	-	-	-

Table 2.2 Nutrient rates used under various cropping systems at different centres of AICRP-LTFE

Location	Crop	Fertilizer rates at 100% NPK based soil test (kg ha^{-1})			*FYM added (Mg ha^{-1})
		N	P	K	
Barrackpore	Rice	120	26	50	5
	Wheat	120	26	50	-
	Jute	60	13	50	-
Ludhiana	Maize	120	26	25	5
	Wheat	120	26	25	-
New Delhi	Maize	120	26	33	5
	Wheat	120	26	33	-
Coimbatore	Finger millet	90	20	14	5
	Maize	135	29	29	-
Jabalpur	Soybean	20	35	17	5
	Wheat	120	35	33	-
Bangalore	Finger millet	100	26	21	5
	Maize	120	26	21	-
Jagtial	Rice (kharif)	120	26	33	5
	Rice (rabi)	120	26	33	-
Ranchi	Soybean	25	26	33	5
	Wheat	80	26	33	-
Bhubaneswar	Rice (kharif)	100	26	50	5
	Rice (rabi)	100	26	50	-
Palampur	Maize	120	26	75	5
	Wheat	90	39	38	-
Pantnagar	Rice	120	26	38	5
	Wheat	120	26	33	-
Junagadh	Groundnut	25	22	0	-
	Wheat	120	26	50	-
Pattambi	Rice (kharif)	90	20	38	5
	Rice (rabi)	90	20	38	-
Udaipur	Maize	90	30	15	5
	Wheat	90	30	15	-
Raipur	Rice	100	26	33	5
	Wheat	100	26	33	-
Akola	Sorghum	100	50	40	5
	Wheat	120	26	50	-
Parbhani	Soybean	30	26	25	5
	Safflower	60	18	0	

** FYM application @ 5 Mg per ha on oven dry basis since 2010*

2.2 Superimposition of Treatments

Continuous use of fertilizers either singly, in combination or integration with FYM resulted in either high build of P and Zn fertility or accentuated the deficiencies of micronutrients, soil acidity, and excessive depletion of P or K. Therefore, interventions were needed to address issues emerged out of the information generated. Superimposition of treatments was done using nested design in one of the replications in certain specified treatments at some centers.

2.2.1 Pantnagar

Treatment	Superimposed treatments since 1993
150% NPK	S_1 150% NPK (Original)
	S_2 150% NPK + S
	S_3 150% NPK – S + Zn
	S_4 150% NPK + S + Zn
	S_5 150% NPK + S + Zn + FYM
	Superimposed treatments since 2002
100% NPK	S_1 100% NPK (Original)
	S_2 100% NPK + S
	S_3 100% NPK – S + Zn
	S_4 100% NPK + S + Zn
	S_5 100% NPK + S + Zn + FYM

2.2.2 Ludhiana

Treatment	Superimposed treatments since 1994
50% NPK	S_1 50% NPK (Original)
	S_2 100% N, 50% P, 50% K
	S_3 100% N, 50% P, 100% K + Zn
100% NPK	S_1 100% NPK (Original)
	S_2 100% N, 50% P, 100% K
	S_3 100% N, 50% P, 100% K + Zn
150% NPK	S_1 150% NPK (Original)
	S_2 150% N, 50% P, 150% K
	S_3 150% N, 50% P, 150% K + Zn
100% NPK (S free)	S_1 100% NPK (S free) (Original)
	S_2 100% NK
	S_3 100% NPK + Zn

2.2.3 Ranchi

Treatment	Superimposed treatments since 2002-2003
100% NP	S_1 100% NP (Original)
	S_2 100% NP + Lime*
	S_3 100% NP + FYM
100% N	S_1 100% N (Original)
	S_2 100% N + Lime*
	S_3 100% N + FYM
100% N(S)PK	S_1 100% N(S)PK (Original)
[S= $NH_4(SO_4)_2$]	S_2 100% N(S)PK + Lime*
	S_3 100% N(S)PK + FYM

** Lime as per requirement*

2.2.4 Bangalore

Treatment	Superimposed treatments since 2002-2003
100% NPK+HW	S_1 100% NPK + Hand Weeding (Original)
	S_2 100% N, 50% P_2O_5, 100% K_2O and FYM (15 t ha^{-1})
	S_3 100% N, 50% P_2O_5, 100% K_2O, FYM (15 t ha^{-1}) & liming
100% NP	S_1 100% NP (Original)
	S_2 100% N, 50% P_2O_5, 100% K_2O and FYM (15 t ha^{-1})
	S_3 100% N, 50% P_2O_5, 100% K_2O, FYM (15 t ha^{-1}) & liming
100% N	S_1 100% N (Original)
	S_2 100% N, 100% P_2O_5, 100% K_2O and FYM (15 t ha^{-1})
	Superimposed treatments since Kharif, 2005-06
150% NPK	S_1 150% NPK (Original)
	S_2 150% NPK+ 5 t ha^{-1} FYM
	S_3 100% NPK + 10 t ha^{-1} FYM

2.2.5 New Delhi

Treatment	Superimposed treatments since 2001-2002
100% NPK+HW	S_1 NPK + Hand Weeding (Original)
	S_2 FYM alone on N basis 120 kg (24 t ha^{-1})
	S_3 50% N basis FYM + 50% NPK

100% N	S_1 100% N (Original)
	S_2 FYM alone on N basis 120 kg (24 t ha^{-1})
	S_3 50% N basis FYM + 50% NPK
Control	S_1 Control (Original)
	S_2 FYM alone on N basis 120 kg (24 t ha^{-1})
	S_3 50% N basis FYM + 50% NPK

2.2.6 Jabalpur

Treatment	Superimposed treatments since 2002-2003
150% NPK	S_1 150% NPK (Original)
	S_2 150% NPK + 2.5 t ha^{-1} FYM
	S_3 150% NPK + 5.0 t ha^{-1} FYM
	S_4 150% NPK + 10.0 t ha^{-1} FYM

2.2.7 Coimbatore

Treatment	Superimposed treatments since 2002-2003
100% NPK	S_1 100% NK
	S_2 100% NK + 50% P
	S_3 100% NK + 100% P (Original)
	S_4 100% NK + 150% P
150% NPK	S_1 150% NPK (Original)
	S_2 150% NPK + 2.5 t ha^{-1} FYM
	S_3 150% NPK + 5.0 t ha^{-1} FYM
	S_4 150% NPK + 10.0 t ha^{-1} FYM

2.2.8 Barrackpore

Treatment	Superimposed treatments since 2002-2003
100% NPK	S_1 100% NPK (Original)
	S_2 100% N+ 66% P+ 100% K
	S_3 100% N+ 33% P+ 100% K
150% NPK	S_1 150% NPK (Original)
	S_2 150% N + 66% P+150% K
	S_3 150% N + 33% P+150% K

100% NP	S_1 100% NP (Original)
	S_2 100% N+ 66% P
	S_3 100% N+ 33% P
100% NPK+ FYM	S_1 100% NPK+ FYM (Original)
	S_2 100% N+ 66% P+ 100% K + FYM
	S_3 100% N+ 33% P+ 100% K + FYM

Results obtained on superimposition of treatments at different centres brought out the information for developing the strategies for reutilizing the accumulated nutrients as a result of continuous application and mitigating the deficiency of P, K, Zn or S due to absence of these nutrients in fertilizer schedule for long time.

3. CROP PRODUCTIVITY

CROP GROWTH AND YIELD are determined by a number of factors such as genetic potential of crop cultivar, soil, weather, cultivation practices and biotic stresses. These, in turn, are dependent upon several climatic, edaphic, hydrological, physiological and management factors. In this chapter, impact of nutrient management on crop productivity over the years under long term fertilizer experiments (LTFEs) in different agroecological zones of India are elaborated:

Rice and wheat are staple foods of majority of people in our country. Thus, rice–wheat cropping system is one of the most important systems of South Asian countries and Indo-Gangetic Plain of India in particular. The system played a significant role in the food security of the region since the era of Green Revolution during early 1970s. But now-a-days, the cultivation of coarse cereals, pulses and fibre crops are also gaining momentum as far as food and human nutrition and clothing are concerned.

3.1 Barrackpore

3.1.1 Rice

Application of fertilizers, alone or in combination with FYM significantly increased the yield of rice compared to control in Inceptisols of Barrackpore (**Table 3.1** & **Figure 3.1**). The yield obtained with 150% NPK was found to be at par with the application of 100% NPK+ FYM, while inclusion of K along with NP (100% NPK) resulted in an increase of around 11, 13 and 4% yield over application of 100% NP in rice, respectively. Reduction in quantum of inputs (50% NPK) and exclusion of one or more nutrients resulted in significant reductions in yield of rice indicating imbalanced use of nutrient application resulted in yield decline. Thus, integrated nutrient management (i.e. NPK + FYM) is one of the options to sustain rice crop productivity.

3.1.2 Wheat

Application of fertilizers and manures significantly increased the yield of wheat and 100% NPK+ FYM and 150% NPK found to give almost similar yield (**Table 3.1** & **Figure 3.1**). The 100% NPK+FYM, 150% NPK, 100% NPK resulted in 25, 24 and 13% more yield over application of 100% NP. There was increase in yield due to application of 100% NPK and 150% NPK by 46 and 24% compared to 50% NPK, respectively. Thus, integration of nutrients i.e. NPK along with FYM is of prime importance for sustaining the crop productivity over the years.

3.1.3 Jute

Jute is a fibre grown as a third crop under intensive cropping at Barrackpore. Data indicated that 100% NPK+ FYM gave maximum yield compared to rest of the treatments (**Table 3.1** & **Figure 3.1**). This treatment gave marginally higher fiber yield than 150% NPK and both the treatments found at par. The imbalanced nutrient application has drastically reduced the fibre yield compared to balanced nutrient use. The NPK+FYM has further improved the fibre yield of jute.

Table 3.1 Effect of long term fertilization and manuring on yield of different crops at LTFE of ICAR-CRIJAF, Barrackpore (2016-19)

Treatment	Rice (kg ha^{-1})				Wheat (kg ha^{-1})				Jute (kg ha^{-1})			
	2016	2017	2018	Mean	2016-17	2017-18	2018-19	Mean	2016	2017	2018	Mean
Control	2033	1207	1110	1450	423	497	640	520	1101	968	847	972
100% N	3462	2096	3317	2958	1867	1705	1910	1827	2173	1663	1590	1808
100% NP	3423	2158	3538	3040	2000	1821	2063	1961	2136	1816	1795	1916
50% NPK	3093	1953	2440	2495	1300	1438	1800	1513	1793	1599	1508	1633
100% NPK	3327	2426	3723	3159	2233	2130	2260	2208	2480	2163	2120	2254
150% NPK	3335	2686	4125	3382	2467	2356	2490	2437	2777	2495	2513	2595
100 % NPK – S	3331	2188	3512	3010	2167	1928	2130	2075	2002	1946	1930	1959
100% NPK+ HW	3153	1985	3508	2882	2200	1969	2190	2120	2027	2090	2120	2079
100% NPK +Zn	3251	2478	3813	3181	2267	2200	2270	2245	1822	2232	2261	2105
100% NPK + FYM	3611	2733	3953	3432	2517	2402	2433	2450	2516	2518	2560	2531
CD (0.05)	397	55	625	-	222	349	569	-	448	144	249	-

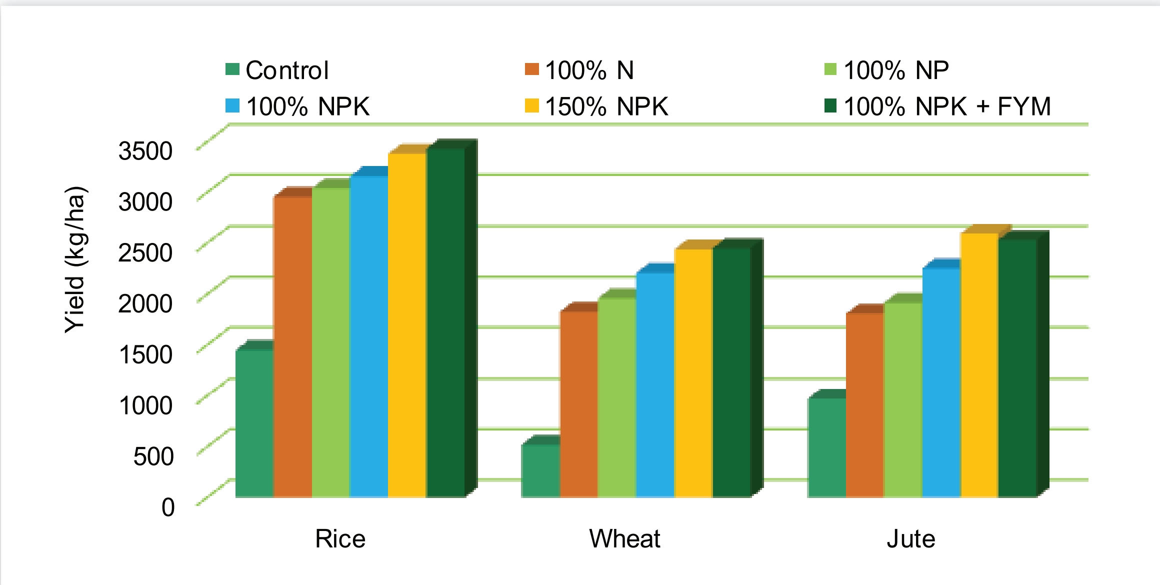


Figure 3.1 Impact of imbalanced, balanced and INM on grain and fibre yield of crops at CRIJAF Barrackpore (2016-19)

3.2 Pantnagar

3.2.1 Rice

Application of 100% NPK + FYM or Zn produced the highest rice grain yield and showed the superiority of these treatments over all other treatments (**Table 3.2** & **Plate 3.1a**). Addition of FYM @ 15 Mg ha^{-1} once in every year and Zn @ 50 kg $ZnSO_4$ approximately at 4-5 years interval along with 100% NPK produced significantly higher grain yield as compared to 100% NPK, 100% NP + Zn, 100% N+Zn and 100% NPK+ Zn-S. Data indicated that Zn is essential for sustaining the crop yield of rice. Thus, it is ascribed to the severe incidence of Khaira disease owing to the heavy application of P fertilizer which causes nutrient imbalance in these treatments. Results revealed that control and bio-fertilizer application recorded lowest grain yields over the years.

3.2.2 Wheat

Result indicated that addition of 50% NPK+Zn significantly enhanced wheat grain yield over control and it was increased further at 100% NPK and 150% NPK even without zinc (**Table 3.2 & Plate 3.1b**). Application of 100% N alone with Zn produced more wheat grain as compared to 50% NPK but it was inferior to 100% NPK and 150% NPK. The mean wheat grain yield over the years showed that combined application of 100% NPK either with FYM or Zn found to optimise grain yield as compared to other treatments.

Table 3.2 Rice and wheat grain yields in LTFE at Pantnagar (2016-19)

Treatment	Rice (kg ha^{-1})				Wheat (kg ha^{-1})			
	2016	2017	2018	Mean	2016-17	2017-18	2018-19	Mean
Control	1258	1363	1203	1274	1145	1235	1212	1184
100% N+Zn	3545	3320	3025	3296	3303	3228	3015	3182
100% NP+Zn	4238	4175	3898	4103	3455	3538	3348	3447
50% NPK	3600	3445	3255	3433	3015	2790	2853	2886
100% NPK	3667	3667	3690	3674	3493	3293	3303	3363
150% NPK	3500	3503	3557	3520	3387	3253	3280	3306
150% NPK+HW+Zn	4463	3963	3863	4096	3698	3730	3661	3696
100% NPK-S+Zn	4375	3910	3760	4015	3648	3703	3603	3651
100% NPK+Zn	4765	4453	4078	4432	4013	4188	4013	4071
100% NPK+FYM	5053	5228	5113	5131	4768	4613	4863	4748
Biofertilizer	1333	1345	1427	1320	1230	1260	1210	1233
CD (0.05)	205.3	244.5	220.5	-	250.5	244.2	302.2	-

3.3 Raipur

3.3.1 Rice

Application of plant nutrients after twenty cropping cycles showed significant response in terms of grain yield over control (**Table 3.3** & **Plate 3.2a**). The highest rice grain yield was recorded with 150% NPK level and it was at par with 100% NPK + FYM. The pooled grain yield of rice in optimal dose of nutrients (100% NPK) and 100% NP are at par indicating K is sufficient in soil (376 kg ha^{-1}). Further, pooled yield data of 100% N was significantly lower as compared to 100% NP treatment which showed the importance and essentiality of phosphatic fertilizer in Vertisols. Among organic sources applied in rice, highest residual effect was noticed with 100% NPK+FYM, 100% NPK, 100% NPK+Zn and 50% NPK+Green Manure (GM).

Control

100% N

100% NP

50% NPK

100% NPK-Zn

150% NPK-Zn

100% NPK + Zn

100% NPK+FYM

Biofertilizer

Plate 3.1 (a) Impact of long term fertilizer and manure on growth and productivity of rice in LTFE at Pantnagar (GBPUA&T, Pantnagar)

100% N

100% NP

100% NPK-Zn

150% NPK-Zn

100% NPK+Zn

100% NPK+FYM

Plate 3.1(b) Impact of long term fertilizer and manure on growth and productivity of wheat in LTFE at Pantnagar (GBPUA&T, Pantnagar)

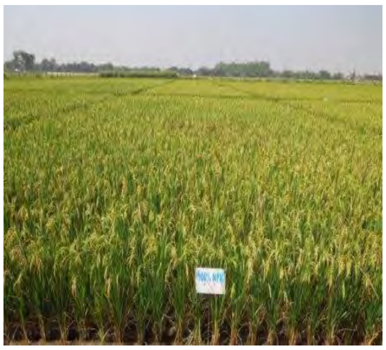
3.3.2 Wheat

After 20 cropping cycles the result showed that there was no response to micronutrient (i.e. Zn) on wheat which may be due to higher initial Zn status in the Vertisols of Raipur (1.2 mg kg^{-1}) (**Table 3.3** & **Plate 3.2b**). The sustainability in wheat yield was increased with graded levels of balanced application of fertilizers from sub optimal to super optimal dose of balanced nutrients i.e., 50 to 150% NPK. The graded levels of inorganic fertilizers application along with organic manure and biofertilizer (FYM, green manure and blue green algae) sustained crop yields.

Control

100% N

100% NP



100% NPK

150% NPK

100% NPK+Zn

100% NPK+FYM

50% NPK+Green manure

50% NPK+BGA

Plate 3.2 (a) Impact of long term fertilizer and manure on growth and productivity of rice at Raipur (IGKV, Raipur)

Control

100% N

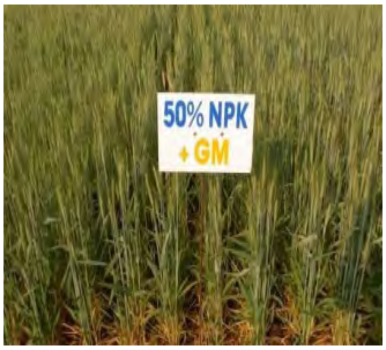
100% NP

100% NPK

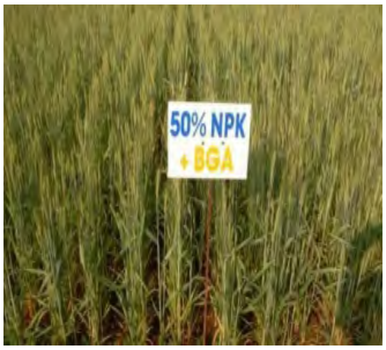
150% NPK

100% NPK+Zn

100% NPK+FYM



50% NPK + Green Manure



50% NPK+BGA

Plate 3.2 (b) Impact of long term fertilizer and manure on growth and productivity of wheat at Raipur (IGKV, Raipur)

Table 3.3 Effect of long-term fertilizer application on rice and wheat yield at IGKVV Raipur (2016-18)

Treatment	Rice (kg ha^{-1})				Wheat (kg ha^{-1})			
	2016	2017	2018	Mean	2016-17	2017-18	2018-19	Mean
Control	2068	1990	1920	1993	1255	1120	1021	1132
100% N	3600	3200	3125	3308	1840	1645	1654	1713
100% NP	4420	4200	4800	4473	2835	2910	2793	2846
50% NPK	3800	3605	3810	3738	1920	2200	2156	2092
50% NPK + BGA	3793	3595	3720	3703	2120	2405	2250	2258
50% NPK + GM	4240	4035	4130	4135	2265	2550	2530	2448
100% NPK	4500	4485	4865	4617	2850	2895	2835	2860
150% NPK	5220	5105	5195	5173	3105	3200	3233	3179
100% NPK+$ZnSO_4$	4465	4235	4850	4517	2893	2920	2806	2873
100% NPK + FYM	5010	4970	5170	5050	3005	3110	3193	3103
CD (0.05)	451	733	484	-	398	561	484	-

3.4 Ludhiana

3.4.1 Maize

Data on maize grain yield indicated that significantly higher yield was observed with application of 100% NPK compared to the application of 50% NPK (**Table 3.4** & **Plate 3.3a**). The grain yield of maize increased significantly with addition of individual nutrients (N, P & K) and it was increased to the tune of 145, 30 and 15% with 100% NPK as compared to control, 100% N and 100% NP, respectively. Application of 100% NPK along with FYM showed 17.5% higher maize grain yield compared to the application of NPK. The 150% NPK recorded lower maize grain yield by 12.5% compared to NPK+FYM indicated that higher dose of fertilizer could not substitute the FYM. There was no response to S application as absence or presence of S did not change grain yield of maize when P was supplied through di-ammonium phosphate or single superphosphate. However, maize showed a response to Zn application. The grain yield of maize under weed control measures indicates that chemical weed control is more suitable than hand weeding to overcome labour shortage conditions in Punjab state without compromising maize yield.

3.4.2 Wheat

The wheat grain yield data indicated that 37% more yield was recorded with 100% NPK compared to 50% NPK. The wheat yield response followed almost similar trend to that of maize and addition of individual nutrients (N, P & K) have gradually enhanced the yield (**Table 3.4** & **Plate 3.3b**). The residual effect of 100% NPK + FYM showed significant increase in wheat grain yield to an extent of 14% as compared to 100% NPK. There was no response to S but wheat responded to Zn application in Inceptisols of Ludhiana.

Control

100% N

100% NP

50% NPK

100% NPK

150% NPK

100% NPK+Zn

100% NPK+FYM

100% NPK (-S)

Plate 3.3 (a) Impact of long term fertilizer and manure on growth and productivity of maize in LTFE at Ludhiana (PAU, Ludhiana)

Control

100% N

100% NP

50% NPK

100% NPK

150% NPK

100% NPK+Zn

100% NPK+FYM

Plate 3.3 (b) Impact of long term fertilizer and manure on growth and productivity of wheat in LTFE at Ludhiana (PAU, Ludhiana)

Table 3.4 Effect of long-term fertilizer application on maize and wheat yield at PAU Ludhiana (2016-19)

Treatment	Maize (kg ha^{-1})				Wheat (kg ha^{-1})			
	2016	2017	2018	Mean	2016-17	2017-18	2018-19	Mean
Control	1430	1490	1390	1440	1840	1960	1950	1920
100% N	3890	3470	3220	3530	3430	3640	3640	3570
100% NP	4760	4550	4490	4600	4600	4520	4520	4550
50% NPK	3690	3540	3680	3640	3630	3710	3710	3680
100% NPK	5380	5310	5180	5290	4860	5460	4760	5030
150% NPK	5640	5610	5350	5530	4910	5760	5760	5470
100% NPK-S	5360	5290	5210	5290	4680	5360	5000	5010
100% NPK+W	5250	5410	5270	5310	4780	5540	5540	5290
100% NPK+Zn	5200	5520	5370	5370	4950	5630	5510	5360
100% NPK+FYM	6170	6420	6070	6220	5340	5950	5950	5750

3.5 Palampur

3.5.1 Maize

Application of 100% NPK + FYM recorded significantly higher productivity of maize compared to 100% NPK (**Table 3.5** & **Plate 3.4**). Application of 100% NPK+lime recorded yields at par with 100% NPK + FYM. Thus, soil amendment with lime is essential to maintain soil quality and crop yields in particular. Plots with hand weeding had recorded comparatively higher yield than plots with chemical weed control measures under similar nutrient management practices. Imbalanced fertilizer application resulted in significant decline in crop productivity. Continuous application of 100% N alone had deleterious effect on crop productivity as yield of crops declined to zero. Continuous omission of K and S reduced the productivity significantly in comparison to balanced fertilization (100% NPK). Application of 150% NPK significantly reduced the productivity of maize crops due to emerging deficiency of secondary nutrients, particularly Mg.

3.5.2 Wheat

Application of FYM or lime along with 100% NPK recorded significantly higher productivity of wheat as compared to 100% NPK (**Table 3.5**). The highest yield was recorded in 100% NPK + FYM treatment. Imbalanced fertilization resulted in significant decline in crop productivity. Similar to maize, continuous application of 100% N alone had also recorded deleterious effect on the wheat yield as it has declined to zero. In wheat also, S and Zn are equally important to sustain productivity.

Table 3.5 Long-term effect of fertilizers and amendments on grain yield of maize and wheat in LTFE at Palampur (2016-19)

Treatment	Maize (kg ha^{-1})				Wheat (kg ha^{-1})			
	2016	2017	2018	Mean	2016-17	2017-18	2018-19	Mean
Control	979	818	625	807	334	392	400	375
100% N	0	0	0	0	0	0	0	0
100% NP	1823	1826	1456	1702	875	917	863	885
50% NPK	3835	4095	3041	3657	1638	1667	1729	1678
100% NPK	4002	3981	3175	3719	1819	1867	1904	1863
150% NPK	3778	3511	2732	3340	1558	1525	1542	1542
100% NPK (-S)	1720	1770	1363	1618	808	858	809	825
100% NPK +HW	4257	4358	3612	4076	2025	2083	2192	2100
100% NPK + Zn	3953	3878	2903	3578	1784	1758	1658	1733
100% NPK + Lime	5703	5733	4174	5203	2508	2392	2771	2557
100% NPK + FYM	5948	6044	4559	5517	2717	2525	2879	2707
CD (0.05)	516	434	336	-	237	125	185	-

Control

100% N


100% NP


100% NPK


100% NPK + lime


100% NPK + FYM

Plate 3.4 Impact of long term fertilizer and manure on growth and productivity of maize in LTFE at Palampur (CSK HPKV, Palampur)

3.6 Jabalpur

3.6.1 Soybean

The yield was significantly higher with sub-optimal fertilizer dose (50% NPK) than with the application of 100% N alone indicating imbalanced nutrient application resulted in lower productivity (**Table 3.6** & **Plate 3.5a**). Similarly, it was also noted that when P fertilizer was included (100% NP) about 79% higher yield was obtained; while there was a further improvement noted by 94% when K was included (100% NPK) in fertilizer schedule compared to 100% N alone. These results established the importance of P application as a major fertility constraint in controlling productivity of soybean grown especially in black soil. Likewise, addition of S through SSP exhibited an increase in crop yield over without S supplementation through DAP fertilizer. Application of recommended optimal dose (100% NPK) resulted in higher grain yield but exclusion of sulphur (i.e. 100% NPK-S) resulted in comparatively lower grain yield which was accounted to about 7%. On the other hand, the grain yield obtained in 100% NPK + FYM treatment was higher than 150% NPK treatment. The data clearly indicated that addition of integrated application of fertilizer with FYM was found to be beneficial for maintaining the fertility and consequently improved the productivity potential of soybean–wheat cropping system.

3.6.2 Wheat

The wheat grain yield reveals that successive additions of fertilizer from sub optimal to optimal and optimal to super optimal doses resulted in progressive increment in the productivity of wheat (**Table 3.6** & **Plate 3.5b**). Further addition of organic manure with optimal fertilizer dose enhanced the yield. On the other hand, use of 100% N alone was found to be at par with control. Application of P fertilizer along with N (NP treatment) had resulted in higher grain yield of wheat. Inclusion of K along with NP (100% NPK) contributed by around 28% higher grain yield compared to application of 100% NP. However omission of sulphur (100% NPK-S) had considerably declined the wheat yield by about 15% as compared to optimal fertilizer dose. These findings indicated that balanced application of recommended NPKS through fertilizer led to higher yield over imbalanced applications. Integrated use of optimal fertilizer and organic manure was found to be superior over 100% NPK for sustaining the fertility of soil and subsequent crop productivity.

Table 3.6 Yields of soybean and wheat in long term fertilizer experiment at Jabalpur (2016-19)

Treatment	Soybean (kg ha^{-1})				Wheat (kg ha^{-1})			
	2016	2017	2018	Mean	2016-17	2017-18	2018-19	Mean
Control	394	963	738	698	1188	1450	1363	1334
100% N	438	975	825	746	1675	1783	1775	1744
100% NP	800	1769	1444	1338	4269	4375	4150	4265
50% NPK	681	1501	1301	1161	4113	4300	4188	4200
100% NPK	906	1813	1638	1452	5788	5375	5225	5463
150% NPK	1038	2113	1988	1713	6313	5988	6025	6108
100% NPK-S	844	1750	1480	1358	5113	4575	4544	4744
100% NPK+HW	894	1800	1625	1440	5538	5325	5250	5371
100% NPK+Zn	888	1794	1594	1425	5544	5369	5263	5392
100% NPK+FYM	1075	2281	2106	1821	6525	6175	6138	6279
CD (0.05)	117	281	214	-	854	764	708	-

Control

100% N

100% NPK

150% NPK

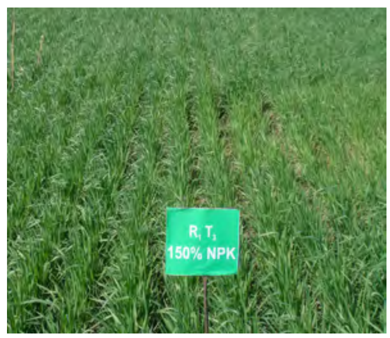
100% NPK-Sulphur

100% NPK+FYM

Plate 3.5 (a) Impact of long term fertilizer and manure on growth and productivity of soybean in LTFE at Jabalpur (JNKVV Jabalpur)

50% NPK

100% NPK



150% NPK

Control

100% NPK-Sulphur

100% NPK+FYM

Plate 3.5 (b) Impact of long term fertilizer and manure on growth and productivity of wheat in LTFE at Jabalpur (JNKVV Jabalpur)

3.7 Ranchi

3.7.1 Soybean

Data revealed that suboptimal dose of NPK (50% NPK) was inferior to optimal dose of NPK (100% NPK) (**Table 3.7** & **Plate 3.6a**). Continuous application of N in the form of urea drastically declined yield that was even less than control plots. Application of N through ammonium sulphate and supplementing P and K through SSP and MOP, respectively, (i.e. 100% N (S) PK), reduced the grain yield drastically even less than 50% NPK for few years. Changes in the N fertilizer source from ammonium sulphate to urea during 2010 resulted in spectacular increase in grain yield of soybean and it was found to be better than 100% NPK. Over the years, it was found that application of FYM along with the recommended dose of NPK recorded maximum grain yield of soybean followed by NPK+lime application but difference was not statistically significant. Application of 100% N alone recorded around 80% reduction in grain yield of soybean as compared to 100% NPK. Similarly application of 100% NP recorded 46-53% reduction in grain yield of soybean as compared to 100% NPK fertilizers and deficiency of K was noticed in soybean. Supplementing lime/FYM along with recommended dose of NPK fertilizers increased grain yield of soybean up to 46% as compared to the recommended dose of 100% NPK.

3.7.2 Wheat

Application of optimal level of fertilizers produced higher yield than suboptimal dose of fertilizers and the increase was around 28% (**Table 3.7** & **Plate 3.6b**) Application of 150% NPK recorded marginally more yield over 100% NPK and with higher magnitude compared to 50% NPK. Application of 100% N alone declined grain yield drastically indicating adverse effect on soil quality and crop yield. Application of NP without K i.e. 100% NP recorded similar grain yield of wheat as compared to 100% NPK. Application of FYM or lime along with optimal dose of NPK to soybean increased grain yield of succeeding wheat by around 30% during this period.

Control

100% N

100% NP

50% NPK

100% NPK

150% NPK

100% NPK+Lime

100% NPK+FYM

100% NPK+Sulphur

Plate 3.6 (a) Impact of long term fertilizer and manure on growth and productivity of soybean in LTFE at Ranchi (BAU, Ranchi)

Control

100% N

100% NP

50% NPK

100% NPK

150% NPK

100% NPK+Lime

100% NPK+FYM

100% NPK+Sulphur

Plate 3.6 (b) Impact of long term fertilizer and manure on growth and productivity of wheat in LTFE at Ranchi (BAU Ranchi)

Table 3.7 Effect of continuous use of fertilizer, manure and lime on yield of soybean and wheat in LTFE at Ranchi (2016-19)

Treatment	Soybean (kg ha^{-1})				Wheat (kg ha^{-1})			
	2016	2017	2018	Mean	2016-17	2017-18	2018-19	Mean
Control	548	458	650	552	736	719	689	715
100% N	437	440	437	438	792	701	1072	855
100% NP	762	537	721	673	3044	3579	3634	3419
50% NPK	1618	1148	1040	1268	2383	2163	2370	2305
100% NPK	1625	1253	1401	1426	2570	3663	3545	3259
150% NPK	1907	1544	1508	1653	2839	3482	3888	3403
100% NPK +HW	1680	1275	1050	1335	2888	3540	3713	3380
100% N (S) PK	1812	1763	1479	1685	2579	3690	3852	3374
100% NPK + Lime	2250	1973	2020	2081	4195	4190	4270	4218
100% NPK + FYM	2398	1875	1885	2053	4013	4538	4355	4302
CD (0.05)	323	206	244	-	468	273	492	-

3.8 New Delhi

3.8.1 Maize

Application of 150% NPK or 100% NPK+FYM produced significantly higher yields than other treatments over the years (**Table 3.8**). Grain yield under 100% NP was significantly higher as compared to N alone, underlining the response to P fertilization. Yield response to S and Zn application was inconsistent. The yield performance under 100% NPK+ hand weeding (HW) was comparable with 100% NPK treatment, indicating no significant difference between hand weeding and chemical weed control. Maize yield indicated the superiority of 150% NPK and 100% NPK+FYM, for sustaining higher crop productivity. On the other hand, the initial productivity level could not be sustained under treatments receiving inadequate (50% and 100% NPK) or an imbalanced (100% N and 100% NP) fertilizer application. The high yielding variety, PMH-1 grown since 2016 registered higher yields as compared to PEEHM-5, GS 2 and Vijay composite varieties.

3.8.2 Wheat

The grain yield was significantly higher in 150% NPK as compared to other treatments and similar to yield obtained in 100% NPK with FYM application (**Table 3.8**). The wheat grain yield with 100% NPK was also significantly greater than N alone or NP treatment underlining the response to balanced fertilization. The wheat yield performance under 100% NPK+ hand weeding (HW) was comparable with 100% NPK treatment, indicating no significant difference between hand weeding and chemical weed control.

Table 3.8 Grain yield of maize and wheat as influenced by long-term nutrient management options in LTFE at ICAR-IARI New Delhi (2016-19)

Treatment	Maize (kg ha^{-1})				Wheat (kg ha^{-1})			
	2016	2017	2018	Mean	2016-17	2017-18	2018-19	Mean
Control	1940	1300	1700	1647	1990	1950	1950	1963
100% N	3250	3340	3550	3380	3900	4620	3450	3990
100% NP	5050	4320	4580	4650	3870	4800	4940	4537
50% NPK	3250	3160	3830	3413	3680	3790	3980	3817
100% NPK	5250	5450	5700	5467	5330	5490	5380	5400
150% NPK	6240	6010	6990	6413	6560	5580	6530	6223
100% NPK+S	5430	5520	5860	5603	5430	5550	5520	5500
100% NPK+Zn	5430	5560	6020	5670	5350	5560	5460	5457
100% NPK+HW	5130	5250	5630	5337	4990	4490	5430	4970
100% NPK+FYM	5780	6070	6680	6177	6020	5990	6120	6043
CD (0.05)	320	530	620	-	460	270	460	-

3.9 Bangalore

3.9.1 Finger millet

Data on yield indicated that the application of 100% NPK + FYM + lime recorded maximum grain yield of finger millet followed by 150% NPK (**Table 3.9** & **Plate 3.7a**). Results revealed that crop production was sustained with INM over the years. In almost all the treatments, except 100% NP, 100% N and control where inadequate dosage and imbalanced nutrient supply resulted in lower grain yield. However, there has been a declining trend in crop productivity from last few years mainly in 150% NPK treatment.

Table 3.9 Grain yield of finger millet and maize in LTFE at Bangalore (2016-19)

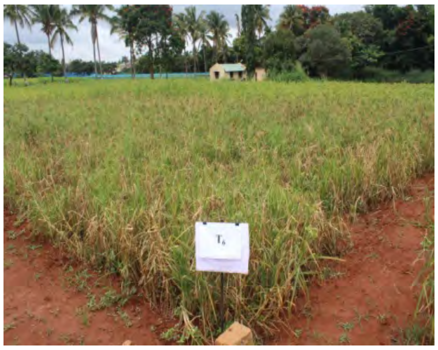
Treatment	Finger millet (kg ha^{-1})				Maize (kg ha^{-1})			
	2016	2017	2018	Mean	2016-17	2017-18	2018-19	Mean
Control	640	980	720	780	480	1090	1150	907
100% N	760	1020	720	833	1210	1030	420	887
100% NP	580	900	750	743	1200	1520	1020	1247
50% NPK	2120	2570	2490	2393	5900	4000	3060	4320
100% NPK	2690	2720	2830	2747	7760	4830	3690	5427
150% NPK	3110	3230	3790	3377	8310	5540	3950	5933
100% NPK+HW	2670	2640	3040	2783	7870	5010	3800	5560
100% NPK+Lime	2800	2920	3180	2967	7850	5100	3840	5597
100% NPK+FYM	3230	3320	3240	3263	8830	5660	3960	6150
100% NPK (S-free)	2740	2790	2820	2783	6850	5200	3530	5193
100% NPK+FYM+lime	3290	3510	3500	3433	8990	6030	4350	6457

3.9.2 Maize

Application of recommended dose of NPK along with FYM and lime recorded the maximum maize grain yield (**Table 3.9** & **Plate 3.7b**). The beneficial effect of liming on enhancing grain yield of maize is obvious from 100% NPK+FYM+lime treatment compared to 100% NPK+FYM. Similarly, increased yield in 100% NPK + lime over recommended dose of fertilizer (100% NPK) have been maintained over the years. Similar to finger millet, the yield levels have been maintained under balanced dosage of NPK application; whereas, very low yields were recorded with 100% N, 100% NP and control.

Control

100% N



100% NP

100% NPK

100% NPK + Lime

100% NPK+FYM

Plate 3.7 (a) Impact of long term fertilizer and manure on growth and productivity of finger millet (GPU-28) in LTFE at Bangalore (UAS GKVK, Bangalore)

Control

100% N

100% NP

50% NPK

100% NPK

150% NPK

100% NPK+Lime

100% NPK+FYM

100% NPK+FYM+Lime

Plate 3.7 (b) Impact of long term fertilizer and manure on growth and productivity of maize (Hybrid) in LTFE at Bangalore (UAS GKVK, Bangalore)

3.10 Coimbatore

3.10.1 Finger millet

Results indicated that various fertilizer treatments increased the grain yield of finger millet compared to control (**Table 3.10** & **Plate 3.8a**). Among the treatments maximum grain yield was recorded with 100% NPK+FYM having 18.7% more than 100% NPK. The crop response in term of increase in grain yield was observed with the increasing levels of NPK from 50 to 150%. However, grain yield attained under 150% NPK was 9.2% lower than the yield under 100% NPK+FYM. Imbalanced nutrient application as 100% N significantly reduced grain yield up to 30% as compared to 100% NPK. Grain yields under 100% NPK and 100% NP were comparable.

Control

100% N

100% NP

50% NPK

100% NPK

150% NPK

100% NPK + Hand weeding

100% NPK+FYM

100% NPK + Zn

Plate 3.8 (a) Impact of long term fertilizer and manure on growth and productivity of finger millet in LTFE at Coimbatore (TNAU, Coimbatore)

3.10.2 Maize

Like finger millet, the maximum grain yield of maize was obtained with 100% NPK + FYM having 13.7% more yield than under 100% NPK. Application of 150% NPK recorded lower yield than INM indicating the superiority of INM over higher rates of inorganic fertilization (**Table 3.10** & **Plate 3.8b**). The 100% N application resulted in lowest yield indicating a reduction of 24.4% as compared to 100% NPK. Application of imbalanced use of nutrients, 100% N or without fertilization, the crop productivity could not be sustained over the years.

Control

100% N

100% NP

50% NPK

100% NPK

150% NPK

100% NPK+Hand weeding

100% NPK+FYM

100% NPK+$ZnSO_4$

Plate 3.8 (b) Impact of long term fertilizer and manure on growth and productivity of maize hybrid (COHM6) in LTFE at Coimbatore (TNAU, Coimbatore)

Table 3.10 Grain yield of finger millet and maize in LTFE at Coimbatore (2016-19)

Treatment	Finger millet (kg ha^{-1})				Maize (kg ha^{-1})			
	2016	2017	2018	Mean	2016 -17	2017-18	2018-19	Mean
Control	1325	1339	1233	1299	3144	2890	2721	2918
100% N	1638	1664	1468	1590	4418	4138	3986	4181
100% NP	2215	2313	2048	2192	5518	5289	5240	5349
50% NPK	1968	2025	1766	1920	5340	5088	5055	5161
100% NPK	2276	2435	2174	2295	5598	5325	5399	5441
150% NPK	2466	2588	2328	2461	5707	5525	5421	5551
100% NPK (-S)	2218	2307	2043	2189	5567	5278	5151	5332
100% NPK + Zn	2306	2438	2234	2326	5823	5453	5382	5553
100% NPK + HW	2156	2206	2004	2122	5528	5441	5330	5433
100% NPK + FYM	2698	2822	2564	2695	6404	6258	6245	6302
CD (0.05)	55	84	76	-	232	174	214	-

3.11 Akola

3.11.1 Sorghum

The grain yield of sorghum increased significantly with application of 100% NPK + FYM. The magnitude of response was observed in the order: control < 100% N < 50% NPK < FYM < 100% NP < 75% NPK <100% NPK < 150% NPK < NPK + FYM (**Table 3.11** & **Plate 3.9a**). Application of FYM @ 10 Mg ha^{-1} alone could not sustain grain yield of sorghum. The application of 100% NPK + FYM @ 5 Mg ha^{-1} recorded significantly maximum grain yield of sorghum. Inclusion of S and Zn showed beneficial effect on grain yield of sorghum.

3.11.2 Wheat

Application of 100% NPK + FYM @ 5 Mg ha^{-1} recorded significantly highest grain yield followed by 150% NPK. Addition of S and Zn along with 100% NPK had beneficial effect on grain yield of wheat (**Table 3.11** & **Plate 3.9b**). Imbalanced (N or NP) application of fertilizer resulted in significant decline in the yield and the lowest grain yield was recorded in the control.


Control


100% N


100% NP


50% NPK


100% NPK


150% NPK


100% NPK+Zn


100% NPK+FYM


100% NPK+Sulphur


FYM


75% NPK+FYM


100% NPK (S free)

Plate 3.9 (a) Impact of long term fertilizer and manure on growth and productivity of sorghum in LTFE at Akola (Dr. PDKV, Akola)

Control

100% N

100% NP

50% NPK

100% NPK

150% NPK

100% NPK+Zn

100% NPK+FYM

100% NPK+Sulphur

FYM

75% NPK +FYM

100% NPK (S free)

Plate 3.9 (b) Impact of long term fertilizer and manure on growth and productivity of wheat in LTFE at Akola (Dr. PDKV, Akola)

Table 3.11 Long term effect of fertilizer and manure on yield of sorghum and wheat at Akola (2016-19)

Treatment	Sorghum (kg ha^{-1})				Wheat (kg ha^{-1})			
	2016	2017	2018	Mean	2016-17	2017-18	2018-19	Mean
Control	546	374	362	427	558	317	294	390
100% N	1815	1344	1947	1702	824	711	628	721
100% NP	3055	1898	3004	2652	2258	1503	2092	1951
50% NPK	2308	1623	2590	2174	1833	1377	1710	1640
100% NPK	3468	2381	3837	3229	2604	1982	2588	2391
150% NPK	4289	3065	4456	3937	3242	2652	3287	3060
100% NPK S free	3276	2206	3520	3001	2630	1793	2465	2296
100% NPK + S	3815	2576	4154	3515	2976	2048	2901	2642
100% NPK + Zn	3759	2467	4033	3420	2790	2143	2748	2560
100% NPK + FYM	4510	3432	4839	4260	3401	2709	3449	3186
FYM only	2093	1708	2696	2166	1089	1123	1295	1169
75% NPK + 25% N through FYM	3156	2278	4015	3150	2949	2134	2805	2629
CD (0.05)	634	227	415	-	467	348	327	-

3.12 Bhubaneswar

3.12.1 Rice (Kharif)

Data on rice grain yield revealed that application of 100% NPK + FYM (@ 5 t ha^{-1}) gave highest yield of rice during kharif season (**Table 3.12**). Application of secondary and micronutrients (S, Zn and B) did not show

Table 3.12 Impact of nutrient management options on rice during Kharif and rabi season in LTFE at Bhubaneswar (2016-19)

Treatment	Rice (Kharif) (kg ha^{-1})				Rice (Rabi) (kg ha^{-1})			
	2016	2017	2018	Mean	2016-17	2017-18	2018-19	Mean
Control	2654	2156	1777	2196	1060	1325	1015	1133
100% N	3988	2983	2979	3317	1585	1751	1369	1568
100% NP	4826	3789	3131	3915	3021	2186	1475	2227
100% PK	3810	2871	2872	3184	2441	2291	1458	2063
100% NPK	5017	4123	3456	4199	3252	3063	1859	2725
150% NPK	5255	4363	3803	4474	3971	3469	2459	3300
100% NPK +Zn	4508	4250	3353	4037	3328	2625	1678	2544
100% NPK +FYM	5601	5359	4750	5237	4904	4347	3499	4250
100% NPK + Lime +FYM	5145	5238	4890	5091	4533	4453	3451	4146
100% NPK + B + Zn	4736	4394	3511	4214	3325	2560	1601	2495
100% NPK + S + Zn	4739	3949	3582	4090	3973	2763	1881	2872
100% NPK + Lime	4633	4389	3806	4276	3594	3525	1925	3015
CD (0.05)	614	439	409	-	589	454	250	-

any significant effect on rice growth and yield. Under imbalanced nutrition with exclusion of either K (100% NP) or PK (100% N) or N (100% PK) the yield after 13 years was much lower than 100% NPK with FYM or lime. Application of lime (1 Mg ha^{-1}) in conjunction with FYM (5 Mg ha^{-1}) to rice grown in acid soil did not have any positive effect on grain yield. Crop response to additional 50% NPK was significant, suggesting one or two of the three nutrients applied through recommended dose are inadequate to meet the crop demand. Further, the crop yield was increased even upto 13 years of application without having any constraint of micronutrient deficiency. From the trend of the zinc status it is however inferred that with exclusion of Zn there is continuous fall in available Zn @ 10 mg kg^{-1} in 100% NPK and 150% NPK application.

3.12.2 Rice (Rabi)

Data on rice grain yield during rabi season followed the similar trend to that of Kharif rice (**Table 3.12**). However, 100% NPK + FYM gave significantly higher compared to rest of the treatments. Application of secondary (S) and micronutrients (Zn and B) did not influence the growth and yield of rabi rice. Thus, imbalanced nutrition has drastically reduced the yield over the years. The INM and lime amendment has improved the soil quality as well as productivity of crops.

3.13 Jagtial

3.13.1 Rice (Kharif)

Data pertaining to yield of kharif rice suggests that on inclusion of P along with N (i.e. 100% NP) led to remarkable increment **(Table 3.13).** The kharif rice grain yield was highest in 150% NPK dose followed by 100% NPK+FYM and found at par. The results clearly depict the importance of balanced and INM combinations for sustaining the yield over the years.

Table 3.13 Effect of long-term fertilizers and manures on grain yield of rice during Kharif and rabi season in LTFE at Jagtial (2016-19)

Treatment	Rice (Kharif) (kg ha^{-1})				Rice (Rabi) (kg ha^{-1})			
	2016	2017	2018	Mean	2016-17	2017-18	2018-19	Mean
Control	2994	2822	4016	3122	1971	2422	2257	2461
100% N	4561	3629	4570	4348	3732	1793	1417	3121
100% NP	6377	5027	7586	5539	5136	5551	6367	4967
50% NPK	5127	4571	6727	4735	3779	4235	4899	4047
100%NPK	6368	5275	7997	5655	5386	5651	6385	5075
150% NPK	6642	4950	7959	6025	6221	6364	7422	5864
100% NPK – S	6267	4931	7803	5641	5596	5552	6411	5004
100% NPK + HW	6188	5132	7517	5684	5441	5153	6472	5096
100% NPK + Zn	6439	5265	7652	5704	5643	5634	6031	5154
100% NPK + FYM	6732	5335	8023	5961	6224	6175	7214	5510
FYM	5471	4975	7634	4548	3901	4206	5919	3715
CD (0.05)	575	594	872	-	912	703	691	-

3.13.2 Rice (Rabi)

The grain yield of rabi rice showed the similar trend to that of kharif rice with maximum yield in 150% NPK followed by 100% NPK+FYM **(Table 3.13).** The integration of nutrients led to significant improvement in the grain yield of rice over the years. Thus, the balanced and integrated nutrient management performed better over imbalance nutrient application.

3.14 Junagadh

3.14.1 Groundnut

The maximum groundnut pod yield was recorded with 50% NPK + 10 t FYM ha^{-1} followed by 100% NPK (P as SSP) and 100% NPK + Zn (i.e. 50 kg $ZnSO_4$ per ha). Application of 50% NPK + FYM recorded 36.9% higher pod yield as compared to 100% NPK (**Table 3.14**).

3.14.2 Wheat

The treatment 100% NPK + 10 t FYM ha^{-1} recorded significantly higher grain yield of wheat (**Table 3.14**). Application of 100% NPK + FYM recorded 27.1% higher grain yield as compared 100% NPK, respectively.

Table 3.14 Mean yield of groundnut (*Kharif*) and wheat (*Rabi*) at JAU Junagadh (2016-19)

Treatment	Groundnut pod (kg ha^{-1})				Wheat grain (kg ha^{-1})			
	2016	2017	2018	Mean	2016-17	2017-18	2018-19	Mean
Control	687	701	380	589	1821	1477	1435	1578
100% N	610	641	338	530	1571	1765	1374	1570
100% NP	716	722	354	597	2438	1898	2304	2213
50% NPK	744	816	457	672	2163	2332	2236	2244
100% NPK	850	969	469	763	2867	2930	3207	3001
150% NPK	1060	1094	555	903	3260	3141	3618	3340
100% NPK+ Zn	965	990	530	828	2971	2897	3272	3047
NPK as per soil test	840	1001	475	772	2854	2689	3159	2901
50% NPK+FYM*	1289	1355	588	1077	3796	3716	4234	3915
FYM#	1134	1238	561	978	3608	3420	4107	3712
50% NPK+Rhizobium+PSM$	756	905	464	708	2774	2779	3031	2861
100% NPK (P as SSP)	997	1015	418	810	3094	2566	3191	2950
CD (0.05)	178	153	69	-	405	385	381	-

**50% NPK+10 Mg ha^{-1} FYM to groundnut and 100% NPK to wheat; #Only FYM 25 Mg ha^{-1} to groundnut only: $50% NPK +Rhizobium+PSM to groundnut and 100% NPK to wheat*

3.15 Parbhani

3.15.1 Soybean

Data clearly showed that 100% NPK + FYM proved its superiority over other treatments and recorded highest grain yield of soybean (**Table 3.15** & **Plate 3.10a**). Application of 100% NPK + FYM resulted in

Control

100% N

100% NP

50% NPK

100% NPK

150% NPK

100% NPK + Zn

100% NPK+FYM @ 5 Mg ha^{-1}

100% NPK+HW

100% NPK-S

FYM @ 10 Mg ha^{-1}

Plate 3.10 (a) Impact of long term fertilizer and manure on growth and productivity of soybean in LTFE at Parbhani (VNMKV, Parbhani)

Control

100% N

100% NP

50% NPK

100% NPK

150% NPK

100% NPK+Zn

100% NPK+FYM

100% NPK+HW

100% NPK-S

FYM @ 10 Mg ha^{-1}

Plate 3.10 (b) Impact of long term fertilizer and manure on growth and Productivity of safflower in LTFE at Parbhani (VNMKV, Parbhani) soybean yield statistically at par with 100% NPK, 100% NPK + hand weeding, 100% NPK+Zn, 150% NPK, 100% NPK and significantly superior over 50% NPK, 100% NP, 100% NPK-Sulphur, only FYM @ 10t ha^{-1} and absolute control.

3.15.2 Safflower

Data on grain yield of safflower clearly indicated that maximum grain yield was found with 100% NPK + FYM @ 5 Mg ha^{-1} treatment which was statistically at par with 100% NPK+Zn and 150% NPK and significantly superior over the other treatments (**Table 3.15** & **Plate 3.10b**).

Table 3.15 Effect of organic manures and inorganic fertilizers on grain yield of soybean and safflower at Parbhani (2016-19)

Treatment	Soybean (kg ha^{-1})				Safflower (kg ha^{-1})			
	2016	2017	2018	Mean	2016-17	2017-18	2018-19	Mean
Control	985	588	685	753	1052	116	734	634
100% N	1263	615	492	790	990	298	734	674
100% NP	2778	1553	1530	1954	1837	647	1500	1328
50% NPK	2510	1546	1690	1915	1686	559	1422	1222
100% NPK	2904	1650	1820	2125	1937	775	1494	1402
150% NPK	3111	1778	1934	2274	2244	831	1724	1599
100% NPK+HW	2814	1624	1897	2112	1921	670	1376	1322
100% NPK+Zn	2967	1710	1841	2173	2159	618	1569	1448
100% NPK+FYM	3059	1830	2062	2317	2188	866	1784	1612
100% NPK-S	2542	1580	1892	2005	1872	505	1428	1268
FYM @ 10 Mg ha^{-1}.	2254	1586	1847	1896	1745	643	1411	723
CD (0.05)	321	216	488	-	261	298	312	-

3.16 Udaipur

3.16.1 Maize

The different fertilizer treatments significantly increased grain yield of maize over control (**Table 3.16**). Continuous cropping without addition of fertilizer or manure reduced crop productivity, however, application of nitrogenous fertilizer (100% N) and phosphatic fertilizer along with N (100% NP) increase maize grain yield significantly over control. Application of potassic fertilizer did not increase yield till 2005, however, afterwards potassium became yield limiting factor. Inclusion of S or Zn in fertilizer schedule did not improve the crop yield even after twenty-two years of experimentation. Balanced fertilization through inorganic sources (NPK) gave higher yield of maize, which was further increased with application of super optimum dose (150% NPK), but it was found to be equally good as that of 100% NPK. Integrated use of 100% NPK+FYM always higher @ 10 Mg ha^{-1} resulted in maximum grain yield (**Table 3.16, Figure 3.2** & **Plate 3.11a**). On the other hand, the application of FYM alone (20 Mg ha^{-1}) gave significantly by higher yield over control but the yield was lower than 100% NPK. Thus, application of FYM @ 20 Mg ha^{-1} alone to maize crop could not sustain the yield to that of 100% NPK but gave yield at par with 100% N alone.

Control

100% N

100% NP

100% NPK+Zn

100% NPK+S

100% NPK+Zn+S

150% NPK

FYM @ 20 Mg ha^{-1}

100% NPK+FYM @10 Mg ha^{-1}

Plate 3.11 (a) Impact of long term fertilizer and manure on growth and productivity of maize in LTFE at Udaipur (MPUA&T, Udaipur)

3.16.2 Wheat

The continuous cropping without use of fertilizer or manure drastically reduced the grain yield of wheat (**Table 3.16** & **Plate 3.11b**). Similar to maize crop, application of N alone (100% N) and 100% NP significantly increased wheat yield over control. The application of K did not show any yield response up to seven year. The addition of Zn or S or both did not improve crop yield even after twenty two years of experimentation in wheat also. Application of FYM @ 20 Mg ha^{-1} (in maize) increased grain yield of wheat significantly over control but it was at par with 100% N alone (**Table 3.16, Figure 3.3** & **Plate 3.11b**). The maximum wheat yield was recorded with 100% NPK + FYM @ 10 Mg ha^{-1} followed by 150% NPK. However, the yield levels of NPK+ FYM were significantly superior over 150% NPK treatment. Application of 100% NPK with *Azotobacter* inoculation of wheat seed improved crop yield.

Control

100% N

100% NP

100% NPK

100% NPK+Zn

100% NPK+Zn+S

FYM+(NPK-NPK of FYM)

100% NPK+FYM @ 10 Mg ha^{-1}

100% NPK+S

150% NPK

100% NPK-Biofertilizer

Plate 3.11 (b) Impact of long term fertilizer and manure on growth and productivity of wheat in LTFE at Udaipur (MPUA&T, Udaipur)

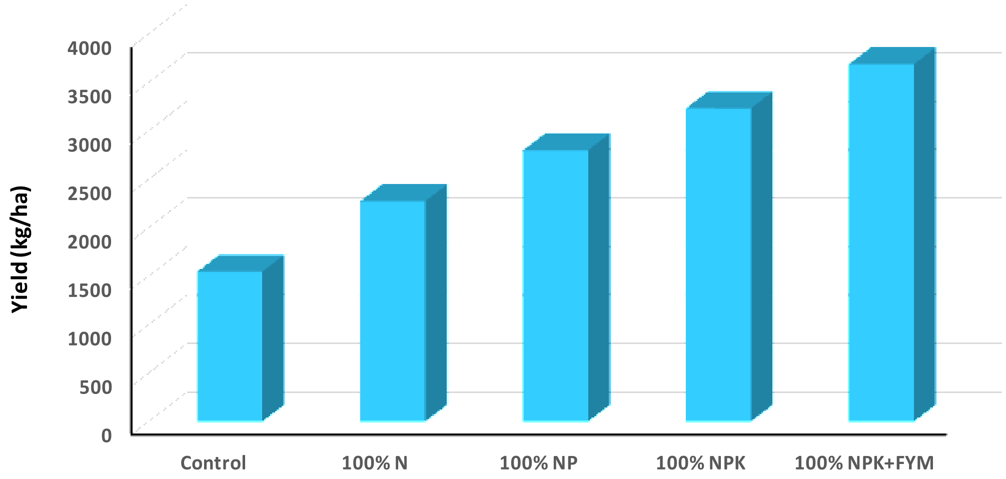


Figure 3.2 Impact of long term fertilizer and manure on grain yield of maize in LTFE at Udaipur (2016-19)

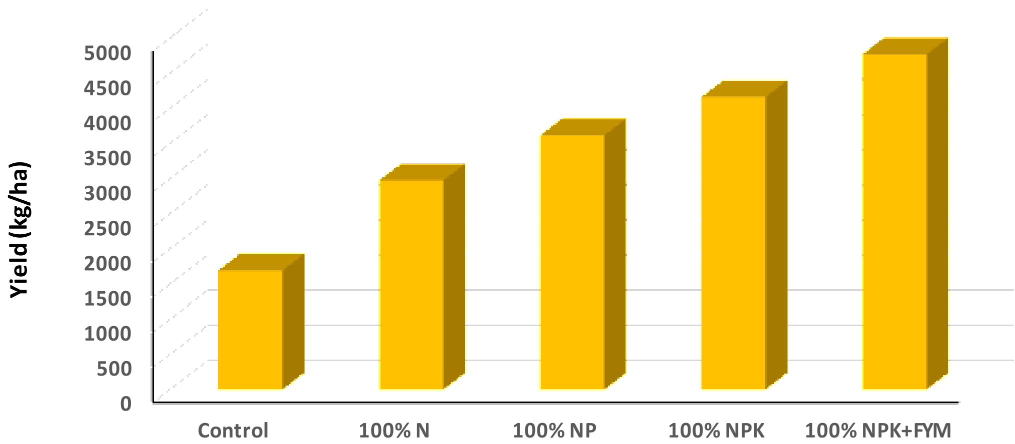


Figure 3.3 Impact of long term fertilizer and manure on grain yield of wheat in LTFE at Udaipur (2016-19)

Table 3.16 Long term effect of fertilizers on grain yield of maize and wheat in LTFE at Udaipur (2016-19)

Treatment	Maize (kg ha^{-1})				Wheat (kg ha^{-1})			
	2016	2017	2018	Mean	2016-17	2017-18	2018-19	Mean
Control	1388	1346	1412	1550	1586	1586	1480	1698
100% N	2230	2120	2177	2276	2938	2938	2815	2979
100% NP	2850	2790	2757	2802	3652	3652	3505	3622
100% NPK	3310	3340	3196	3235	4424	4424	4414	4162
150% NPK	3665	3382	3479	3441	4695	4640	4670	4498
100% NPK + Zn	3420	3380	3313	3302	4664	4664	4525	4352
100% NPK + S	3360	3310	3235	3208	4519	4519	4505	4254
100% NPK + Zn + S	3540	3470	3390	3359	4712	4712	4620	4446
100% NPK - FYM	3540	3150	3276	3167	4651	4585	4530	4368
100% NPK + FYM	4110	3573	3784	3690	5251	4940	4990	4770
FYM @ 20 Mg ha^{-1}	2500	2415	2329	2416	2754	2706	2733	2804
100% NPK + Biofertilizer	3456	3206	3366	3262	4589	4402	4482	4271
CD (0.05)	355	356	277	-	284	329	310	-

4. SOIL HEALTH

SOIL HEALTH is essential to improve and to sustain the productivity over a long period. In this chapter, effect of nutrient management on changes in soil properties over the period under LTFEs is illustrated.

4.1 Soil Chemical Properties

4.1.1 pH

Soil pH is one of the most widely accepted dominant factors that regulates availability of soil nutrients, structure of vegetation and of microbial community, primary productivity of soil and range of soil processes. Perusal of data (**Table 4.1)** revealed that continuous use of fertilizer did not have any effect on soil pH except in Alfisols at Bangalore, Bhubaneswar, Palampur, Pattambi and Ranchi. Application of fertilizer in Alfisols (Red soil) resulted in decline in soil pH and the effect is more pronounced with application of urea alone (100% N) (**Figure 4.1**). Data further indicated that application of organic manure (FYM) has maintained soil pH. The decline in soil pH of acid soil is due to production of H^+ on mineralization of urea and hydrolysis of Al^{+3} and Fe^+ but incorporation of FYM chelated Al^{+3} in acid soils, which reduces the release of H^+ ions.

Table 4.1 Effect of long term nutrient management on soil pH at long term fertilizer experimental (LTFEs) sites of AICRP LTFE (2019)

Location	Initial	Control	100% N	100% NP	100% NPK	150% NPK	100% NPK+ Zn	100% NPK +Lime	100% NPK +FYM
Akola	8.1	8.1	7.9	8.0	8.0	8.0	8.0	-	8.1
Bangalore	6.2	5.6	4.5	5.1	5.3	4.8	-	5.5	5.3
Barrackpore	7.1	7.3	7.3	7.4	7.3	7.4	7.4	-	7.6
Bhubaneswar	5.8	4.3	4.7	5.0	4.8	4.9	5.0	5.8	5.6
Coimbatore	8.2	8.5	8.5	8.6	8.7	8.8	8.7	-	8.7
Jabalpur	7.6	7.5	7.5	7.5	7.6	7.6	7.6	-	7.5
Jagtial	8.2	8.3	8.4	8.3	8.1	8.2	8.3	-	8.2
Junagadh	8.2	8.0	7.9	8.0	8.0	7.9	8.0	-	8.1
Ludhiana	8.2	7.7	7.2	7.1	7.2	7.0	7.1	-	7.1
Palampur	5.8	5.5	4.4	5.1	5.2	4.9	5.4	6.3	5.5
Pantnagar	7.3	8.2	8.2	8.2	8.3	8.3	8.2	-	8.3
Parbhani	8.1	8.3	8.2	8.2	8.2	8.1	8.2	-	7.4
Pattambi	5.5	5.0	4.9	5.0	5.0	4.9		5.4	5.2
Raipur	7.7	7.4	7.6	7.5	7.5	7.6	7.4	-	7.7
Ranchi	5.3	5.6	4.4	5.4	5.5	5.0	-	5.8	5.5
Udaipur	8.2	8.3	8.3	8.3	8.3	8.3	8.2	-	8.2

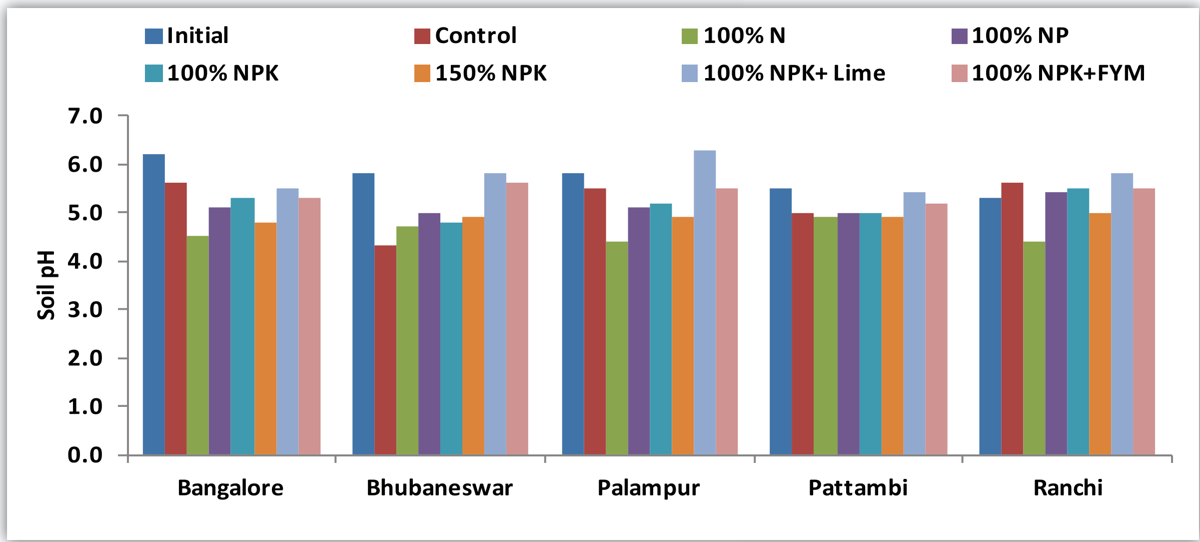


Figure 4.1 Status of pH in Alfisols under AICRP LTFE

4.1.2 Electrical conductivity

Electrical conductivity (EC) indicates soluble salt present in the soil solution. Data revealed that there is little increase in electrical conductivity may be due to application of phosphatic and potassic fertilizer over the years (**Table 4.2**). However, the change noted is very meagre and far less than the maximum critical value.

Table 4.2 Effect of nutrient management on EC (dS m^{-1}) in long-term fertilizer experimental sites of AICRP LTFE (2019)

Location	Initial	Control	100% N	100% NP	100% NPK	150% NPK	100% NPK+ Zn	100% NPK +Lime	100% NPK +FYM
Akola	0.30	0.24	0.30	0.32	0.35	0.36	0.34	-	0.36
Bangalore	0.06	0.15	0.11	0.13	0.13	0.09	-	0.12	0.17
Coimbatore	0.20	0.52	0.56	0.56	0.61	0.64	0.61	-	0.63
Jabalpur	0.18	0.16	0.17	0.16	0.18	0.17	0.18	-	0.18
Jagtial	0.47	0.54	0.62	0.59	0.61	0.59	0.64	-	0.49
Junagadh	0.37	0.39	0.43	0.43	0.42	0.49	0.43	-	0.31
Ludhiana	0.20	0.27	0.25	0.22	0.29	0.23	0.25	-	0.26
Palampur	-	0.44	0.46	0.50	0.62	0.68	0.56	0.68	0.69
Pantnagar	0.35	0.80	0.84	0.85	0.82	0.86	0.84	-	0.87
Parbhani	0.22	0.25	0.25	0.24	0.25	0.26	0.25	-	0.22
Pattambi	-	0.04	0.03	0.04	0.03	0.04	-	0.03	0.04
Raipur	0.20	0.21	0.21	0.24	0.24	0.25	0.22	-	0.24
Ranchi	-	0.09	0.12	0.10	0.10	0.13	-	0.10	0.13
Udaipur	0.49	0.86	0.85	0.89	0.86	0.92	0.88	-	0.86

4.1.3 Soil organic carbon

Soil organic carbon (SOC) is crucial constituent of soil which governs the soil condition and to a large extent nutrient status also as most of soil processes such as chemical, physical and biological are dependent on soil organic carbon. It is well documented that if there is more carbon in soil better will be the soil condition. Data revealed that imbalanced or no use of fertilizer nutrients resulted in decline of soil organic carbon at almost all the LTFE sites (**Table 4.3)**. On the contrary, balanced use of fertilizer resulted in increase in carbon status of soil. Decline in SOC was due to addition of carbon less than the quantity lost from the system on annual basis. Imbalanced use of nutrients (N, NP) led to poor crop productivity which in turn added less amount of carbon through residual biomass (stubble and roots), whereas balanced use of nutrient resulted in increase in crop productivity which in turn add more carbon through residual biomass. However, Pantnagar is an exception where except NPK + FYM, none of the treatments could maintain initial carbon (**Figure 4.2**). Decline in carbon at Pantnagar is due to change in land use pattern from forest to agriculture which accelerated oxidization of native carbon from soil. Only NPK+ FYM could maintain the C status because of additional supply of carbon through FYM annually.

Table 4.3 Effect of nutrient management on SOC (g kg^{-1}) at long term fertilizer experimental sites of AICRP LTFE (2019)

Location	Initial	Control	100% N	100% NP	100% NPK	150% NPK	NPK + Zn	NPK+ Lime	NPK+ FYM
Akola	4.6	3.1	4.0	4.8	5.4	6.9	6.5	-	7.8
Bangalore	4.6	4.2	3.7	4.3	4.8	5.1	-	4.6	5.6
Barrackpore	7.1	5.6	6.6	7.1	7.2	7.3	7.0	-	8.9
Bhubaneswar	4.3	3.6	3.6	4.1	5.3	5.5	5.0	5.6	5.9
Coimbatore	3.0	4.6	5.1	6.0	6.2	6.4	6.2	-	7.1
Jabalpur	5.7	4.2	5.2	6.7	7.6	8.7	7.6	-	8.9
Jagtial	7.9	6.1	5.4	6.6	7.5	6.7	7.2	-	8.2
Junagadh	8.9	6.1	5.9	7.2	7.4	8.1	7.6	-	9.1
Ludhiana	2.2	2.9	3.8	3.8	4.2	4.1	4.1	-	5.3
New Delhi	4.4	3.0	4.4	4.3	4.4	5.2	4.7	-	5.3
Palampur	7.9	8.0	8.1	9.7	10.1	9.7	9.2	11.1	13.3
Pantnagar	14.8	6.1	9.0	9.9	9.8	8.8	10.0	-	15.6
Parbhani	5.5	5.5	5.5	5.5	6.3	6.6	5.6	-	6.7
Raipur	6.2	4.3	4.4	5.4	6.5	6.9	6.3	-	7.0
Ranchi	4.5	4.1	4.7	4.6	4.7	4.6	-	3.8	5.5
Udaipur	6.8	5.2	6.5	6.9	7.5	7.9	7.6	-	9.1

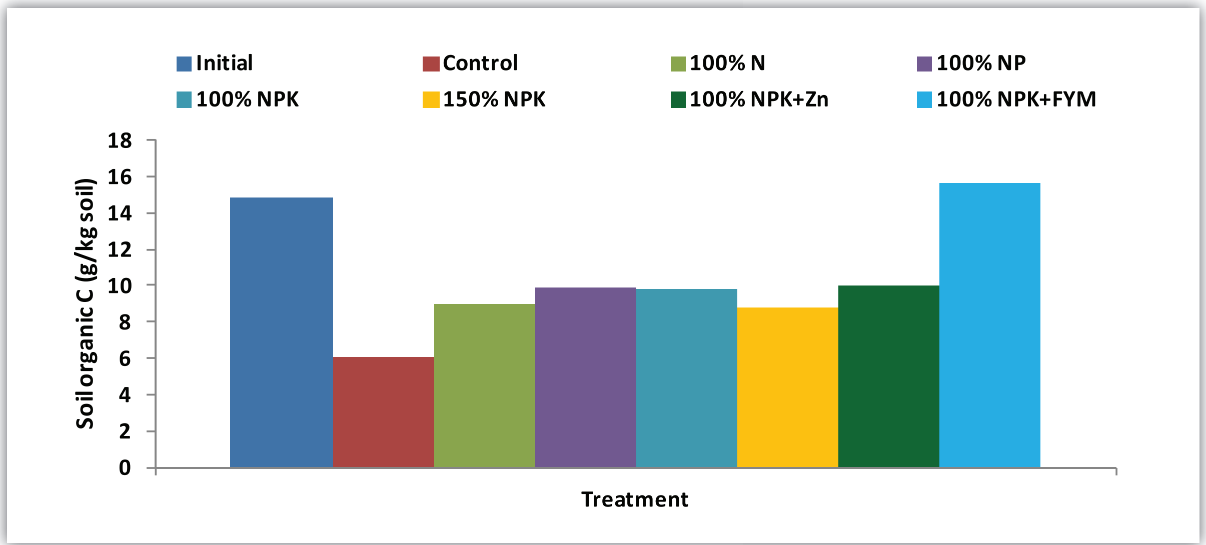


Figure 4.2 Status of soil organic C in Mollisols of Pantnagar (AICRP LTFE)

4.2 Nutrient Status

4.2.1 Available Nitrogen

Available nitrogen (N) represents that form which is easily absorbed by plant roots and is quite dependent on soil organic carbon content. Data indicated increase in available N status with balanced use of nutrients and followed the pattern similar to soil carbon (**Table 4.4**). Most of the places there was increase in soil N compared to initial status. This is due to addition of carbon through residual biomass, which also contain N. Thus, from the results it is concluded that balanced use of nutrient irrespective of soil not only increased the crop productivity but also carbon and available N status. This could be one of the reasons for continuous increase in soil productivity at most of the sites of LTFE.

Table 4.4 Available N (kg ha^{-1}) in soil under different nutrient management options at AICRP LTFE (2019)

Location	Initial	Control	100% N	100% NP	100% NPK	150% NPK	NPK+ Zn	NPK+ Lime	NPK+ FYM
Akola	120	115	219	240	248	309	262	-	318
Bangalore	257	167	155	175	179	200	-	174	214
Barrackpore	223	211	230	232	245	265	245	-	263
Bhubaneswar	187	184	198	207	232	234	222	240	271
Coimbatore	178	151	185	198	193	231	213	-	244
Jabalpur	193	178	210	250	288	328	288	-	340
Jagtial	108	129	134	139	139	140	128	-	142
Junagadh	161	143	177	192	203	241	207	-	260
Ludhiana	87	85	115	118	119	128	121	-	130
New Delhi	-	191	229	234	234	285	234	-	274

Palampur	736	267	330	355	365	370	366	361	397
Pantnagar	392	173	226	233	232	302	232	-	313
Parbhani	216	191	213	242	260	282	245	-	286
Pattambi	-	182	201	210	216	204	-	236	230
Raipur	236	177	206	213	220	250	217	-	252
Ranchi	295	159	167	171	192	180	-	148	183
Udaipur	360	251	292	311	351	399	345	-	386

4.2.2 Available Phosphorus

Phosphorus (P) is an essential macronutrient and required for plant nutrition and contributes significantly to crop productivity. Perusal of data on crop productivity indicated that crop responded to applied P at majority of sites (**Table 4.5**). Continuous absence of P in nutrient schedule resulted in decline of available P status in soil, whereas inclusion of P in fertilizer schedule increased P status in soil. Increase in available P status was more in alluvial (**Figure 4.3**) and acid soil compared to Vertisols. This is due to very high P fixation capacity of Vertisols. Increase in soil P status is quite obvious, because of uptake of P by crop is less than the quantity applied. The unused P is reflected in different forms of P in soil.

Table 4.5 Available P (kg ha^{-1}) in soil under different nutrient management options at AICRP-LTFE (2019)

Location	Initial	Control	100% N	100% NP	100% NPK	150% NPK	NPK+ Zn	NPK+ Lime	NPK+ FYM
Akola	8.4	4.8	8.0	16.9	17.7	21.9	18.0	-	22.9
Bangalore	34.3	17.7	17.8	70.8	42.0	84.8	-	41.6	78.5
Barrackpore	41.5	5.7	7.3	41.6	46.8	58.8	41.1	-	61.0
Bhubaneswar	19.4	6.0	8.6	10.2	12.0	11.9	9.9	11.1	41.3
Coimbatore	11.0	7.8	11.9	20.1	22.9	26.1	22.1	-	27.2
Jabalpur	7.6	8.5	9.8	27.8	33.7	37.2	31.9	-	36.9
Jagtial	19.3	9.6	7.9	26.1	22.7	31.4	23.9	-	33.5
Junagadh	9.5	13.7	13.6	24.5	25.7	31.3	24.9	-	37.9
Ludhiana	9.0	13.8	15.8	52.4	49.6	82.3	53.1	-	88.5
New Delhi	16.0	18.9	17.5	34.5	35.7	43.4	34.6	-	41.2
Palampur	12.1	16.0	16.0	110.0	64.0	148.0	75.0	78.0	135.0
Pantnagar	18.0	7.8	9.9	18.6	18.8	32.5	18.9	-	29.0
Parbhani	16.0	13.3	13.6	16.7	15.4	18.4	15.6	-	19.1
Pattambi	15.6	12.8	9.8	18.7	18.2	19.1	-	18.1	19.1
Raipur	16.0	10.0	14.0	25.6	26.0	27.3	26.3	-	29.0
Ranchi	12.6	14.4	19.5	82.5	73.0	167.7	-	77.7	152.0
Udaipur	22.4	15.8	16.2	24.2	25.4	33.5	27.6	-	31.2

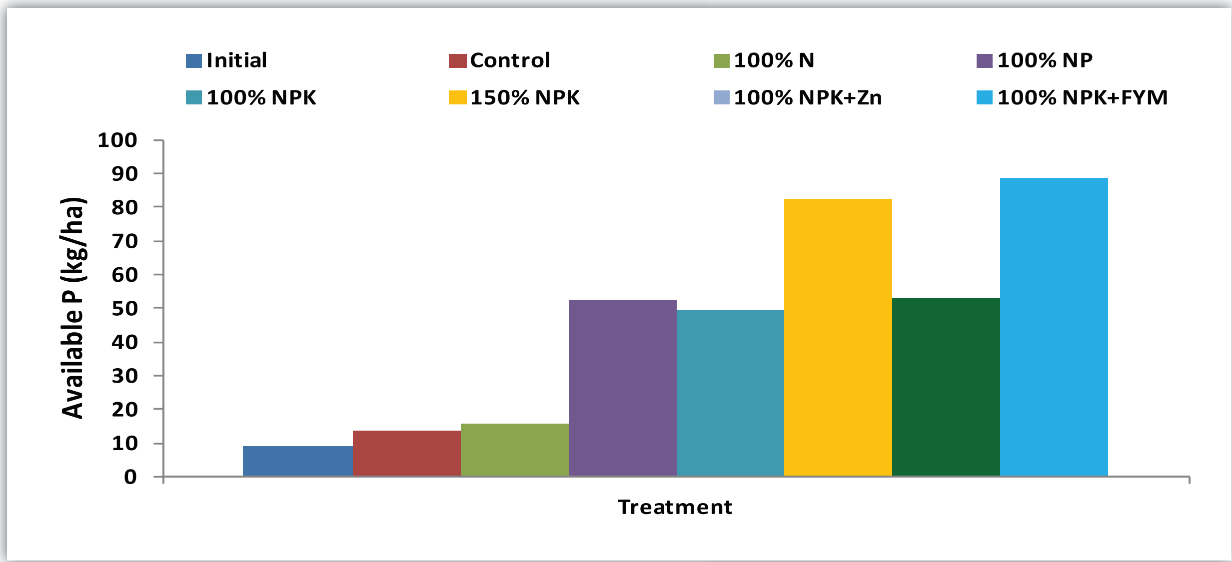


Figure 4.3 Status of available P in Inceptisols at Ludhiana (AICRP LTFE)

4.2.3 Available Potassium

Potassium (K) is an essential element for catalyzing enzymatic activities, root development and crop growth. Available status of K showed variation in different soils (**Table 4.6)**. In Alfisols, there has been decline in available K status in most of the treatments except 150% NPK and NPK+ FYM. But at Bhubaneswar and Jagtial increase in available K status was recorded in the plots which were deprived off supply of K. This is due to supply of K through irrigation water. In Vertisols there was decline in available K in the imbalanced treatments and it was maintained with 100% NPK, 150% NPK as well as 100% NPK+FYM with exception of few sites (**Figure 4.4**). In 100% NPK+FYM supply of K through organic manure is more than the crop removal. On the contrary to Vertisols, increase in available K status was recorded in alluvial soils of Punjab, Delhi and Pantnagar with the presence of K in fertilizer schedule. Such increase in available K status is due to addition of K through irrigation water, flood water and upward movement of soluble K and addition of root biomass.

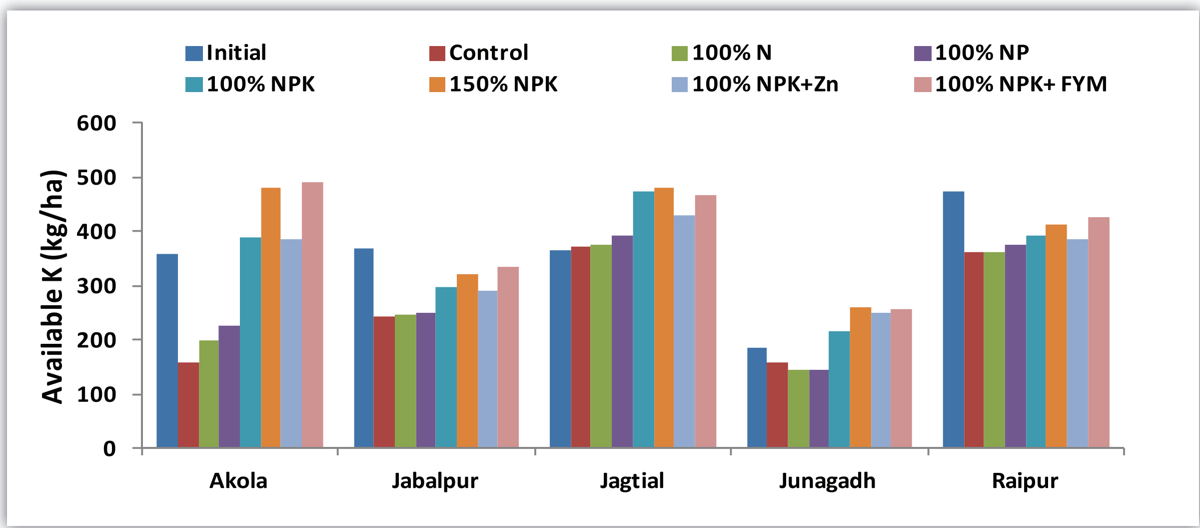


Figure 4.4 Status of available K in Vertisols under AICRP LTFE

Table 4.6 Effect of nutrient management options on available soil K status (kg ha^{-1}) at AICRP-LTFE locations (2019)

Location	Initial	Control	100% N	100% NP	100% NPK	150% NPK	NPK+ Zn	NPK+ Lime	NPK+ FYM
Akola	358	157	198	225	389	481	384	-	492
Bangalore	123	78	64	64	145	185	-	164	177
Barrackpore	143	138	126	130	174	201	173	-	200
Bhubaneswar	43	93	91	97	103	115	102	114	153
Coimbatore	810	536	567	572	668	701	654	-	759
Jabalpur	370	244	247	250	298	320	289	-	336
Jagtial	364	373	375	393	475	481	430	-	466
Junagadh	184	159	146	145	215	261	250	-	258
Ludhiana	88	78	83	109	127	146	118	-	144
New Delhi	155	209	193	182	268	332	289	-	314
Palampur	194	109	130	127	156	184	164	162	203
Pantnagar	125	93	89	91	129	142	123	-	145
Parbhani	766	621	645	693	697	771	651	-	783
Pattambi	173	46	50	51	72	81	-	71	79
Raipur	474	361	361	376	391	414	385	-	425
Ranchi	157	119	126	83	118	136	-	101	126
Udaipur	671	471	477	487	556	598	558	-	584

4.2.4 Available Sulphur

Sulphur (S) is one of the secondary nutrients, helps in synthesis of amino acid in plant and required for many growth functions. Data on S status in LTFEs indicated that application of S resulted in increase of S status in soil whereas absence of S in fertilizer schedule resulted in decline of S status (**Table 4.7**). At some of the places S deficiency was recorded particularly during kharif season when S is reduced to sulphide form and not available to plant.

Table 4.7 Effect of nutrient management options on available soil sulphur status (kg ha^{-1}) at AICRP-LTFE locations (2019)

Location	Initial	Control	100% N	100% NP	100% NPK	100% NPK (-S)	150% NPK	NPK+ Zn/Lime	NPK+ FYM
Akola	26.4	17.7	21.5	40.8	49.6	21.7	58.8	48.3	62.8
Bangalore	46.4	37.5	30.8	49.4	46.1	18.9	57.2	50.1	45.4
Bhubaneswar	22.2	12.7	20.6	24.9	24.8	-	29.6	35.2	34.9
Jabalpur	17.5	10.6	11.2	29.6	31.6	10.9	35.7	30.0	37.6
Junagadh	17.4	19.2	22.8	24.9	23.6	-	32.5	28.8	34.5
Palampur	-	16.1	19.0	29.7	32.0	15.7	36.4	29.5	36.1
Pantnagar	-	7.2	27.7	14.1	26.2	9.6	29.3	25.6	18.0
Parbhani	30.5	25.6	28.6	28.8	29.7	29.5	31.5	30.8	33.5
Pattambi	-	16.0	17.2	17.5	15.8	-	17.7	18.8	19.6
Raipur	17.3	12.6	18.0	26.5	27.2	-	36.4	35.0	30.1
Ranchi	-	22.3	20.4	21.0	22.3	-	22.0	21.5	22.7
Udaipur	50.2	34.8	35.3	36.9	38.9		38.8	37.1	41.1

4.2.5 Micronutrients

In the post green revolution period there were emergence of deficiency of micronutrients, hence, crops grown in most of the soils suffer from deficiencies of either for one or more micronutrients that adversely affect crop productivity. Even though in LTFEs except Zn and B other micronutrients were added at a regular interval or whenever, status of micronutrients went down. Samples were analyzed at a regular interval to monitor the status of micronutrients. The status of different micronutrients (DTPA extractable micronutrients) has been furnished hereunder.

4.2.5.1 Available Zinc

The wide spread deficiency of zinc (Zn) has been reported, however, in the recent past, area under deficiency of Zn has reduced due to application of Zn. Perusal of data (**Table 4.8**), revealed that Zn availability is not a problem in red soils of Bangalore, Bhubaneswar, Pattambi, Palampur and Ranchi. At the same time there are places where Zn status is quite high. In Vertisols, Zn status at Jabalpur is below the critical limits in some of the treatments (**Figure 4.5**). Availability of Zn even under imbalance nutrient application does not decrease much which may be due to decomposition of roots thats dissolve Zn from soil. Increase in Zn availability in spite of greater mining in 100% NPK and 150% NPK support the statement.

Table 4.8 Effect of continuous use of fertilizers and manure on available Zn (mg kg^{-1}) status in soil at different centres of AICRP LTFE (2019)

Location	Initial	Control	100% N	100% NP	100% NPK	150% NPK	100% NPK +HW	100% NPK + Zn/Lime	NPK+ FYM
Akola	0.62	0.35	0.38	0.40	0.55	0.65	-	0.64	0.91
Bangalore	2.34	2.41	2.59	2.32	2.37	1.59	2.11	3.19	4.75
Bhubaneswar	1.80	0.90	1.19	0.99	1.07	0.98	-	-	2.70
Coimbatore	2.58	0.54	0.78	0.81	0.81	0.84	0.82	2.26	1.14
Jabalpur	0.33	0.24	0.36	0.51	0.55	0.57	0.54	1.06	0.64
Jagtial	2.64	1.86	2.16	1.99	2.22	2.04	2.10	3.57	2.31
Ludhiana	-	0.50	1.20	1.30	2.30	2.60	2.40	4.00	2.60
New Delhi	1.10	0.83	0.97	1.07	1.16	1.12	1.12	2.21	1.33
Pantnagar	2.70	0.60	1.22	1.20	0.60	0.53	1.25	1.22	1.06
Parbhani	0.98	0.73	0.76	0.68	0.75	0.85	0.87	1.61	1.35
Pattambi	4.17	1.62	1.83	1.68	2.09	2.08	-	1.97	2.18
Raipur	1.20	0.67	0.76	0.87	1.03	1.19	-	1.94	1.43
Ranchi	1.10	1.98	1.74	1.47	1.79	1.53	1.85	1.67	2.93
Udaipur	-	1.90	2.07	2.28	2.28	2.34	-	3.67	3.29

Critical limit of available Zn in soil = 0.6 mg kg^{-1}

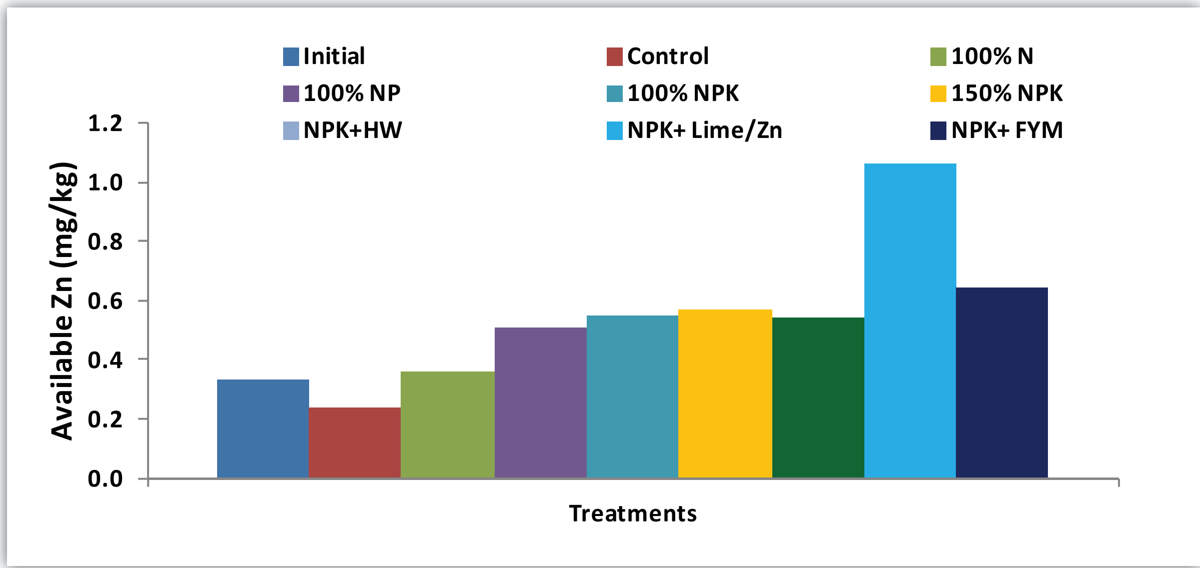


Figure 4.5 Status of available Zn in Vertisols of Jabalpur (AICRP LTFE)

4.2.5.2 Available Iron

Data indicated that there is no problem as far as status of available iron (Fe) is concerned at all the places except at Coimbatore and Udaipur (**Table 4.9** & **Figure 4.6**). At Coimbatore, Fe deficiency in maize is noted in some of the years during early crop growth stages which disappear after first irrigation due to conversion of ferric to ferrous.

Table 4.9 Effect of cropping and fertilizers on available Fe (mg kg^{-1}) in soil at different centres of AICRP LTFE (2019)

Location	Initial	Control	100% N	100% NP	100% NPK	150% NPK	NPK+HW	NPK+ Zn/ Lime	NPK+ FYM
Bangalore	5.2	6.4	15.6	15.3	15.5	16.2	14.7	9.5	17.7
Bhubaneswar	33.0	27.9	22.9	42.7	38.6	46.3	-	-	59.6
Coimbatore	2.7	1.8	1.8	2.2	2.1	2.4	2.0	2.3	2.7
Jabalpur	2.5	13.7	18.5	19.2	20.7	26.3	21.3	21.6	28.3
Jagtial	14.5	11.8	12.5	12.4	12.3	12.5	12.5	12.8	12.9
Ludhiana	-	5.5	11.9	14.1	16.9	16.8	15.7	15.3	18.1
Pantnagar	29.5	22.6	28.1	36.3	36.1	38.6	35.3	38.1	45.1
Pattambi	123.6	113.0	137.0	132.4	108.2	110.7	-	107.5	143.1
Ranchi	47.0	24.4	25.6	24.8	20.7	16.1	29.9	25.2	30.6
Udaipur	-	2.5	2.6	2.9	2.9	2.7	-	3.0	4.1

Critical limit of available Fe in soil = 4 mg kg^{-1}

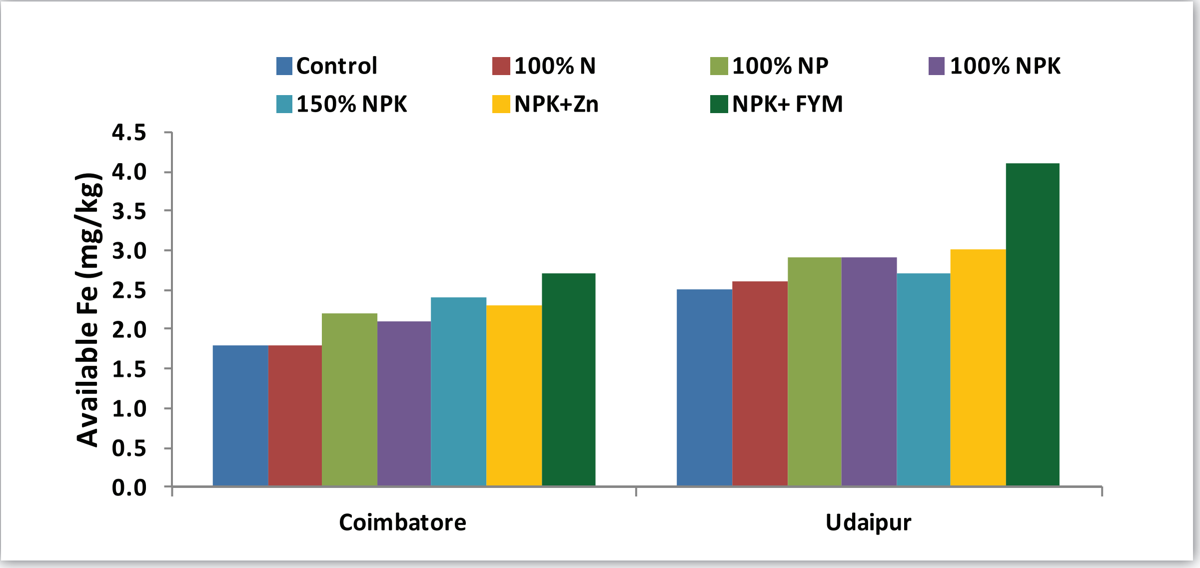


Figure 4.6 Status of available Fe in LTFE at Coimbatore and Udaipur (AICRP LTFE)

4.2.5.3 Available Copper

Data on available status of copper (Cu) revealed that soils of Coimbatore and Ludhiana are marginally above the critical status of Cu and crop may respond to applied Cu (**Table 4.10**). Decline in Cu status in soils of Ranchi was noted and the status has reached below the critical limit. It means crops may respond to applied Cu and due care has to be taken to follow to apply Cu as per soil status.

Table 4.10 Effect of fertilizers on available Cu (mg kg^{-1}) in soil at different centers of AICRP LTFE (2019)

Location	Initial	Control	100% N	100% NP	100% NPK	150% NPK	NPK+HW	NPK+ Zn/ Lime	NPK+ FYM
Bangalore	2.30	1.04	1.52	1.44	1.10	1.20	1.36	1.27	1.67
Bhubaneswar	3.15	1.62	1.54	1.90	1.46	1.85	-	-	2.11
Coimbatore	0.42	0.81	0.89	0.94	0.98	0.99	0.92	0.98	1.03
Jabalpur	0.11	1.07	1.14	1.37	1.44	1.67	1.51	1.53	1.86
Jagtial	2.58	1.66	2.03	1.83	2.20	2.06	2.11	2.17	2.27
Ludhiana	-	0.53	0.53	0.68	0.72	0.74	0.73	0.71	0.77
Pantnagar	2.90	3.04	3.75	3.82	3.83	3.63	4.10	3.80	4.8
Pattambi	4.05	12.5	12.15	12.28	7.88	9.57	-	9.43	15.2
Ranchi	2.00	1.25	1.09	1.05	0.31	1.39	0.45	0.06	0.17
Udaipur	-	1.56	1.58	1.75	1.70	1.69	-	1.73	2.59

Critical limit of available Cu in soil = 0.2 mg kg^{-1}

4.2.5.4 Available Manganese

Data revealed that at all the sites the available status of manganese (Mn) in soil is in higher range and the crop did not suffer for Mn at any of the LTFE site (**Table 4.11)**.

Table 4.11 Effect of cropping and fertilizers on available Mn (mg kg^{-1}) in soil at different centers of AICRP LTFE (2019)

Location	Initial	Control	100% N	100% NP	100% NPK	150% NPK	NPK+ HW	NPK+ Zn/ Lime	NPK+ FYM
Bangalore	55.4	12.1	21.4	19.8	14.1	15.5	13.9	13.7	17.3
Bhubaneswar	7.5	8.1	8.8	47.2	22.7	8.1	-	-	30.7
Coimbatore	2.7	5.5	5.6	6.7	6.6	6.7	6.4	6.6	6.9
Jabalpur	16.1	11.0	11.2	13.9	15.6	14.8	14.3	15.0	17.7
Jagtial	8.7	4.5	5.3	5.9	6.7	7.1	6.3	5.7	7.7
Ludhiana	-	4.7	8.2	8.5	9.0	12.4	8.8	9.0	8.3
Pantnagar	26.8	13.3	15.1	20.0	20.1	24.2	20.0	20.3	26.1

Pattambi	-	9.1	10.5	12.7	12.5	14.7	-	11.3	17.6
Ranchi	57.0	11.3	21.9	9.5	10.7	13.0	7.6	10.7	11.1
Udaipur	-	9.0	9.3	9.3	9.5	9.4	-	9.6	12.8

Critical limit of available Mn in soil = 2.5 mg kg^{-1}

4.3 Heavy Metal Contamination

4.3.1 Bhubaneswar

Surface soil samples (0-15 cm) from the experimental site were analyzed for heavy metal content. Results revealed that cadmium (Cd) and lead (Pb) content found very low and were below the critical limit of their toxicity (**Table 4.12**).

Table 4.12 Effect of long term manuring on heavy metal content in soil in LTFE at Bhubaneswar (2017)

Treatment	Heavy metal accumulation (mg kg^{-1})	
	Cadmium (Cd)	Lead (Pb)
Control	0.012	1.60
100% N	0.019	1.66
100% NP	0.025	1.49
100% PK	0.023	1.57
100% NPK	0.021	1.44
150% NPK	0.024	1.93
100% NPK +Zn	0.031	1.64
100% NPK +FYM	0.016	1.81
100% NPK + Lime + FYM	0.023	1.44
100% NPK + B + Zn	0.031	2.07
100% NPK + S + Zn	0.028	1.94
100% NPK + Lime	0.023	1.66

Critical limit of toxicity for Cd= 0.8 and Pb = 85 mg kg^{-1}

4.3.2 Udaipur

Study on effect of long term application of fertilizer and manure on accumulation of heavy metals in soil after completion of twenty two years in maize-wheat cropping system indicated that DTPA extractable nickel (Ni) concentration ranged from 0.49 Mg kg^{-1} in NPK + *Azotobacter* seed treatment to 0.60 Mg kg^{-1} in NPK + FYM (**Table 4.13**). The cadmium (Cd) concentration ranged from 0.18 to 0.26 mg kg^{-1}. Highest value was recorded in the plots where NP and NPK were applied whereas lowest in NPK+ *Azotobacter.* The DTPA extractable lead (Pb) concentration in soil ranged from 5.73 to 6.47 mg kg^{-1}. Maximum lead concentration in soils was observed in control whereas, minimum Pb in NPK+FYM. Chromium contents ranged from 4.70 to 6.63 mg kg^{-1} with maximum value depicted with N alone applied treatment and minimum in soils with NPK + S application. A perusal of data indicated that various nutrient combinations, organic manure and integrated use failed to influence the accumulation of DTPA extractable heavy metals of the soil after twenty two years of maize-wheat cropping system. All the soil samples are in the permissible range as described by Maclean *et al.* (1987).

Table 4.13 Long term effect of fertilizer and manure on DTPA extractable heavy metals after 22 years of maize-wheat cropping system in LTFE at Udaipur

Treatment	DTPA (mg kg^{-1})			
	Nickel (Ni)	Cadmium (Cd)	Lead (Pb)	Chromium (Cr)
100% N	0.56	0.26	6.36	6.63
100% NP	0.51	0.25	5.95	4.99
100% NPK	0.55	0.26	6.44	5.85
100% NPK + Zn	0.58	0.24	5.97	5.20
100% NPK + S	0.56	0.24	6.10	4.70
100% NPK + Zn + S	0.56	0.24	6.02	5.10
150% NPK	0.60	0.24	6.36	4.99
100% NPK + FYM	0.59	0.22	6.47	5.35
FYM @ 20 Mg ha^{-1}	0.56	0.21	6.10	6.53
100% NPK + Biofertilizer	0.49	0.18	5.73	6.59
CD (0.05)	NS	NS	NS	NS
Permissible limit	8.1	0.31	13.00	8.00

4.4 Soil Physical Properties

Soil physical properties are very crucial for proper functioning of soil processes as well as plant growth and survival. Results emanated from LTFEs are illustrated hereunder.

4.4.1 Akola

4.4.1.1 Bulk density

Continuous application of FYM alone significantly decreased the bulk density (BD) of soil as compared to balanced fertilization and control (**Table 4.14** & **Figure 4.7**). Bulk density decreased significantly with NPK along with FYM and FYM alone but did not vary significantly among the NPK levels (100% NPK, 100% NPK + Zn, 100% NPK + S, 100% NPK-S). Lower bulk density of soil when applied with 100% NPK + FYM, FYM alone and 150% NPK may be due to higher organic carbon, more pore space and good soil aggregation. The balanced fertilization caused marginal reduction in bulk density than control, which could be attributed to the increased biomass production with consequent increase in organic matter in the soil.

4.4.1.2 Hydraulic conductivity

The hydraulic conductivity influenced significantly with the conjoint use of fertilizer continuously over the years. The balanced use of fertilizer also found effective in maintaining higher hydraulic conductivity as compared to imbalanced use of fertilizer (**Table 4.14** & **Figure 4.7**). The increasing level of fertilizer significantly increased the hydraulic conductivity. Application of FYM @ 10 Mg ha^{-1} had also recorded higher hydraulic conductivity as compared to balanced fertilization. Thus, application of FYM and fertilizers had favourable effect on hydraulic conductivity of the soil.

Table 4.14 Long term effect of fertilizer and manure application on soil physical properties in Vertisols of Akola (2019)

Treatment	Bulk density (g cm^{-3})	Hydraulic conductivity (cm h^{-1})
Control	1.57	0.29
100% N	1.56	0.34
100% NP	1.49	0.43
50% NPK	1.51	0.42
100% NPK	1.39	0.52
150% NPK	1.31	0.64
100% NPK S free	1.43	0.50
100% NPK + Zn @ 2.5 kg ha^{-1}	1.34	0.61
100% NPK + FYM @ 5 Mg ha^{-1}	1.28	0.77
100% NPK + 37.5 kg S ha^{-1}	1.34	0.62
FYM @ 10 Mg ha^{-1}	1.31	0.67
75% NPK + 25% N through FYM	1.33	0.63
CD (0.05)	0.033	0.026

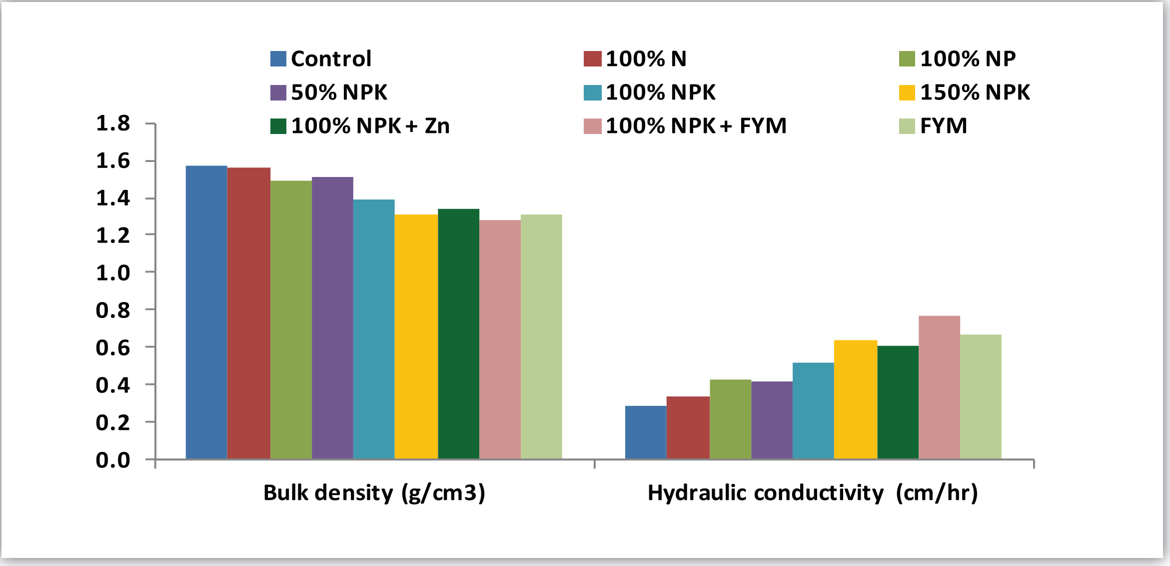


Figure 4.7 Physical parameters in Vertisols at Akola (AICRP LTFE)

4.4.2 Bhubaneswar

4.4.2.1 Bulk density and hydraulic conductivity

Bulk density was significantly influenced with long term nutrient management and there was decrease in bulk density from initial value (**Table 4.15**). Lowest bulk density was observed in 100% NPK + FYM treatment and highest in control. All other treatments had almost similar bulk density which was significantly higher than that of 100% NPK + FYM and lower than the control. Thus, continuous application of FYM improved soil bulk density which might be due to better aggregating effect of organic manures. Similarly, balanced fertilizer use also enhanced hydraulic conductivity. The application of NPK+FYM has further improved these physical parameters.

4.4.2.2 Maximum water holding capacity

Data on water holding capacity (WHC) of surface layer revealed that, the treatment 100% NPK + FYM possessed significantly higher WHC than all other treatments except 100% NPK+Lime+FYM (**Table 4.15**). The WHC varied between 31.54 to 41.38%. The application of NPK+FYM/Lime further improved WHC of soil.

4.4.2.3 Aggregate Stability

Results on aggregate analysis clearly demonstrated that long term fertilizer application improved the proportion of all size of water stable aggregates compared to control (**Table 4.16**). Highest value was observed with INM i.e. 100% NPK + FYM. Increase in proportion of bigger size fraction in FYM treated plot is due to increase in soil organic carbon content. Increase in mean weight diameter of the aggregates supports the results obtained in hydraulic conductivity and water holding capacity of soil.

Table 4.15 Effect of long term fertilizer and manuring on physical properties in LTFE at Bhubaneswar (2019)

Treatment	BD (Mg m^{-3})	MWHC (%)	HC (cm h^{-1})
Control	1.46	31.54	1.25
100% N	1.38	33.33	1.30
100% NP	1.35	33.21	1.29
100% PK	1.43	32.56	1.04
100% NPK	1.33	33.38	1.46
150% NPK	1.35	37.26	1.37
100% NPK+Zn	1.37	36.00	1.36
100% NPK+FYM	1.29	40.29	1.65
100% NPK+Lime+FYM	1.28	41.38	1.66
100% NPK+B+Zn	1.36	36.50	1.26
100% NPK+S+Zn	1.37	38.52	1.30
100% NPK+Lime	1.34	37.96	1.56
CD (0.05)	0.03	2.24	0.08
Initial	1.55	42.2	1.52

BD-Bulk Density; MWHC-Maximum water holding capacity; HC-Hydraulic conductivity

Table 4.16 Effect of long term fertilizer and manure application on aggregate stability (% WSA) and mean weight diameter (MWD) in LTFE at Bhubaneswar

Treatment	Aggregate stability (% WSA)						MWD (mm)
	> 2000 µm	2000 – 1000 µm	1000 - 500 µm	500 – 250 µm	250 - 100 µm	100-53 µm	
Control	10.25	4.75	11.65	12.62	4.85	0.51	1.29
100% N	10.25	6.85	10.68	15.18	9.48	1.54	1.13
100% NP	13.65	4.88	19.02	11.15	10.54	1.13	1.20
100% PK	10.81	5.62	11.62	13.29	3.02	0.14	1.34
100% NPK	13.21	6.75	11.92	15.02	6.92	0.78	1.34
150% NPK	17.76	5.85	18.42	11.91	7.05	1.69	1.44
100% NPK+Zn	17.11	6.55	18.65	14.38	6.88	1.79	1.39
100% NPK+B+Zn	11.27	6.98	18.15	15.22	7.72	1.60	1.16
100% NPK+S+Zn	13.65	5.42	11.71	12.05	7.22	1.17	1.34
100% NPK+Lime	13.98	6.82	14.42	10.88	7.42	1.05	1.36
100% NPK+FYM	28.91	13.38	23.38	24.08	12.62	2.82	1.43
100% NPK+Lime+FYM	30.25	13.91	21.98	21.38	18.38	2.71	1.41
CD (0.05)	2.27	1.33	2.26	2.44	1.29	0.29	0.09

4.4.3 Coimbatore

There was no distinguishable change in bulk density and it varied from 1.25 to 1.38 Mg m^{-3} (**Table 4.17**). Under INM practice bulk density was low; however, aggregate stability and total porosity were high. Further, maximum hydraulic conductivity and moisture content at field capacity were recorded under INM i.e. 100% NPK +FYM.

Table 4.17 Effect of long term nutrient management options on soil physical condition in LTFE at Coimbatore

Treatment	BD (Mg m^{-3})	HC (cm h^{-1})	IR (mm h^{-1})	FC (%)	PWP (%)	MWD (cm)	AS (%)	TP (%)
Control	1.38	1.48	21.43	24.44	12.80	0.75	64.7	53.2
100% N	1.37	1.53	22.74	32.70	17.10	0.77	68.3	53.8
100% NP	1.36	1.75	24.22	31.65	16.70	0.74	66.1	57.1
50% NPK	1.35	1.45	23.20	30.74	16.46	0.75	63.9	50.7
100% NPK	1.32	1.94	25.62	31.97	16.22	0.77	65.6	52.8
150% NPK	1.33	2.05	26.78	34.04	17.95	0.74	68.4	54.6
100% NPK +HW	1.33	1.84	24.14	29.91	15.61	0.74	69.5	55.5

100% NPK + Zn	1.30	1.92	26.72	32.24	16.80	0.76	70.7	56.2
100% NPK +FYM	1.25	2.92	34.12	38.11	19.75	0.75	73.8	57.6
100% NPK (-S)	1.32	1.88	25.65	34.89	18.34	0.75	71.1	52.0
CD (0.05)	0.06	0.08	1.02	4.46	2.58	NS	-	-

BD-Bulk density; HC-Hydraulic conductivity; IR-Infiltration rate; FC-Field capacity; PWP-Permanent wilting point; MWD-Mean weight diameter; AS-Aggregate stability; TP-Total porosity

4.4.4 Jagtial

The perusal of data on soil physical properties showed that the bulk density improved over the years especially in balanced and INM treatment having 1.33 Mg m^{-3} to 1.35 Mg m^{-3} in FYM alone but was relatively lower than other treatments (**Table 4.18**). Similarly, the soil % pore space and gravimetric water content was also higher in these treatments. This might be due to organic matter addition that improves the physical structure of soil. The infiltration rate was highest with FYM alone due to more porosity of organic manure followed by 100% NPK+FYM (**Table 4.18**).

Table 4.18 Effect of long term fertilizer and manure application on physical properties in LTFE at Jagtial (Telangana) (2018-19)

Treatment	BD (Mg m^{-3})	PS (%)	GMC (%)	IR (mm hr^{-1})
Control	1.51	43.14	11.84	5.66
100% N	1.65	37.92	12.51	5.66
100% NP	1.50	43.23	16.50	7.66
50% NPK	1.51	43.20	16.47	6.66
100% NPK	1.38	47.90	17.59	7.66
150% NPK	1.40	47.18	19.67	8.00
100% NPK + HW	1.46	44.93	19.73	8.33
100% NPK + Zn	1.43	46.11	15.90	7.33
100% NPK + FYM	1.33	49.96	19.74	8.66
100% NPK - S	1.45	45.30	17.48	8.00
FYM @ 15 Mg ha^{-1}	1.35	49.13	25.68	9.33
CD (0.05)	0.02	1.20	3.85	-
Fallow	1.51	46.04	14.27	6.00

BD-Bulk density; PS-Pore space; GMC-Gravimetric moisture content; IR- Infiltration rate

4.4.5 Palampur

A significant reduction in bulk density with balanced application of chemical fertilizers (100% NPK) was found over imbalanced application of fertilizers in 100% N and 100% NP (**Table 4.19)**. The bulk density of soil reduced to 1.21, 1.23 and 1.24 Mg m^{-3} in plots receiving 100% NPK+FYM, 100% NPK + lime and 100% NPK + hand weeding. The saturated hydraulic conductivity varied from 2.53 to 5.39 cm hr^{-1} (**Table 4.19)**.

Highest saturated hydraulic conductivity (5.39 cm hr^{-1}) was recorded with NPK + FYM and was significantly higher in comparison to rest of the treatments. The mean weight diameter varied from 0.95 mm under 100% N to 4.61 mm under 100% NPK along with FYM (**Table 4.19**).

Table 4.19 Effect of different treatments on physical characteristics after wheat harvest in LTFE at Palampur (2017-18)

Treatment	BD (Mg m^{-3})	SHC (cm hr^{-1})	MWD (mm)
Control	1.37	2.53	1.02
100% N	1.39	2.65	0.95
100% NP	1.31	2.79	1.57
50% NPK	1.27	3.21	1.65
100% NPK	1.26	3.42	1.93
150% NPK	1.28	3.44	1.56
100% NPK +HW	1.24	3.58	2.22
100% NPK + Zn	1.28	3.32	1.62
100% NPK + FYM	1.21	5.39	4.61
100% NPK (-S)	1.31	3.50	1.59
100% NPK + lime	1.23	4.06	3.64
CD (0.05)	0.03	0.23	0.27
Initial	1.31	-	-

BD-Bulk density; SHC-Saturated hydraulic conductivity; MWD-Mean weight diameter

4.4.6 Pantnagar

Data on bulk density revealed that incorporation of FYM in combination with fertilizer resulted in significant decline in bulk density (**Table 4.20**). Even though reduction in bulk density was also noted on application of fertilizer nutrients but these values were not statistically significant. The remarkable and significant decline in bulk density was recorded from 1.49 to 1.29 Mg m^{-3} with NPK+FYM. Lowering of bulk density might be due to higher organic C content in soil. Higher pore space is the result of good soil aggregation. Continuous use of organic manure in combination with inorganic fertilizers significantly increased hydraulic conductivity, MWD and water holding capacity of soil and reduced penetration resistance. The increase in hydraulic conductivity, MWD and water holding capacity might be due to addition of organic matter which in turn increases porosity of soil (**Table 4.20**). Similarly, balanced use of nutrient fertilizers increase mean weight diameter of soil aggregates. The water stable soil aggregates increased with the application of fertilizer and manure and varied between 20.84% in control to 59.24% in (NPK+FYM). Improvement in water stable aggregates could be attributed to the higher microorganisms' population and beneficial effect of certain polysaccharides formed during decomposition of organic residues by microbial activity.

Table 4.20 Long-term effects of fertilizer and manure application on physical properties of soil in Mollisols of Pantnagar

Treatment	BD ($Mg\ m^{-3}$)	MWD (mm)	PR ($kg\ cm^{-2}$)	HC ($cm\ h^{-1}$)	WSA% (> 0.25 mm)	WHC (%)
Control	1.49	0.55	3.54	0.63	20.84	21.84
100% N+Zn	1.38	0.68	3.39	0.70	44.52	40.52
100% NP+Zn	1.29	0.74	3.23	0.78	50.81	43.81
50% NPK+Zn	1.38	0.66	3.36	0.70	41.80	40.01
100% NPK	1.36	0.70	3.32	0.78	52.10	45.10
150% NPK	1.32	0.71	3.36	0.75	50.40	46.40
100% NPK+HW	1.30	0.77	3.20	0.82	53.01	48.01
100% NPK+Zn	1.31	0.78	3.16	0.86	54.10	50.10
100% NPK+FYM	1.29	1.07	2.42	0.95	59.24	56.20
100% NPK-S+Zn	1.32	0.72	3.28	0.75	49.55	45.55
CD (0.05)	0.035	0.042	0.073	0.09	4.53	4.53
Natural fallow	1.08	1.14	2.15	1.02	45	54.00

BD-Bulk density; MWD-Mean weight diameter; PR-Penetration resistance; HC- Hydraulic conductivity; WSA- Water stable aggregates; WHC- Water holding capacity

4.4.7 Parbhani

The bulk density of soil decreased significantly with the application of 100% NPK+FYM @ 5 Mg ha^{-1} as compared to all other treatments except application of FYM @ 10 Mg ha^{-1} **(Table 4.21)**. Bulk density increased from its initial value in control to fallow and where there was imbalance use of fertilizer. Maximum water holding capacity was recorded with 100% NPK+FYM @ 5 Mg ha^{-1} and significantly superior over control, fallow and imbalanced use of fertilizers **(Table 4.21)**.

Table 4.21 Effect of organic and inorganic fertilizers on bulk density and maximum water holding capacity at Parbhani (2018-19)

Treatment	Bulk density ($Mg\ m^{-3}$)	Maximum water holding capacity (%)
Control	1.35	53.16
100% N	1.34	55.54
100% NP	1.33	58.42
50% NPK	1.32	56.34
100% NPK	1.31	58.16
150% NPK	1.30	61.85
100% NPK + HW	1.29	59.20
100% NPK + Zn	1.29	60.83

100% NPK + FYM @ 5 Mg ha^{-1}	1.24	62.44
100% NPK – Sulphur	1.29	56.59
Only FYM @ 10 Mg ha^{-1}	1.25	59.81
Fallow	1.36	53.05
CD (0.05)	0.017	0.83

4.4.8 Ludhiana

Long-term fertilization in maize-wheat cropping system for 46 years resulted in significant decline in bulk density (BD) relative to control (**Table 4.22**). The maximum (1.59 Mg m^{-3}) and the minimum bulk density (BD), (1.48 Mg m^{-3}) in the surface soil was recorded with control and 100% NPK+FYM, respectively. In response to the continuous application of fertilizer and FYM, a significant variation with respect to aggregate stability (0-15 cm) was recorded. The total water stable aggregates (WSA) varied between 66.9 and 74.5% under different treatments (**Table 4.22**). The macro-aggregates contributed 19.4 to 30.9% of total WSA as compared to 43.5 to 47.5% of micro-aggregates. Among the macro-aggregates, 0.25-0.053 mm fraction contributed maximum (14.2 to 16.7%) and >2 mm fraction contributed the least (0.52% to 2.64%). With the application of FYM, there was a significant improvement in macro-aggregates fraction. Application of fertilizer (100% NPK) improved the macro-aggregate fraction from 19.4 under control to 25.2%. On the contrary, the proportions of micro-aggregates were significantly lower under the application of FYM (43.5%) as compared to control (47.5%). A similar trend as of micro-aggregates was noticed in mineral fraction, the application of FYM (25.5%) had lower mineral fractions as compared to control (33.1%).

Table 4.22 Effect of long-term nutrient options on physical parameters in LTFE at Ludhiana.

Treatment	BD (Mg m^{-3})	TWSA (%)	MA (%)				TMA (%)	MiA (%) 0.053-0.25 mm	MF <0.053mm
			Macro aggregates		Meso aggregates				
			>2mm	1-2 mm	0.5-1mm	0.25-0.5 mm			
Control	1.59	66.9	0.52	0.71	1.43	16.7	19.4	47.5	33.1
100% N	1.58	67.6	0.69	0.95	2.92	16.3	20.9	46.7	32.4
100% NP	1.54	67.8	1.10	1.45	3.53	15.9	22.1	45.7	32.2
100% NPK	1.52	69.7	1.43	3.14	5.93	14.7	25.2	44.4	30.4
150% NPK	1.51	70.2	1.71	3.93	6.29	14.4	26.4	43.9	29.8
100% NPK+FYM	1.48	74.5	2.64	5.29	8.91	14.2	30.9	43.5	25.5

BD-Bulk density; TWSA-Total water stable aggregates; MA-Macro aggregate; TMA-Total macro aggregate; MiA-Micro aggregate; MF-Mineral fraction

4.4.9 Raipur

4.4.9.1 Bulk density

Data on bulk density (BD) showed significant influence under different organic sources over control. Significant differences in BD values were observed between different treatments at 0-5, 5-10 and 10-15 cm soil layers (**Table 4.23**). In general, BD increased with increase in soil depth. The organic manures applied with inorganic fertilizers showed the lower BD values than the inorganic fertilizer alone. The lower values of BD were recorded in 100% NPK+FYM and the control plot showed the highest that was on par with imbalanced inorganic fertilized plots. The organic manures incorporation in soil helps to reduce the soil weight due to appropriate maintenance of soil: air: moisture ratio, which ultimately reflected on BD reduction in Vertisols. The increasing dose of organic manure helps to improve bulk density.

4.4.9.2 Penetration resistance

Penetration resistance (PR) of soils is an important parameter that influences the root growth and water movement. Soil strength, as measured penetration resistance (PR), increased with soil depth under balanced as well as imbalanced fertilizer use. Cone resistance (penetration resistance) was measured in situ after harvest of rice crop at the depth 5, 10 and 15 cm (**Table 4.23**). The cone resistance data revealed that the penetration resistance increased with increase in depth. The highest PR value was recorded in control at respective depths. Similarly, the lowest PR value was found in 100% NPK+FYM that was at par with 50% NPK+green manure (GM) and 150% NPK for all the depths. The reduction of PR value may be due to low BD values as well as high porosity of soil which was resulted by the addition of organic matter through organic manures. The control plot had shown the highest PR value at all depths.

4.4.9.3 Saturated hydraulic conductivity

The data on saturated hydraulic conductivity (K_{sat}) indicated that the K_{sat} was significantly improved with organic and inorganic fertilizers but the more evident effect was found with 100% NPK+FYM than inorganic fertilizers alone (**Table 4.23**). The highest K_{sat} was found in 100% NPK + FYM followed by 50% NPK + GM and 50% NPK + BGA. The lowest hydraulic conductivity was recorded in control. Increase in K_{sat} may be due to increase in soil organic carbon content of higher root biomass with application of fertilizer and more aggregate formation with FYM.

4.4.9.4 Porosity

Porosity is reciprocally related to the bulk density. The percentage of micro pores and macro pores indicates the ability of soil to retain the moisture. There was a greater total porosity in the 100% NPK+FYM and 50% NPK + green manuring compared to the control and 100% NPK (**Table 4.23**). The control plot showed the lowest porosity percentage that was on par with imbalanced inorganic treated plots i.e. 100% NP and 100% N.

4.4.9.5 Soil Temperature

The lowest soil temperature was found with 100% NPK + FYM followed by 50% NPK+ green manuring (**Table 4.23**). The highest soil temperature was observed under control.

Table 4.23 Effect of inorganic fertilizer and organic manure on soil physical properties after harvest of rice in LTFE at Raipur

Treatment	BD ($Mg\ m^{-3}$)			CR ($k\ N\ cm^{-2}$)			K_{sat} ($cm\ hr^{-1}$)	P (%)	ST (°C)
Depths (cm)	5	10	15	5	10	15	0-10	0-15	0-10
Control	1.33	1.36	1.40	4.2	5.6	6.4	0.78	44.2	24.27
100% N	1.30	1.33	1.39	3.7	5.4	6.2	0.75	45.4	23.2
100% NP	1.29	1.31	1.33	3.3	5.1	5.3	0.85	49.4	20.7
50% NPK	1.29	1.33	1.37	3.6	5.3	6.0	0.92	46.7	23.0
100% NPK	1.21	1.25	1.26	3.0	4.5	4.9	1.00	50.9	19.2
150% NPK	1.20	1.22	1.25	2.9	4.4	4.8	1.03	51.4	18.9
100% NPK+Zn	1.24	1.26	1.28	3.2	5.0	5.1	1.01	50.1	19.9
100% NPK+FYM	1.13	1.16	1.19	2.6	3.9	4.0	1.20	53.5	16.4
50% NPK+BGA	1.26	1.28	1.29	3.4	5.2	5.5	1.08	49.8	21.4
50% NPK+GM	1.16	1.18	1.22	2.9	4.4	4.5	1.13	51.9	17.6
CD (0.05)	0.11	0.16	0.17	0.6	0.88	0.9	0.14	6.7	3.3

BGA-Blue green algae; GM-Green manure; BD-Bulk density; CR-Cone resistance; K_{sat}*: Saturated hydraulic conductivity; P-Porosity; ST-Soil temperature*

4.4.9.6 Volumetric moisture content

A significant difference was observed between treatments and highest values were recorded with 100% NPK + FYM and 150% NPK; whereas at the upper soil layer 100% NPK + FYM had higher moisture than 150% NPK (**Table 4.24**). The lowest volumetric moisture was observed for control at 0-5, 5-10 and 10-15 cm depths. The increase in percent moisture content in the organic manure treated plot may be due to increase in macro and micro pores of the soil and also better aggregation of soil separates.

Table 4.24 Volumetric moisture content as affected by the continuous application of fertilizers and organic manure at harvest of rice

Treatment	Volumetric moisture content (θ_v %)		
	0-5 cm	5-10 cm	10-15 cm
Control	21.2	23.5	25.4
100% N	23.4	23.9	25.5
100% NP	27.0	27.0	28.0
50% NPK	24.3	25.8	27.5
100% NPK	26.1	26.4	28.4
150% NPK	26.7	28.8	29.8

100% NPK+Zn	25.6	26.4	27.5
100% NPK+FYM	27.0	28.5	30.0
50% NPK+Blue green algae (BGA)	24.0	24.9	26.0
50% NPK+Green manure (GM)	24.6	27.4	28.7
CD (0.05)	4.8	4.5	5.7

4.4.10 Udaipur

The lowest bulk density was recorded with FYM incorporation at 20 Mg ha^{-1} followed by NPK + FYM (**Table 4.25**) which were at par with each other, whereas highest bulk density (1.41 Mg m^{-3}) was observed in N alone plot. Lowering of bulk density might be due to higher organic C, more pore space and good soil aggregation. Porosity of the soil was also influenced with application of FYM singly or in combination with chemical fertilizer.

Table 4.25 Effect of long term fertilizer use and manure on physical parameters in LTFE at Udaipur (2017-18)

Treatment	Bulk density (Mg m^{-3})	Particle density (Mg m^{-3})	Porosity (%)
Control	1.44	2.62	45.04
100% N	1.40	2.62	46.56
100% NP	1.37	2.61	47.51
100% NPK	1.39	2.60	46.54
150% NPK	1.38	2.60	46.92
100% NPK +Zn	1.40	2.60	46.15
100% NPK+ S	1.38	2.60	46.92
100% NPK+ Zn + S	1.38	2.61	47.13
100% NPK + Biofertilizer	1.40	2.60	46.15
100% NPK + FYM	1.31	2.58	49.22
100% NPK - FYM	1.32	2.59	49.03
FYM @ 20 Mg ha^{-1}	1.29	2.58	50.00
CD (0.05)	0.08	NS	2.92

4.5 Soil Biological Properties

Soil microbes play a key role in decomposition of organic matter and plant nutrition as a whole. Enzymatic activities by microbes govern nutrient supply and also soil health. Similarly, soil microbial biomass acts as the transformation agent of the organic matter in the soil. As such, the biomass acts as both a source and sink of the carbon, nitrogen, phosphorus, sulphur and micronutrients. The biomass acts as a centre of biological activity and regulates nutrients transformation in soil. Soil and crop management practices greatly influence soil biological activities. Thus, knowledge on biological parameters is essential to understand plant nutrition mechanism. Results emanated from LTFEs are elaborated hereunder:

4.5.1 Bhubaneswar

4.5.1.1 Microbial count

The 100% NPK+FYM recorded significantly maximum microbial population followed by 100% NPK+lime+FYM (**Table 4.26**). Soil fungal population varied from 11×10^4 to 34×10^4 cfu/g. Bacterial population varied from 9×10^6 to 27×10^6 cfu/g. Actinomycetes population varied from 1×10^6 cfu/g to 6×10^6 cfu/g. Application of FYM with or without lime showed highest actinomycetes population. No significant difference was found due to secondary (S) and micronutrient application (Zn and B). Lime application caused an increase in actinomycetes population in particular. Soil microbial respiration varied from a lowest of 0.172 mg CO_2/g to 0.25 mg CO_2/g. Maximum respiration was found in 100% NPK+Lime+FYM and 100% NPK+FYM. There was an increase of 50.5% in the highest respired plot over control. In case of balanced fertilization an increase of 16.2% was recorded over control. No significant difference was found among secondary and micronutrient treated plots.

Table 4.26 Effect of manurial treatments on microbial population (cfu g^{-1} soil) and basal soil respiration (mg CO_2/g of soil) in LTFE at Bhubaneswar

Treatment	Fungi ($\times 10^4$)	Bacteria ($\times 10^6$)	Actinomycetes ($\times 10^6$)	Basal soil respiration (mg CO_2/g of soil)
Control	11.75	9.00	1.75	0.172
100% N	13.50	11.88	1.62	0.202
100% NP	14.50	12.00	2.62	0.217
100% PK	12.00	11.13	1.37	0.192
100% NPK	14.75	13.00	4.37	0.200
150% NPK	15.75	11.25	4.62	0.241
100% NPK+Zn	14.00	18.50	2.12	0.237
100% NPK+B+Zn	15.00	7.50	3.37	0.222
100% NPK+S+Zn	18.25	7.13	2.75	0.230
100% NPK+Lime	15.50	18.63	6.25	0.233
100% NPK+FYM	34.75	18.75	5.00	0.255
100% NPK+Lime+FYM	26.75	27.50	6.12	0.259
CD (0.05)	3.48	2.60	1.21	0.02

4.5.1.2 Microbial biomass C, N and P

Results revealed that microbial biomass carbon (MBC) significantly higher in plots receiving both organic and inorganic fertilizers and lowest in unamended control plots (**Table 4.27** & **Figure 4.8**). There was significant variation in MBC content in the combination of lime and compost or compost with mineral fertilizer with inorganic fertilizer. The microbial biomass N (MBN) content in soil ranged from 16 µg g^{-1} in unfertilized control plot and 85 µg g^{-1} dry soils in the plots receiving organic manure and lime combined with mineral fertilizer. Addition of micronutrient either Zn alone or combination with B or S recorded significantly higher MBN content than balanced fertilization i.e 100% NPK. The microbial biomass P (MBP) content was lowest (3.38 µg g^{-1} dry soil) in control and the highest in 100% NPK+ FYM+ lime.

Table 4.27 Effect of manurial treatments on microbial biomass of soil in LTFE at Bhubaneswar

Treatment	Microbial biomass (µg/g of dry soil)		
	Carbon	Nitrogen	Phosphorus
Control	49.68	16.04	3.38
100% N	80.62	34.34	4.95
100% NP	90.22	44.85	5.29
100% PK	85.04	33.48	5.06
100% NPK	97.63	35.87	10.60
150% NPK	117.69	51.20	13.72
100% NPK +Zn	113.67	48.30	10.99
100% NPK +FYM	147.18	82.78	16.76
100% NPK + B + Zn	124.87	58.48	7.98
100% NPK + S + Zn	126.89	62.16	9.03
100% NPK + Lime	135.64	67.04	10.71
100% NPK + Lime + FYM	151.83	85.76	20.40
CD (0.05)	7.85	6.14	1.34

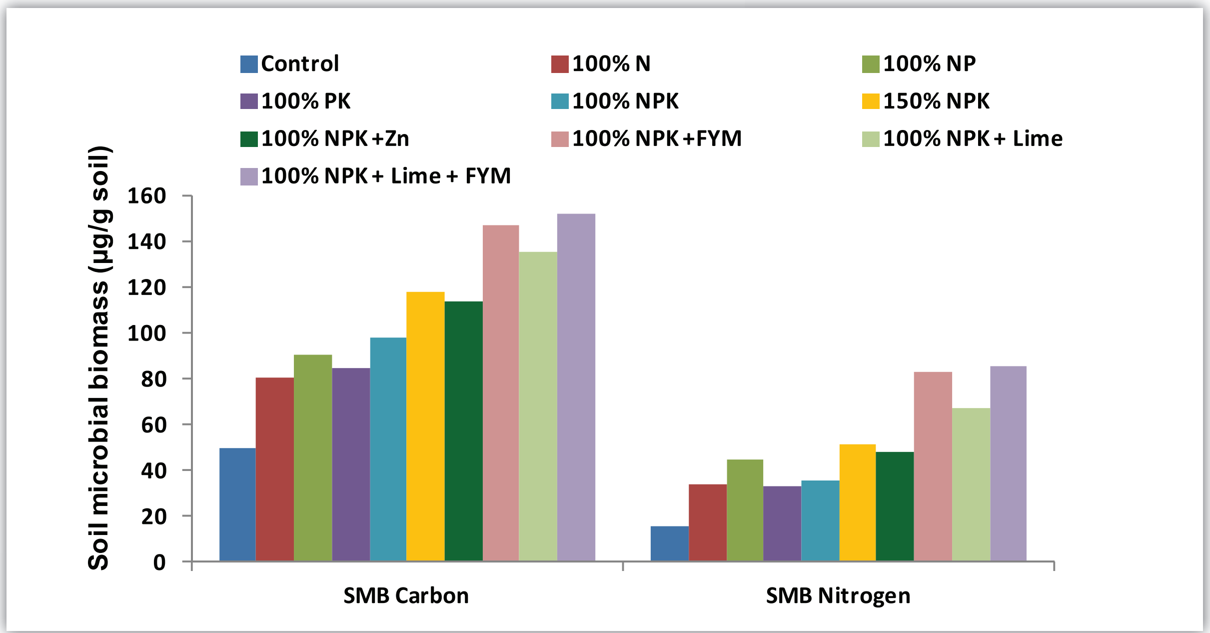


Figure 4.8 Microbial biomass C and N at Bhubaneswar (AICRP LTFE)

4.5.1.3 Enzymatic activities

The dehydrogenase activity (**Table 4.28**) was maximum in 100% NPK+ FYM+ Lime followed by 100% NPK+FYM and 150% NPK. Lowest dehydrogenase activity was measured in unfertilised control. There was a significant increase in dehydrogenase activity in only N and NP treatment over control. Urease another enzyme related to nitrogen metabolism was highest in 100% NPK+ FYM+ lime which were at par with 100% NPK+FYM (**Table 4.28**). Lowest activity was observed in unfertilised control. There was a significant difference among all fertilised treatments except micronutrient addition. Application of 100% NPK caused significant increase over control but increasing NPK dose to 150% did not have any significant effect. Addition of Zn or Zn +B or Zn + S resulted in decrease in urease activity compared to 100% NPK.

Table 4.28 Effect of long term fertilisation on soil enzyme activity in LTFE at Bhubaneswar

Treatment	Dehydrogenase activity (mg of TPF kg^{-1} of soil 24 h^{-1})	Urease activity (mg NH_4^+-N kg^{-1} of soil 24 h^{-1})
Control	12.16	34.27
100% N	26.47	53.47
100% NP	36.45	58.07
100% PK	24.73	45.27
100% NPK	35.25	69.67
150% NPK	45.93	72.07
100% NPK +Zn	23.25	66.13
100% NPK +FYM	58.53	79.67
100% NPK + Lime + FYM	59.20	80.47
100% NPK + B + Zn	33.47	66.47
100% NPK + S + Zn	36.08	56.20
100% NPK + Lime	43.47	65.40
CD (0.05)	5.05	5.51

4.5.1.4 Macro fauna and earthworm population

Earthworm population (number/m^2) measured on the surface soil during three periods of *rabi* season **(Table 4.29)**. The earthworm and nematode population were maximum with NPK+lime+FYM followed by NPK+FYM across all crop growth stages i.e. pre-planting stage (PPS), maximum tillering stage (MTS) and flowering stage (FS), respectively. Higher population of plant parasitic nematode was also observed at FS as compared to pre-planting (PP) and maximum tillering stage (MTS). Mean population showed an increase of 6.75% at FS compared to TS.

Free living nematode population collected from dry soils in the month of January i.e. at PPS revealed that there was a stable variation between treatments. Highest population was observed in 100% NPK+lime+FYM followed by 100% NPK+FYM and 100% NPK+lime. Mean treatment population was, however, decreased by 8.48% in maximum TS from PPS. The 150% NPK recorded significantly higher population than that of 100% NPK. Highest population was observed at FS. There was significant difference between combined application of FYM and Lime over sole application. There was a significant increase in population in 100% NPK+Zn and 100% NPK+S+Zn over 100% NPK treatment.

Table 4.29 Effect of manurial treatments on earthworm population and nematode population at different growth stages of rabi rice in LTFE at Bhubaneswar (2017-18).

Treatment	Earthworm population (number m^{-2})			Nematode population (number per 200 g soil)		
	PPS	MTS	FS	PPS	MTS	FS
Control	3.18	6.08	5.26	213	183	238
100% N	5.35	8.78	12.82	194	169	160
100% NP	5.68	7.22	7.88	190	193	210
100% PK	4.00	4.42	4.55	192	164	205
100% NPK	7.30	8.77	10.28	172	149	196
150% NPK	8.38	6.82	14.92	196	175	248
100% NPK+Zn	5.73	13.70	12.06	172	173	217
100% NPK+B+Zn	1.68	11.94	12.08	195	177	193
100% NPK+S+Zn	2.00	9.02	10.46	171	138	228
100% NPK+Lime	10.49	11.96	13.80	216	202	274
100% NPK+FYM	21.50	24.22	24.06	216	209	240
100% NPK+Lime+FYM	25.02	27.20	26.84	226	220	318
Mean	8.36	11.68	12.92	196	179	227
CD (0.05)	1.57	2.12	2.4	37.7	16.6	19.5

PPS-Pre planting stage, MTS-Maximum tillering stage, FS-Flowering stage

4.5.2 Akola

4.5.2.1 CO_2 Evolution

Application of 100% NPK + FYM @ 5 Mg ha^{-1} evolved maximum amount of CO_2 i.e. 41.80 mg 100 g^{-1} as compared to unmanured control (20.08 mg 100 g^{-1}) (**Table 4.30**). The application of 100% NPK or its higher levels significantly influenced the CO_2 evolution. Absence of P or PK from fertilizer schedule in the sequence caused drastic reduction in the CO_2 evolution. High respiration in FYM supplemented treatment is indicative of nutrient turnover at high carbon expenses met through added organics and sufficient flow of photosynthates from the roots due to high crop yields. Continuous application of 100% NPK + S and 100% NPK + Zn to the sequence resulted significant improvement in the CO_2 evolution of soil, the high crop yield and root exudates might have helped in the buildup of respiration and thereby increased CO_2 evolution under these treatments.

4.5.2.2 Dehydrogenase activity

The dehydrogenase is commonly used as an indicator of biological activity in soil. The activity of dehydrogenase enzyme was strongly affected by long term fertilizer use. The application of 100% NPK + FYM @ 5 Mg ha^{-1} significantly increased the dehydrogenase activity followed by 150% NPK (**Table 4.30**).

The application of FYM increased availability of substrates for dehydrogenase and comparatively more activity of dehydrogenase in 150% NPK may be attributed to the fact that inorganic sources of nutrients stimulated the activity of microorganisms to utilize the native pool of organic carbon as a source of carbon, which act as substrate for dehydrogenase.

4.5.2.3 Urease activity

The soil urease activity ranged between 37.45 to 67.79 ug/g/24 hrs (**Table 4.30**). The treatment comprising nitrogen application (except control) recorded the urease activity in the range of 51 to 67.79 ug/g/24 hrs. However, the highest urease activity was observed with the combined application of 100% NPK + FYM @ 5 Mg ha^{-1}.

Table 4.30 Long term effect of various treatments on soil biological properties at LTFE Akola

Treatment	CO_2 Evolution (mg 100 g^{-1})	Dehydrogenase activity (µg TPF g^{-1} 24 h^{-1})	Soil urease activity (ug g^{-1} 24 h^{-1})
Control	20.08	35.93	37.45
100% N	24.75	43.67	51.00
100% NP	28.05	44.81	53.23
50% NPK	27.23	41.89	46.35
100% NPK	31.63	46.90	57.48
150% NPK	38.23	54.89	63.54
100% NPK (S free)	29.98	45.90	54.85
100% NPK + Zn @ 2.5 kg ha^{-1}	32.73	48.98	58.29
100% NPK + FYM @ 5 Mg ha^{-1}	41.80	61.45	67.79
100% NPK + 37.5 kg S ha^{-1}	35.48	49.32	58.08
FYM @ 10 Mg ha^{-1}	40.15	56.51	64.76
75% NPK + 25% N through FYM	39.05	53.23	61.32
CD (0.05)	4.20	2.10	8.04

4.5.3 Coimbatore

4.5.3.1 Microbial count

Regarding the microbial population in the post harvest soil of finger millet and maize crops varied widely among treatments (**Table 4.31**). Under INM of 100% NPK+FYM the highest population of bacteria, fungi and Actinomycetes were recorded. Fertilization with inorganic NPK fertilizers alone registered moderate population of bacteria, fungi and actinomycetes. Imbalance nutrient application (control, 100% N, 100% NP, 50% NPK) has drastically reduced the microbial count i.e., bacteria, fungi and actinomycetes in Inceptisols of Coimbatore.

Table 4.31 Soil microbial population in LTFE at Coimbatore

Treatment	Bacteria (10^6 CFU / g of dry soil)	Fungi (10^3 CFU / g of dry soil)	Actinomycetes (10^4 CFU / g of dry soil)
Control	45	11	7
100% N	72	12	8
100% NP	72	12	8
50% NPK	81	13	9
100% NPK	90	14	10
150% NPK	83	13	9
100% NPK (-S)	87	13	9
100% NPK + HW	90	14	10
100% NPK + $ZnSO_4$	87	13	9
100% NPK + FYM	131	16	12

4.5.3.2 Soil microbial biomass C and N

Soil microbial biomass is being a driving force of biochemical process and pool of soil nutrients for crop growth. The long term fertilizer application along with organic manure significantly increased soil biomass carbon (SMBC) and nitrogen (SMBN) than control (**Table 4.32**). Irrespective of the treatments, INM (100% NPK+FYM @10 Mg ha^{-1}) showed significantly higher SMBC and SMBN in finger millet. The 100% NPK+FYM recorded highest biomass C and biomasses N in post harvest maize soils. However, the lowest biomass C and biomass N were recorded with control.

Table 4.32 SMBC and SMBN in post harvest soils of finger millet and maize at LTFE Coimbatore (2019)

Treatment	Finger millet		Maize	
	SMBC (mg kg^{-1})	SMBN (mg kg^{-1})	SMBC (mg kg^{-1})	SMBN (mg kg^{-1})
Control	193	18.41	189	19.46
100% N	199	26.30	214	25.64
100% NP	271	33.51	262	34.86
50% NPK	262	27.21	244	27.91
100% NPK	281	38.09	262	38.05
150% NPK	294	44.92	279	44.71
100% NPK (-S)	280	40.45	265	40.46
100% NPK + Zn	285	42.03	273	41.84
100% NPK +HW	276	38.91	256	38.88
100% NPK + FYM	301	47.82	284	46.47
CD (0.05)	9.26	0.62	6.73	1.83

4.5.3.3 Soil enzymes

Biochemical reactions are the important nutrient transformation processes in organic and inorganic substance in soil environment through the catalytic activity of biomolecules called enzymes. The enzyme dehydrogenase, acid phosphatase, alkaline phosphatase and urease had observed significant in plot which applied in 100% NPK +FYM of 6.3 (µg TPF g^{-1} soil day^{-1}), 47.5, 150.7 (µg p-nitro phenol g^{-1} soil hr^{-1}) and 149 µg NH_4^+ g^{-1} soil hr^{-1} respectively (**Table 4.33**). Comparing the treatments, other than INM, 100% NPK observed moderate enzymatic activity and low in control plots.

Table 4.33 Soil enzymatic activities at LTFE Coimbatore

Treatment	DHA (µg TPF g^{-1} soil day^{-1})	AcP (µg p- nitro phenol g^{-1} soil h^{-1})	AlP (µg p- nitro phenol g^{-1} soil h^{-1})	Urease (µg NH_4^+ g^{-1} soil h^{-1})
Control	2.7	36.8	90.6	59
100% N	3.9	33.5	99.8	91
100% NP	4.1	30.9	103.6	99
50% NPK	3.8	33.0	105.8	96
100% NPK	3.7	30.8	118.3	112
150% NPK	4.1	27.9	109.4	85
100% NPK (-S)	3.6	30.5	101.5	117
100% NPK + HW	3.8	30.9	113.3	112
100% NPK + $ZnSO_4$	4.0	29.1	109.1	115
100% NPK + FYM	6.3	47.5	150.7	149

DHA-Dehydrogenase activity, AcP-Acid phosphatase, AlP-Alkaline phosphatase

4.5.4 Jabalpur

Microbial population was significantly improved with successive application of fertilizers over control (**Table 4.34**). Further, maximum microbial population was found with addition of 100% NPK+FYM indicating the beneficial effect of integrated fertilizer application with organic manure for providing a favourable soil environment in promoting microbial population. Inclusion of organic manure significantly improved the microbial biomass C and N contents in soil The higher content of soil biomass C and N was recorded with 100% NPK+FYM.

Table 4.34 Effect of long term application of fertilizers and manure on microbial population and soil microbial biomass

Treatment	Microbial count (cfu g^{-1} soil)			SMB (µg g^{-1} soil)	
	Bacteria (10^7)	Fungi (10^4)	Actinomycetes (10^6)	SMBC	SMBN
Control	11.67	18.46	13.64	168.32	21.25
100% N	14.28	19.63	15.28	212.15	25.10
100% NP	18.32	23.55	16.32	238.22	26.89

50% NPK	19.77	24.44	17.22	234.12	27.72
100% NPK	23.85	33.22	26.18	292.21	35.21
150% NPK	25.09	37.86	29.03	314.46	40.49
100% NPK-S	23.31	32.44	25.22	285.47	33.18
100% NPK+Zn	23.41	34.02	26.22	286.10	34.10
100% NPK+HW	23.53	34.11	26.07	284.12	33.42
100% NPK+FYM	39.06	42.74	39.60	343.48	44.25
CD (0.05)	2.315	1.580	1.692	15.99	2.711

SMBC-Soil microbial biomass carbon, SMBN-Soil microbial biomass nitrogen

4.5.5 Jagtial

4.5.5.1 Microbial count

The data on microbial population revealed that (**Table 4.35**) balanced and integrated nutrient application leads to enhancement of all the microbial population including actinomycetes, fungi and bacteria. Further, the FYM addition has improved the microbial count.

Table 4.35 Effect of long-term fertilizers and manures on microbial count under rice-rice cropping system (19 years of cropping)

Treatment	Actinomycetes ($x10^4$ cfu g^{-1})	Fungi ($x10^3$ cfu g^{-1})	Bacteria ($x10^6$ cfu g^{-1})
Control	2.67	3.21	8.86
100% N	2.92	2.68	10.23
100% NP	4.63	4.51	15.49
50% NPK	3.74	4.21	12.89
100% NPK	4.26	6.34	20.46
150% NPK	6.27	7.15	19.82
100% NPK - S	4.32	4.78	14.25
100% NPK+Zn	6.09	7.32	20.24
100% NPK+HW	5.62	7.29	18.72
100% NPK + FYM	8.64	10.98	25.67
FYM @ 15 Mg ha^{-1}	8.92	11.25	26.54

4.5.5.2 Enzymatic activities

Soil enzymatic activities as affected by different nutrient management options clarify that it was significantly increased on integration of FYM with 100% NPK as well as in FYM alone (**Table 4.36**).

Table 4.36 Effect of long term fertilizer and manure application on soil enzymatic activity at 90 DAT of rice (2018-19)

Treatment	DHA (mg TPF g^{-1} soil d^{-1})		APA (µg p-nitrophenol g^{-1} soil h^{-1})		ALPA (µg p-nitrophenol g^{-1} soil h^{-1})	
	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif
Control	2.8	2.0	82.3	61.4	98.3	79.3
100% N	2.9	2.9	79.4	61.3	104.4	73.2
100% NP	4.8	3.2	91.4	88.3	113.4	89.4
50% NPK	3.2	2.9	99.4	85.2	102.3	89.1
100% NPK	3.9	3.0	108.3	98.3	121.4	98.2
150% NPK	4.2	3.3	124.7	103.3	143.8	114.4
100% NPK + HW	3.9	3.0	100.2	97.3	118.2	100.4
100% NPK + Zn	4.1	3.2	99.4	95.2	128.2	93.2
100% NPK + FYM	5.2	3.3	128.2	106.2	132.4	106.4
100% NPK – S	4.8	2.7	98.4	95.4	108.3	104.3
FYM @ 15 Mg ha^{-1}	4.2	3.8	102.3	97.9	100.2	93.5
Fallow	3.1	2.9	89.8	82.3	102.8	97.8
CD (0.05)	0.4	0.3	14.9	13.2	8.9	6.9

DHA-Dehydrogenase activity, APA-Acid phosphatase activity, ALPA-Alkaline phosphatase activity

4.5.6 New Delhi

4.5.6.1 Soil enzyme activities

Soil samples (0-15 cm and 15-30 cm) were collected at maximum tillering stage of wheat. At 25°C, dehydrogenase activity (DHA) in bulk soils of 150% NPK and NPK+FYM were 30 and 48% higher in the surface layer and 30 and 50% higher in the sub-surface layer than control, respectively (**Figure 4.9**). The DHA within macroaggregates of NPK+ FYM plots were 19% and 21% higher compared with NPK in surface and sub-surface soil layers, respectively. The DHA activities within microaggregates followed similar trend with a substantial increase under NPK+ FYM over other plots. The mean increment in DHA in surface soil due to temperature rise from 25 to 35°C was 12%, 13% and 14%, in bulk soils, macro- and micro-aggregates, respectively (**Figure 4.9**). Similar trends of DHA increments were recorded in sub-surface soil due to a sudden change in temperature. NPK+ FYM showed ~29 and 9% higher β–glucosidase activity over NPK in the soil surface and sub-surface layers, respectively (**Figure 4.10**). However, 150% NPK application decreased β–glucosidase activity by ~10 and 9% in 0-15 and 15-30 cm soil layers over NPK. The NPK, 150% NPK and NPK+ FYM treated plots had comparable FDA activity in bulk soils, which was significantly higher than that under control. Similar trends were recorded in case of alkaline phosphatase activities, which were highest under NPK+ FYM plot in both soil layers.

In general, FDA and alkaline phosphatase activities were higher in macroaggregates than microaggregates (**Figure 4.11**). In surface soil, NPK+ FYM had 17% higher FDA activity within macroaggregates than NPK. On the other hand, FDA activity within microaggregates was similar under 100% NPK, 150% NPK and NPK+ FYM. The FDA activity within macroaggregates in 150% NPK plots were 12% higher compared with NPK and that within microaggregates was lower by 14%. Alkaline phosphatase activity increased significantly upon NPK+FYM application over NPK in both aggregate size fractions across the soil depths.

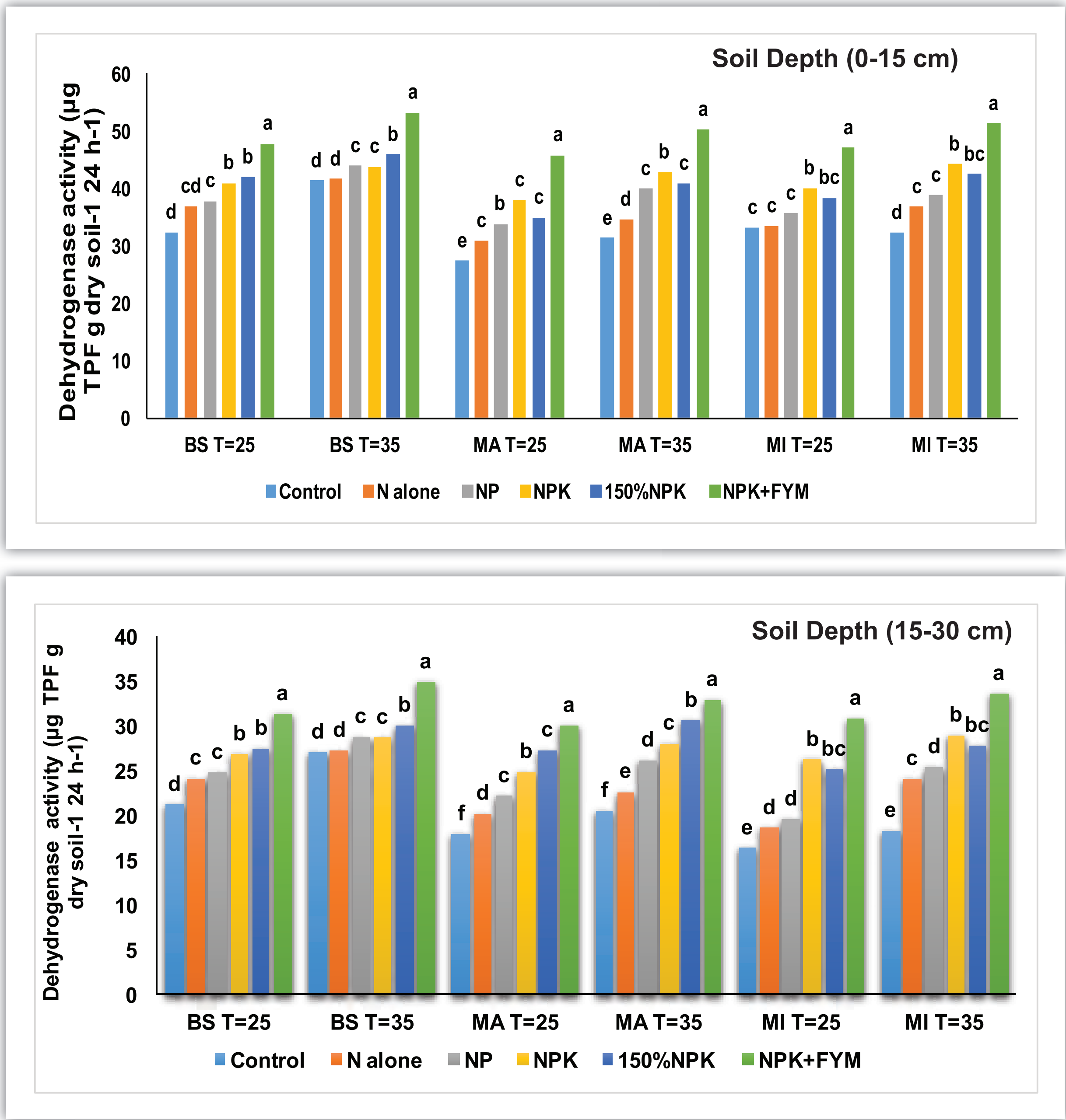


Figure 4.9 Dehydrogenase activity in bulk soils and aggregates at two temperatures as affected by long-term fertilization in the 0–15 cm and 15-30 cm soil layers in wheat under maize-wheat cropping system. BS: Bulk soil, MA: Macroaggregate, MI: Microaggregates, T: Temperature (^{o}C).Bars with similar lowercase letters within a particular soil size fraction are not significantly different at P<0.05

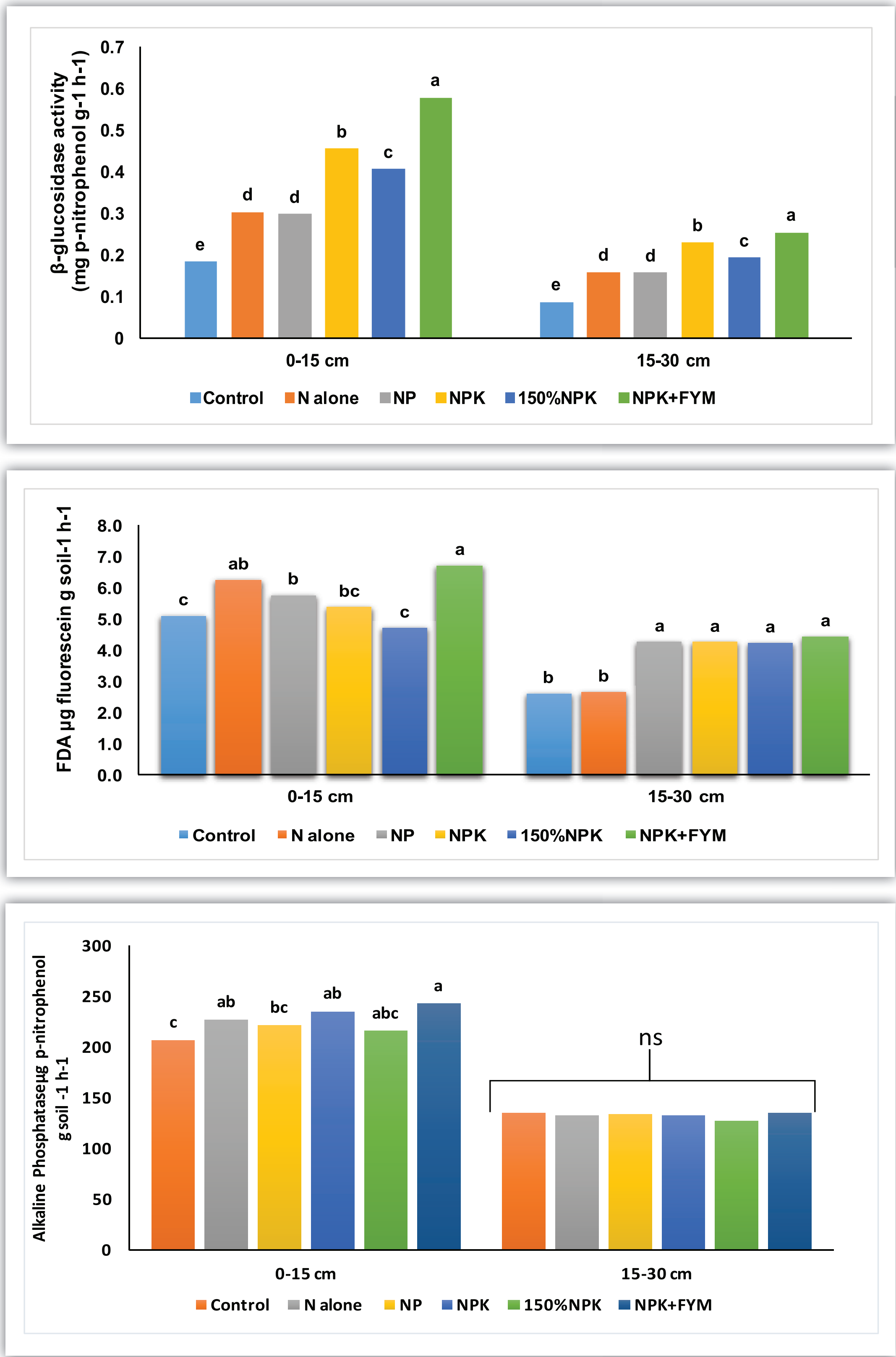


Figure 4.10 β-glucosidase, FDA and alkaline phosphatase activity in bulk soils in 0-15 and 15-30 cm soil depth as affected by long-term fertilization. Bars with similar lowercase letters are not significantly different at *P*<0.05

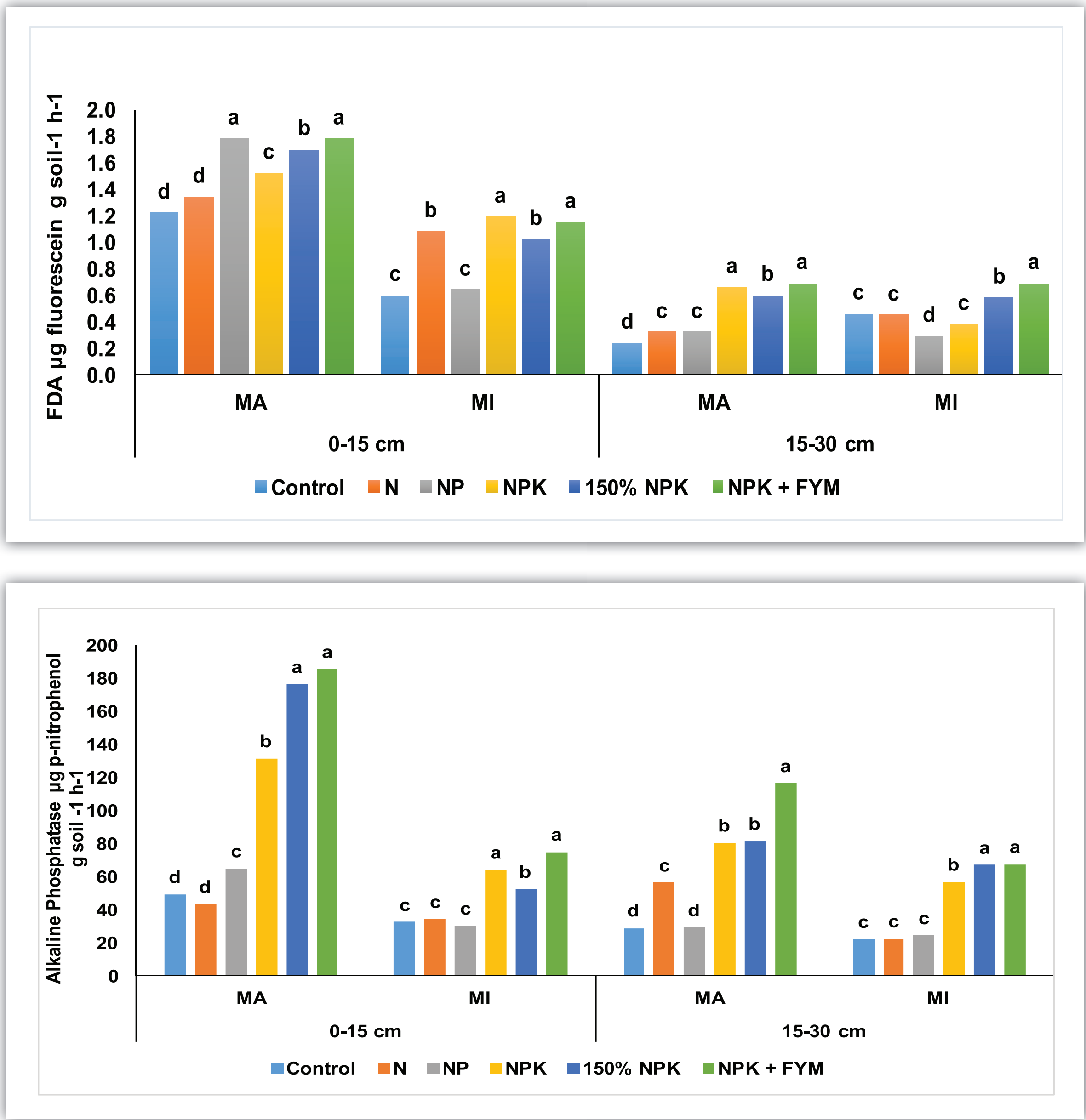


Figure 4.11 FDA and Alkaline phosphatase activity within macro- and microaggregates as affected by long-term fertilization in the 0-15 and 15–30 cm soil layers. MA: Macroaggregates, MI: Microaggregates. Bars with similar lowercase letters are not significantly different at *P*<0.05.

4.5.7 Palampur

The highest microbial biomass carbon (SMBC) and nitrogen (SMBN) was recorded in 100% NPK + FYM followed by NPK+lime amended treatment and the lowest was recorded in 100% N followed by control (**Table 4.37**).

Table 4.37 Effect of different treatments on microbiological properties after wheat harvest

Treatment	Soil microbial biomass C (mg kg^{-1})	Soil microbial biomass N (mg kg^{-1})
Control	263	10.0
100% N	179	11.8
100% NP	271	13.2
50% NPK	372	14.0
100% NPK	455	18.0
150% NPK	425	19.8
100% NPK (-S)	427	14.5
100% NPK + Zn	423	16.8
100% NPK +HW	516	19.4
100% NPK + lime	605	21.6
100% NPK + FYM	629	24.1
CD (0.05)	13	0.92

4.5.8 Pantnagar

4.5.8.1 Microbial count

Microbial population viz., Fungi, actinomycetes and large portion of bacterial population of soil microflora are heterotrophic in nature and their abundance and diversity depend upon the supply of carbon. Therefore, an assessment of soil microbial population under influence of chemical fertilizer, FYM and integrated use of chemical fertilizer; was done at the end of 44^{th} cropping cycles of rice-wheat cropping system at Pantnagar (**Table 4.38**).

Data on fungal population indicated maximum population of fungi with NPK+FYM followed by NPK+Zn and NP+Zn (**Table 4.38**). On the other hand, the lowest fungal population was found under control (no application of fertilizer and manure). Similarly, bacterial count was found maximum with NPK+FYM and NPK+Zn. Actinomycetes population followed more or less same pattern as that of the other group of organisms i.e. fungi and bacteria influenced significantly by integrated nutrient management (100% NPK+FYM). Mineral fertilizers application along with farm yard manure (NPK+FYM) gave maximum population of Azotobacter counts. The Azotobacter population of soil under control was lowest in both the layers and significantly increased on application of NPK fertilizers application.

Table 4.38 Long term effect of fertilizer and manure on microbial population (cfu/g soil) in surface soil (0-15 cm) after 48th crop cycles (LTFE Pantnagar)

Treatment	Fungi (10^4)	Bacteria (10^6)	Actinomycetes (10^5)	Azotobacter (10^3)
Control	0.60	0.55	0.78	152
100% N+Zn	1.27	1.46	1.89	410
100% NP+Zn	1.66	1.68	1.00	476
50% NPK+Zn	1.06	1.60	1.59	236
100% NPK	1.48	1.80	1.71	286
150% NPK	1.48	1.87	1.76	256
100% NPK+HW+Zn	1.84	1.99	1.85	379
100% NPK+Zn	1.91	2.19	1.84	336
100% NPK+FYM	1.99	2.32	2.16	630
100% NPK-S+Zn	1.40	1.79	1.81	422
CD (0.05)	0.11	0.17	0.31	43.9

4.5.8.2 Soil microbial biomass C, N and P

Use of FYM in combination with chemical fertilizers significantly increased the soil microbial biomass carbon (SMBC) compared to the 100% NPK (**Table 4.39**). Supply of additional mineralizable N and readily hydrolysable C due to organic manure application might have resulted in higher microbial activity and in return higher microbial biomass carbon.

Application of FYM in combination with inorganic fertilizers resulted in significantly higher soil microbial biomass nitrogen (SMBN) content as compared to the rest of the treatments (**Table 4.39**). High soil carbon content, more root proliferation and additional supply of N by FYM to microorganism might be responsible for increasing the level of SMBN in soil.

Continuous application of chemical fertilizers either alone or in combination with FYM increased the soil microbial biomass phosphorus (SMBP) content as compared to non P fertilized plots (**Table 4.39**). Integrated use of organic and inorganic plant nutrients significantly increased the crop productivity and thereby provides more substrates essential for microbial growth and activity which is responsible for such increase in SMBP. The low content in control plot could be due to no addition of any external input into the soil over the years and thereby poor crop productivity. Low content of SMBP in 100% N alone was also observed. Such decline in N alone treatment is attributed to reduction of microbial cells in the absence of any phosphate substrate. The addition of higher levels of phosphorus through external sources might have influenced the metabolism of microorganisms, which is probably responsible for higher levels of SMBP.

4.5.8.3 Water soluble carbon and carbohydrates

Water soluble organic carbon is considered as the most labile form of SOC and is immediate source as organic substrate for microorganism. It is released from microbial activity and through root exudation. Maximum water soluble carbon was observed in treatment receiving 100% NPK+FYM treatment followed by continuous addition of 100% NPK+Zn and lowest water soluble carbon content was found in the control plot.

Water soluble carbohydrates (WSCH) are again readily available source of C for microorganisms and contribute to soil quality through its role in the formation and stabilization of soil structure. Significant differences in the amount of water soluble carbohydrate was observed between FYM treated and inorganically fertilized plots in both the crops. The highest amount of water soluble carbohydrate was registered with 100% NPK+ FYM treatment followed by integrated use of organic manure and inorganic fertilizers, while the lowest was in control treatment.

4.5.8.4 Dehydrogenase activity

All biological reactions in soil are catalyzed by enzymes. Soil enzyme activities are believed to indicate the extent of specific processes in soil. The dehydrogenase activity (DHA) is a good indicator of soil fertility. Higher the activity more will be the microbiological activity in soil which in turn have more SMBC, N and P (**Table 4.39**). Thus addition of FYM induced the growth of soil organisms and enzymes. The activity of dehydrogenase enzyme was strongly affected by long-term fertilizer use. Maximum activity was noticed with 100% NPK+FYM treatment and followed by 100% NPK-S (which was at par with each other).

Table 4.39 Long term effect of fertilizer and manure on carbon pools and dehydrogenase activity after 48th cropping cycles

Treatment	SMBC (mg kg^{-1})	SMBN (mg kg^{-1})	SMBP (mg kg^{-1})	WSC (mg kg^{-1})	WSCH (mg kg^{-1})	DHA (mg TPF kg^{-1} soil 24 h^{-1})
Control	7.85	6.94	0.24	2.96	2.30	0.24
100% N+Zn	245.2	34.2	3.7	60.8	41.3	5.78
100% NP+Zn	199.2	36.2	4.1	59.6	40.6	5.45
50% NPK+Zn	168.0	23.2	3.0	42.7	25.8	4.12
100% NPK	177.2	29.0	3.2	51.8	31.1	4.27
150% NPK	186.7	27.5	4.2	53.7	33.2	5.40
100% NPK+HW+Zn	208.5	34.2	5.3	57.1	39.3	5.36
100% NPK+Zn	230.5	33.2	3.6	59.7	40.8	5.45
100% NPK+FYM	260.0	35.2	6.2	74.7	42.5	6.82
100% NPK-S+Zn	289.2	41.2	4.9	78.5	43.0	6.61
CD (0.05)	2.731	2.411	0.08	1.031	0.74	0.08

4.5.9 Parbhani

4.5.9.1 Microbial count

The data on bacteria, fungi and actinomycetes population recorded highest population with 100% NPK + FYM @ 5 Mg ha^{-1} followed by only FYM @ 10 Mg ha^{-1} (**Table 4.40**). The significant variations were observed among the treatments.

4.5.9.2 Enzymatic activities

Soil enzymatic activity is an indicator of chemical reactions and continuous conversion of unavailable form of nutrients to available form. Soil dehydrogenase, acid phosphatase and alkaline phosphatase enzymes activity were estimated after harvest of crop sequence and observed that all the three enzymatic activity such as dehydrogenase, acid phosphatase and alkaline phosphatase were more in 100% NPK + FYM @ 5 Mg ha^{-1} (**Table 4.40**). However, lowest enzyme activities were recorded in the control followed by 100% N alone.

Table 4.40 Effect of organic manures and fertilizers on microbial count and enzymatic activities in soybean–safflower cropping sequence at Parbhani

Treatment	Bacteria (10^7)	Fungi (10^4)	Actinomycetes (10^6)	DHA (ug TPF g^{-1} soil $24h^{-1}$)	APA (ug P-NP g^{-1} soil h^{-1})	ALPA (ug P-NP g^{-1} soil h^{-1})
Control	23.88	2.65	19.63	25.25	36.20	55.72
100% N	23.78	2.40	18.65	22.67	31.85	50.25
100% NP	26.94	2.56	24.50	30.29	42.08	55.85
50% NPK	23.71	2.80	22.53	31.01	41.70	53.23
100% NPK	28.83	3.54	29.35	31.03	42.60	56.90
150% NPK	33.21	4.68	32.60	36.18	44.43	67.71
100% NPK+HW	27.82	4.35	25.60	31.70	43.54	56.00
100% NPK+Zn	27.98	4.13	23.50	35.79	41.88	57.68
100% NPK+FYM @ 5 Mg ha^{-1}	44.05	8.09	35.63	41.71	49.93	72.77
100% NPK-S	27.88	5.00	24.03	31.64	42.13	55.36
Only FYM @ 10 Mg ha^{-1}	43.80	9.25	40.48	38.55	46.38	70.68
Fallow	18.90	2.20	17.90	24.88	32.85	51.78
CD (0.05)	1.696	0.453	1.684	1.61	1.648	2.040

DHA-Dehydrogenase activity, APA-Acid phosphatase activity, ALPA-Alkaline phosphatase activity

4.5.10 Ludhiana

4.5.10.1 Microbial biomass carbon

Microbial biomass carbon (MBC) is an important component of SOM that regulates the transformation and storage of nutrients. Long-term application of inorganic fertilizer and FYM resulted in significantly higher MBC in the surface soil (0-15 cm) with 100% NPK+FYM (**Table 4.41**). The improvement in MBC was 51% under 100% N, 76% under 100% NP, 112% under 100% NPK and 124% under 150% NPK compared to control. The maximum improvement of MBC (182%) recorded 100% NPK+ FYM. The higher MBC due to integrated application of FYM along with NPK fertilizer may be due to higher root biomass produced under NPK+FYM treatment and the supply and availability of additional mineralizable and readily hydrolysable C.

4.5.10.2 Basal soil respiration and mineralizable carbon

The effect of continuous application of fertilizer on basal soil respiration (BSR) and mineralizable carbon (C_{min}) in the surface soil are presented in **Table 4.41**. The BSR ranged from 1.86 under control to 3.10 under 100% NPK+FYM. The BSR was recorded maximum under integrated application of fertilizer and FYM, which was 67% higher than the untreated control. The maximum BSR (32%) recorded under integrated application of fertilizer and FYM. The C_{min} in the surface soil (0-15 cm) ranged from 142.9 under control to 191.9 under 100% NPK+FYM. The C_{min} enhanced by 2% under 100% N, 9% under 100% NP, 15% under 100% NPK and 20% under 150% NPK compared to control. The C_{min} was recorded maximum under 100% NPK+FYM, which was 34% higher than the untreated control.

Table 4.41 Effect of long-term application of inorganic fertilizer and farmyard manure on biological parameters at LTFE Ludhiana

Treatment	Microbial biomass C (mg kg^{-1})	Basal soil respiration (mg CO_2 C $kg^{-1} day^{-1}$)	C_{min} (mg CO_2-C kg^{-1})
Control	137	1.86	142.9
100% N	207	1.90	146.1
100% NP	241	2.14	155.7
100% NPK	290	2.86	163.8
100% NPK+FYM	386	3.10	191.9
150% NPK	307	2.90	170.8

4.5.10.3 Metabolic, mineralization and microbial quotient

The long-term application of inorganic fertilizers and organic manures had a significant effect on metabolic quotient (qCO_2), mineralization quotient (qM) and microbial quotient (qMic) under maize-wheat cropping system (**Table 4.42**). The metabolic quotient (qCO_2) is an indicator of the efficiency of soil microorganisms in processing residue or available soil C. In the surface soil, qCO_2 ($\times 10^3$ mg CO_2-C mg^{-1}MBC day^{-1}) ranged from 8.03 in 100% NPK+FYM to 13.58 in untreated control. The mineralization quotients (qM) of soil varied significantly with respect to fertilization. In the surface soil, qM ($\times 10^3$ mg CO_2-C mg^{-1} TOC) ranged from 28.35 in 100% NPK+FYM to 42.95 in untreated control. The 100% NPK, 150% NPK and 100% NPK+FYM treatments had significantly lower qM over other treatments, but the effect was statistically at par with each other.

Table 4.42 Effect on metabolic quotient (qCO_2), mineralization quotient (qM) and microbial quotient (qMic) under LTFE at Ludhiana

Treatment	Metabolic quotient (10^3 mg CO_2-C mg^{-1} MBC day^{-1})	Mineralization quotient (10^3mg CO_2-C mg^{-1} TOC)	Microbial quotient (%)
Control	13.58	42.95	4.12
100% N	9.19	35.31	5.00
100% NP	8.88	34.95	5.42
100% NPK	9.85	31.05	5.50
150% NPK	9.43	31.08	5.59
100% NPK+FYM	8.03	28.35	5.70

4.5.11 Udaipur

4.5.11.1 Microbial population

A perusal of data indicated that bacterial population (fungi, actinomycetes and azotobacter) were maximum in the plots receiving FYM 20 t ha^{-1} (**Table 4.43**). Application of balanced dose of chemical fertilizers (100% NPK) either alone or combination with FYM resulted in significant increase in microbial count as compared to control. Application of optimal and super optimal dose of NPK viz., 100 and 150% NPK increased the bacterial population (fungi, actinomycetes and azotobacter) over control. This indicated that imbalanced application of fertilizers exerted adverse effect on microbial population. However, 100% NPK, 100% NPK+Zn and 100% NPK+biofertilizer treatments were statistically at par with each other. In general, all the treatments increased microbial population significantly over control.

Table 4.43 Effect of organic and inorganic fertilization on microbial population at LTFE Udaipur.

Treatment	Bacteria (cfu x 10^6)	Fungi (cfu x 10^4)	Actinomycetes (cfu x 10^6)	Azotobacter (cfu x 10^4)
Control	7.22	5.52	5.94	120.14
100% N	7.77	7.24	6.70	133.65
100% NP	14.18	9.38	9.80	138.71
100% NPK	16.70	12.60	12.95	150.41
100% NPK + Zn	18.83	12.84	13.45	153.34
100% NPK+ S	19.03	13.45	13.57	150.31
100% NPK+ Zn + S	20.87	13.73	13.78	154.43
100% NPK+ Biofertilizer	23.33	12.41	12.94	268.51
100% NPK + FYM	30.98	16.95	17.82	216.14
100% NPK- FYM	28.94	16.43	17.63	209.54
150% NPK	19.40	14.65	14.80	163.42
FYM 20 Mg ha^{-1}	33.95	18.95	19.95	248.31
CD (0.05)	1.49	0.89	0.94	12.67

4.5.11.2 Microbial biomass

It is apparent from the data that soil microbial biomass C (SMBC), nitrogen (SMBN), phosphorus (SMBP) and sulphur (SMBS) recorded maximum value in FYM 20 Mg ha^{-1} (**Table 4.44**). The highest content of these enzymatic activities was recorded under FYM 20 Mg ha^{-1} which were significantly superior to rest of the treatments. Application of balanced dose of chemical fertilizers (100% NPK) either alone or combination with FYM resulted in significant increase these enzymatic activities as compared to control. Application of optimal and super optimal dose of NPK viz., 100 and 150% NPK increased these enzymes over control. The enzymatic activities in 100% NPK were found to be significantly higher than treatment receiving 100% NP and 100% N. It indicated that imbalanced application of fertilizers exerted adverse effect on these enzymes. Application of 100% NPK + FYM and 100% NPK-FYM showed significant increase in the content of SMBC by 36.19 and 33.95%, respectively over 100% NPK. Application of 100% NPK + FYM and 100% NPK - FYM showed significant increase in SMBN by 16.07 and 11.23%, respectively over 100% NPK. Application of optimal and super optimal dose of NPK viz., 100 and 150% NPK increased the SMBP by 37.77 and 54.92%, respectively over control. Application of balanced dose of chemical fertilizers (100% NPK) either alone or combination with FYM resulted in significantly increased SMBP as compared to the control. Application of 100% NPK + FYM and 100% NPK - FYM showed significant increase in the SMBS by 60.13 and 56.73 per cent, respectively over 100% NPK alone. However application of 100% NPK and 100% NPK + Zn with values of 7.35 and 7.38 mg kg^{-1}, respectively were statistically at par. The treatment receiving 100% NP alone was significantly increased SMBS as compared to the 100% N treated plots. In general, all the treatments increased SMBS significantly over control.

Table 4.44 Effect of organic and inorganic fertilization on pools of soil microbial biomass after harvest of maize in LTFE at Udaipur (2017-18)

Treatment	Soil microbial biomass pools (mg kg^{-1})			
	SMBC	SMBN	SMBP	SMBS
Control	150.00	23.30	3.15	4.42
100% N	193.00	25.70	3.25	5.77
100% NP	206.00	28.35	3.81	6.64
100% NPK	268.00	36.95	4.34	7.35
150% NPK	317.00	38.74	4.88	7.72
100% NPK + Zn	270.99	36.80	4.70	7.38
100% NPK+ S	269.00	36.84	4.74	7.97
100% NPK+ Zn + S	273.00	36.93	4.76	8.03
100% NPK+ Bio	271.00	38.20	4.95	7.98
100% NPK + FYM	365.00	42.89	5.30	11.77
100% NPK- FYM	359.00	41.10	5.16	11.52
FYM @ 20 Mg ha^{-1}	405.00	43.95	6.02	12.50
CD (0.05)	19.73	2.44	0.31	0.61

4.5.11.3 Enzymatic activities

Data indicates that dehydrogenase activity, alkaline phosphatase, urease and β-glucosidase activity found maximum in FYM 20 Mg ha^{-1} which was statically at par with NPK with FYM and without FYM and significantly superior to rest of the treatments (**Table 4.45**). Application of balanced dose of chemical fertilizers (100% NPK) either alone or combination with FYM resulted in significant increase in these enzymes as compared to control. Application of 100% NPK+FYM and 100% NPK-FYM showed significant increase in the dehydrogenase activity by 16.70 and 16.23 per cent, respectively over 100% NPK alone. Similar pattern was recorded with respect to alkaline phosphatase activity and urease activity. The β-glucosidase activity in 100% N, 100% NP and 100% NPK treatments was higher by 9.83, 14.45 and 24.28%, respectively over control. Application of optimal and super optimal dose of NPK viz., 100% NPK and 150% NPK increased the β-glucosidase activity significantly over control. Imbalanced application of fertilizers exerted adverse effect on enzymatic activities.

Table 4.45 Effect of organic and inorganic fertilization on enzymatic activities under wheat- maize cropping sequence at Udaipur

Treatment	Dehydrogenase (mg TPF 24 $h^{-1} g^{-1}$ soil)	Alkaline phosphatase (µg PNP $g^{-1} h^{-1}$)	Urease (µg NH_3 g^{-1} h^{-1})	β-glucosidase activity (µg PNP g^{-1} h^{-1})
Control	30.55	135.40	4.80	173
100% N	34.37	153.47	5.30	190
100% NP	37.22	170.60	7.60	198
100% NPK	39.38	192.24	8.90	215
150% NPK	44.22	193.48	9.15	219
100% NPK + Zn	39.60	198.35	9.60	217
100% NPK+ S	39.62	203.17	8.95	213
100% NPK+ Zn + S	39.65	206.25	9.80	218
100% NPK+ Biofertilizer	39.78	195.40	8.74	214
100% NPK + FYM	45.96	220.19	14.80	292
100% NPK- FYM	45.77	218.40	14.20	273
FYM @ 20 Mg ha^{-1}	46.98	214.44	11.45	249
CD (0.05)	2.80	13.12	0.70	15.99

4.5.12 ICAR-IISS, Bhopal

An inter institute collaborative project was initiated with the main focus to analyse soil biological properties and microbial community structure. The effect of long-term use of farmyard manure (FYM) and inorganic fertilizers in LTFE, Barrackpore, Inceptisols (rice–wheat-jute rotation), Parbhani, Vertisols (soybean-safflower) and Palampur, Alfisols (maize-wheat) comprising of fallow, control, 100% N, 100% NP, 100% NPK, 100% NPK + FYM have been investigated.

4.5.12.1 Microbial biomass C, N and DHA

Overall soil microbial activity has been represented by Microbial biomass carbon (MBC), Nitrogen (MBN) and dehydrogenase activity (DHA) 100% NPK+FYM has the highest MBC & MBN activity; however it was statistically similar with 100% NPK (**Figure 4.12**). Likewise, in case of dehydrogenase activity highest activity is noticed in 100% NPK+FYM and is significantly higher than 100% NPK.

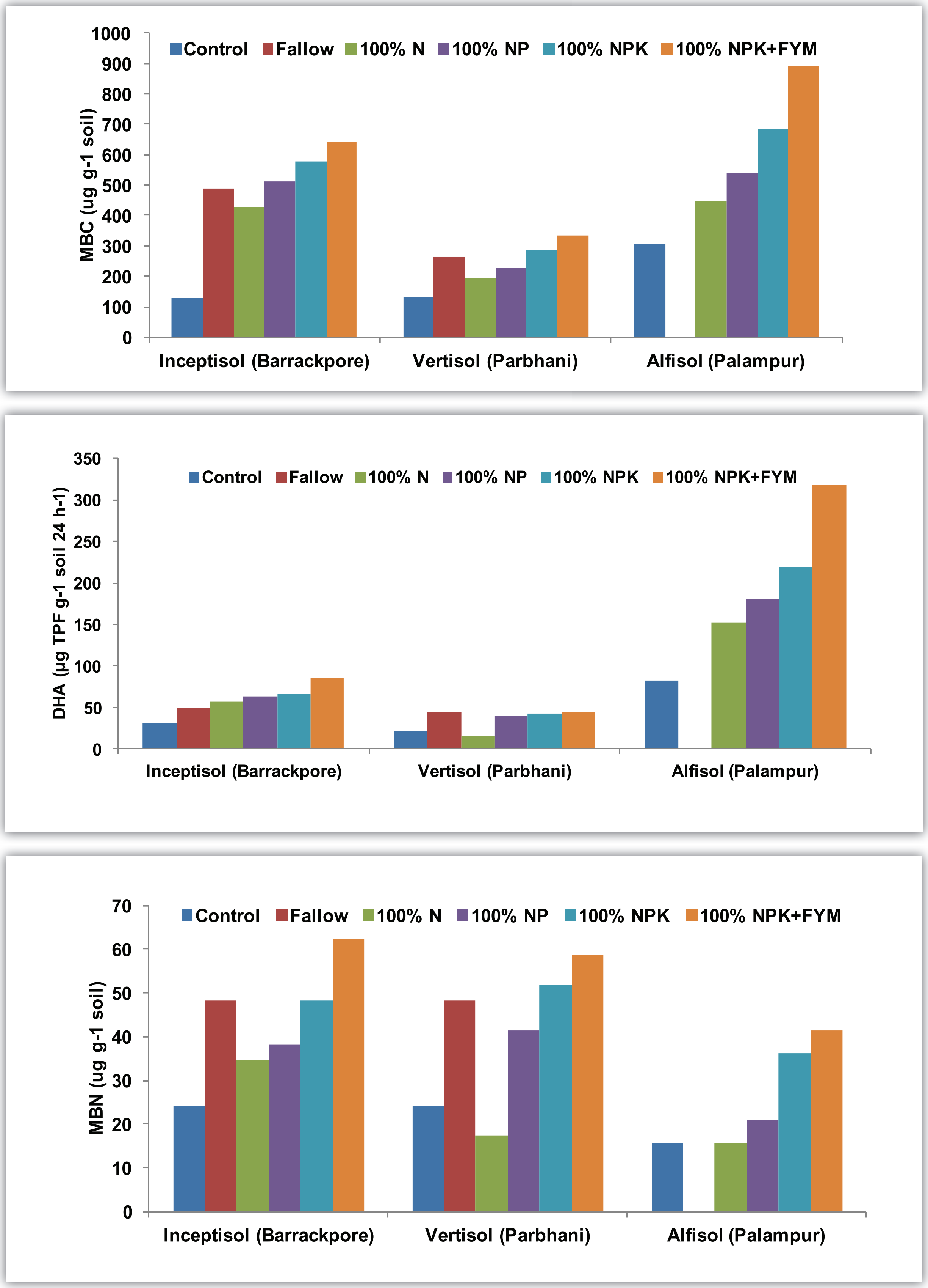


Figure 4.12 Microbial biomass C, N and DHA at different LTFEs

The effect of long-term use of farmyard manure (FYM) and inorganic fertilizers in Inceptisols (rice–wheat-jute rotation) and Vertisols (soybean-safflower) has been investigated for potential nitrogen mineralization (NMP) and ammonification potential (**Figure 4.13**). The NMP which dictates the N supply capacity of soil found to be significantly higher in integrated nutrient management (100% NPK+FYM) in all the three soil orders namely, Inceptisols, Vertisols and Alfisols. Significantly higher arginine ammonification is noticed in 100% NPK + FYM in Vertisols and Alfisols, however, no difference was found in Inceptisols.

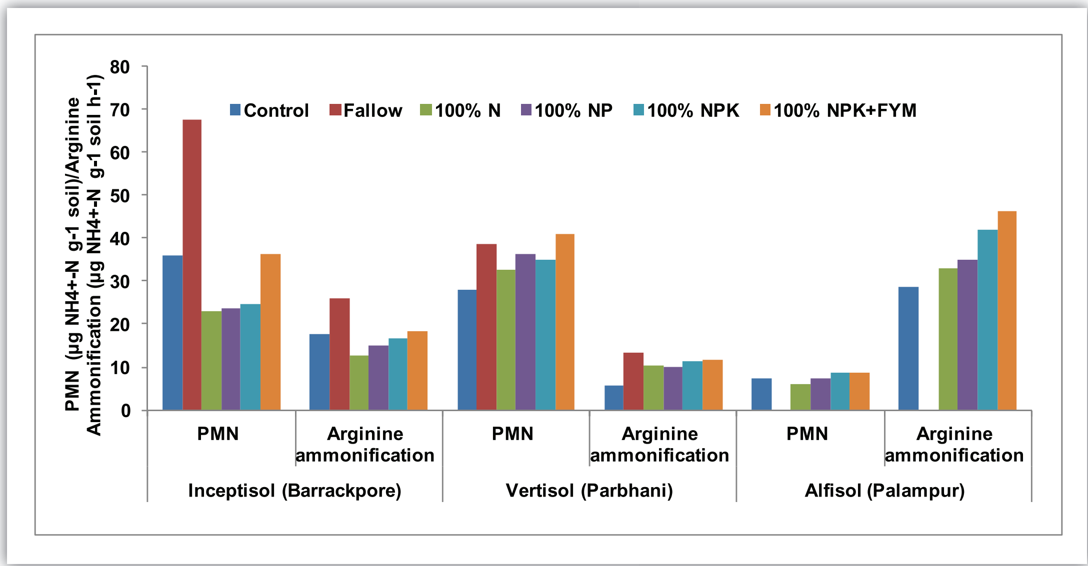


Figure 4.13 Potential mineralizable nitrogen (PMN) and arginine ammonification potential in different LTFEs

4.5.12.2 Nitrification activities

Nitrification potential of LTFE Palampur (Alfisols) has been studied extensively along with autotrophic and heterotrophic nitrification potential (**Figure 4.14)**. As well perceived the major contributor of soil nitrification was autotrophic nitrification enzyme activity (ANA), however heterotrophic nitrification enzyme activity (HNA) had significant contribution. The ANA contributed 53.0-74.6% of total nitrification enzyme activity (NA) in different treatments whereas; HNA contributed 24.6 – 46.4% of total NA. The INM treatment (100% NPK+FYM) significantly increased NIA and HNIA as compared to control and 100% N treatment. Marginal increase of ANA was noticed in INM and balanced fertilization as compared to control and imbalanced fertilization. The ANA ranged from 0.55-1.19 µg g^{-1} soil day^{-1} whereas the HNA ranged from 0.29-1.00 µg g^{-1} soil day^{-1}. The highest HNIA was found in 100% NPK+FYM which was statistically similar with 100% NPK and had 48 -71 % more (*$p<0.05$*) HNA than imbalanced fertilization and control.

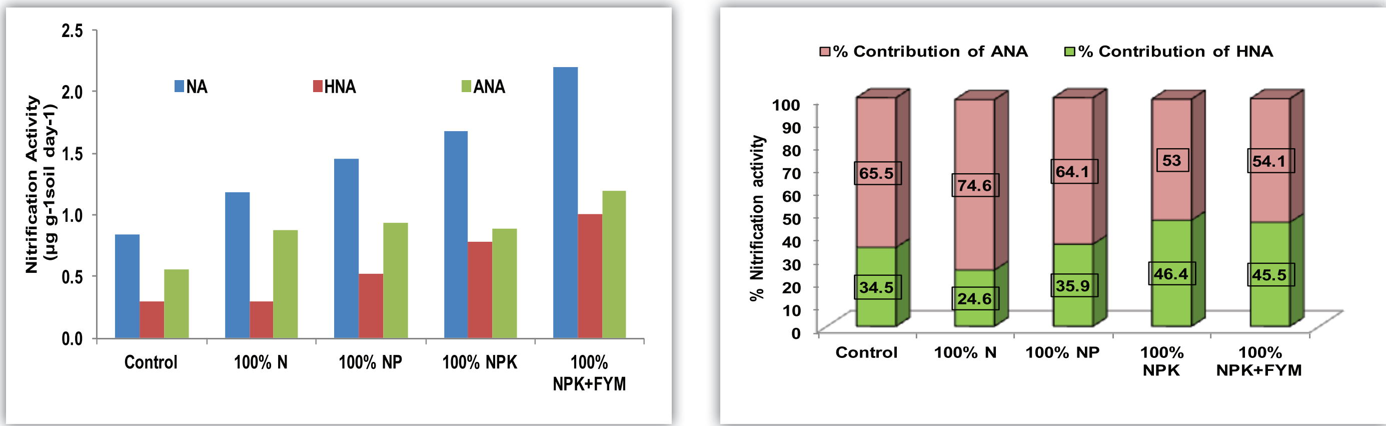


Figure 4.14 Nitrification enzyme activity (heterotrophic and autotrophic) in LTFE at Palampur

4.5.12.3 Nitrogen cycling enzymes

Studies on the N cycling enzymes involved in the transformation of organic N to mineral form were significantly affected by fertilizer and manure application in LTFE Palampur (Alfisol) (**Table 4.46**). The INM had the highest and significantly higher enzyme activity than imbalanced fertilization and control treatments. Nevertheless, INM was statistically comparable with balanced fertilization treatment in different N cycling enzyme activities. A similar trend was noticed in the case of the Geometric mean of enzymes (GMean), where INM had significantly higher value than control (40.6%), imbalanced (29.7–43.5%) and balanced fertilization (12.4%). The balanced fertilization (100% NPK) also recorded significantly higher value of GMean than control and imbalanced fertilization.

Table 4.46 Effect of fertilizer and manure application on N cycling enzymes

Treatment	AA (µg NH_4^+-N g^{-1} soil 2 h^{-1})	UA (µg NH_4^+-N g^{-1} soil 2 h^{-1})	PA (µg Tyr g^{-1} soil 2 h^{-1})	NAG (µg pNNAG g^{-1} soil h^{-1})	GMean
Control	144.20	30.80	20.62	11.01	22.36
100% N	162.80	22.40	21.66	10.57	21.28
100% NP	191.80	25.20	26.81	15.39	26.50
100% NPK	205.80	36.40	28.88	22.09	33.01
100% NPK+FYM	257.60	42.00	32.23	23.20	37.67

AA- Amidase activity; UA- Urease activity; PA- Protease activity; NAG- N-Acetyl β Glucosaminidase activity; GMean- Geometric mean of enzymes

4.5.12.4 Phospho lipid fatty acid

Phospho lipid fatty acid (PLFA) content had distinct variation amongst INM (100% NPK+FYM), balanced and imbalanced fertilizer application in LTFE Palampur (Alfisols) (**Figure 4.15**). Out of different biomarker PLFA corresponding to different groups of microbial community, only total PLFA, total bacteria, actinomycetes, (AMF) and eukaryotes had significant variation due to fertilizer and manure application; rest of the groups i.e Gram+ve, Gram-ve, saprophytic fungi and anaerobes did not have any significant variation amongst the treatments. Results revealed that imbalanced fertilizer application had significantly ($p<0.05$) reduced the abundance of total PLFA (38.6-54.3%) and eukaryotes (42.3-59.8%) as compared to control. Balanced fertilizer application and INM (100% NPK + FYM) had significantly greater abundance of total PLFA, total bacteria, AMF, actinomycetes and eukaryotes than control and imbalanced fertilizer application.

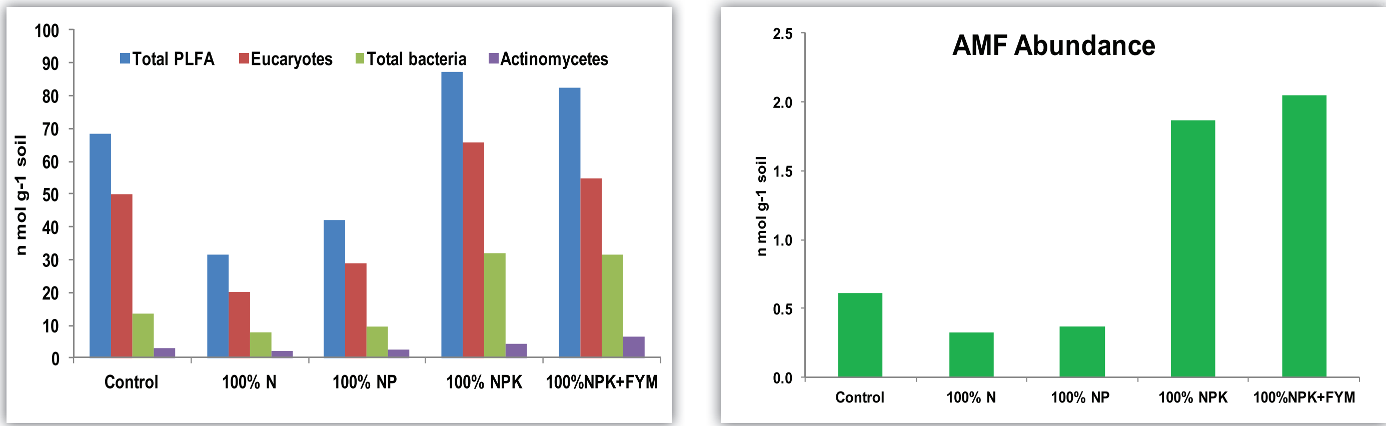


Figure 4.15 Phospho lipid fatty acid (PLFA) & AMF in LTFE at Palampur

4.5.12.5 Discriminant Function Analysis

Stepwise discriminant function analysis with PLFA biomarkers found in Alfisols of LTFE Palampur soil had produced important canonical discriminant functions which contributed 99.3% of total variations amongst treatments (**Figure 4.16**). The model consisting of a canonical discriminant function involving two variables (AMF and eukaryote) could have differentiated the control, imbalanced and balanced fertilizer application, and INM treatments. Among the microbial community, AMF and eukaryote appeared as the most crucial group to distinguish significantly the imbalanced fertilizer application from balanced fertilizer application in LTFE Palampur (Alfisols).

$$\mathbf{DF1 = -18.84 + 9.19AMF + 0.21Eukaryote}$$

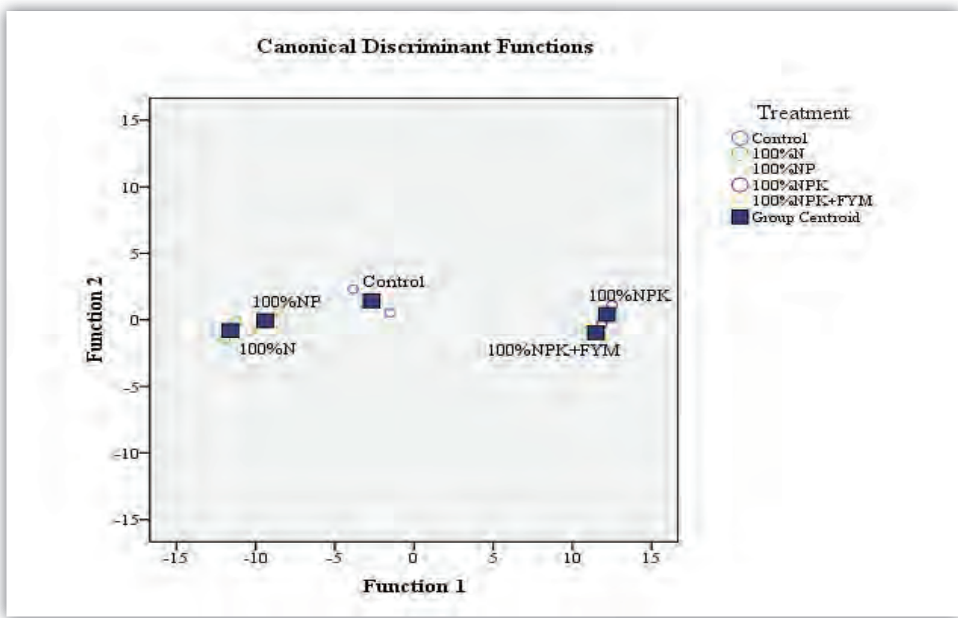


Figure 4.16 Bi-plot of canonical discriminant functions for separation of different treatments

4.5.12.6 Multiple regression and path analysis

A stepwise linear multiple regression analysis with NMP as a dependent variable has been done to find out the interrelationship among soil properties of LTFE Palampur (Alfisols) (**Figure 4.17**). Regression model (R^2=0.97, Adjusted R^2=0.96) predicts that TOC and protease enzyme activity are the key predictors of N mineralization dynamics in sub-humid to humid, Alfisols. Similarly, another multiple regression analysis (R^2=0.99, Adjusted R^2=0.99) followed path analysis with respect to GMea revealed that NH_4^+-N, MBN, Total PLFA, and TOC are the major controlling factors of the soil quality indicator reflecting N cycling enzyme dynamics. Thus, geometric mean of nitrogen cycling enzymes appeared as good soil quality indicator for discriminating the sustainable ecosystem from stressed one in LTFE Palampur (Alfisols). Similarly, TOC and protease activity are found to be the best predictor of nitrogen mineralization potential in LTFE Palampur (Alfisols). In figure 4.17, values on the arrows indicate the unit-less path coefficients (standardized regression weights); d1, d2, d3 and d4 indicate the associated error term.

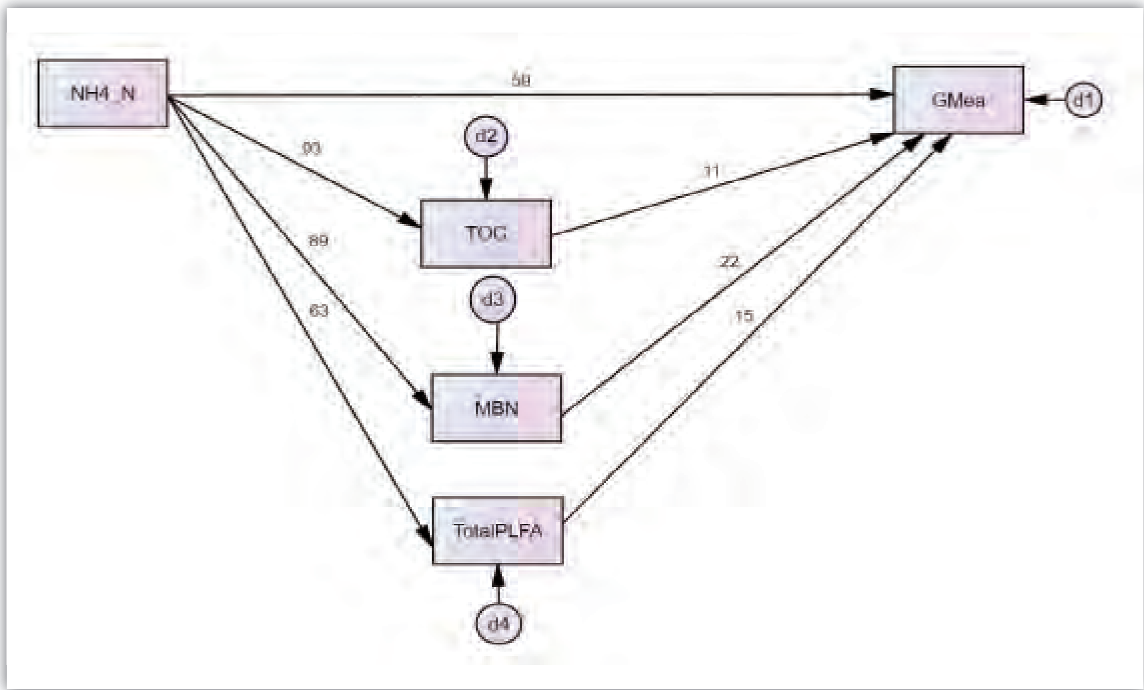


Figure 4.17 Path diagram of the causal relationship among GMea, NH_4^+-N, TOC, MBN and Total PLFA biomass

5. NUTRIENT UPTAKE

NUTRIENTS ARE TAKEN UP by roots via active or passive transport across membranes, and travel from the bulk soil to the roots via diffusion or mass flow. However, in order to access all the available nutrients, plants have evolved dynamic and plastic root systems that explore the soil for maximum nutrient uptake. Nutrient uptake deals with the mechanism by which plants capture all the elements that are essential for their growth and development. In this chapter, the impact of long term nutrient management on major crops and cropping systems has been elaborated here under.

5.1 Akola

5.1.1 Sorghum

Data pertaining to nutrient uptake by sorghum indicated that it increased with an increase in amount of nutrient applied (**Table 5.1**). However, the magnitude of nutrient uptake depends on total biomass produced by a crop. Maximum uptake of N, P and K by sorghum was recorded with an application of 100% NPK + FYM @ 10 Mg ha^{-1} followed by 150% NPK. It removed more amount of nutrients than wheat (**Figure 5.1**). Inclusion of S and Zn enhanced the uptake of sulphur, whereas, its exclusion decreased the uptake. Application of only FYM @ 10 Mg ha^{-1} recorded significantly lowest uptake of N, P and K which may be associated with lower crop yield as compared to balanced 100% NPK and 100% NPK + FYM @ 10 Mg ha^{-1}.

The application of 100% NPK and FYM on long term basis in sorghum had significantly influenced uptake of micronutrients such as Zn, Fe, Cu and Mn similar to macronutrients (**Table 5.1**). Maximum uptake of these micronutrients were recorded with 100% NPK + FYM @ 10 Mg ha^{-1}, however, doses of NPK fertilizers from 50 to 150% significantly increased the uptake of micronutrients.

Table 5.1 Nutrient uptake as influenced by long term nutrient management in sorghum in LTFE at Akola (2018-19)

Treatment	Nutrient uptake (kg ha^{-1})			Micronutrient uptake (g ha^{-1})			
	N	P	K	Zn	Fe	Cu	Mn
Control	9	2.15	10	92	301	19	92
100% N	51	11.3	54	291	932	63	294
100% NP	84	20.4	90	494	1566	110	487
50% NPK	68	16.9	79	390	1220	85	378
100% NPK	104	25.5	125	583	1804	146	567
150% NPK	128	38.5	156	775	2339	204	757
100% NPK (S free)	97	23.6	114	559	1720	136	542
100% NPK + Zn @ 2.5 kg ha^{-1}	116	30.5	138	642	1966	161	626
100% NPK + 37.5 kg S ha^{-1}	116	31.7	140	636	1968	165	630
FYM only @10 Mg ha^{-1}	70	19.0	83	374	1152	78	357
75% NPK + 25% N through FYM	112	28.0	132	548	1670	131	535
100% NPK + FYM @ 10 Mg ha^{-1}	144	47.4	175	823	2344	227	805
CD (0.05)	12.4	4.15	14.9	110	329	27	110

5.1.2 Wheat

Data on uptake of N, P and K by wheat as influenced by long-term fertilizer and manure application indicated that 100% NPK + FYM @ 10 Mg ha^{-1} recorded the maximum uptake followed by 150% NPK. Imbalanced application of fertilizer (N or NP) recorded significantly lowest uptake of nutrient as compared to balanced and integrated nutrient supply. The uptake of micronutrients such as Zn, Fe, Cu and Mn) was increased significantly with INM (100% NPK + FYM @ 10 Mg ha^{-1}) followed by 150% NPK (**Table 5.2 & Figure 5.1**). The application of Zn @ 2.5 kg ha^{-1} along with 100% NPK resulted in higher uptake of Zn; whereas, continuous cropping without Zn application caused significant decrease in uptake of Zn. The uptake of micronutrients viz; Fe, Cu and Mn followed similar trend to that of Zn uptake.

Table 5.2 Nutrient uptake as influenced by long term nutrient management in wheat in LTFE at Akola (2018-19)

Treatment	Nutrient uptake (kg ha^{-1})			Micronutrient uptake (g ha^{-1})			
	N	P	K	Zn	Fe	Cu	Mn
Control	6.8	1.7	6.6	26	115	14	352
100% N	16.3	3.6	14.0	37	162	20	375
100% NP	55.8	13.9	48.7	110	468	56	437
50% NPK	46.2	10.5	42.4	89	397	48	424
100% NPK	71.2	17.9	67.7	128	540	69	470
150% NPK	93.3	25.9	89.0	166	689	95	514
100% NPK (S free)	65.6	16.8	58.8	124	511	64	462
100% NPK + Zn @ 2.5 kg ha^{-1}	75.3	21.8	74.0	140	589	78	482
100% NPK + 37.5 kg S ha^{-1}	80.4	24.1	78.0	149	616	84	493
FYM only @10 Mg ha^{-1}	34.7	9.0	32.5	56	245	29	396
75% NPK + 25% N through FYM	77.4	20.1	75.7	151	650	80	481
100% NPK + FYM @ 10 Mg ha^{-1}	101.0	30.3	103.5	181	735	105	536
CD (0.05)	9.2	2.2	8.4	21.8	99.3	12.9	17.8

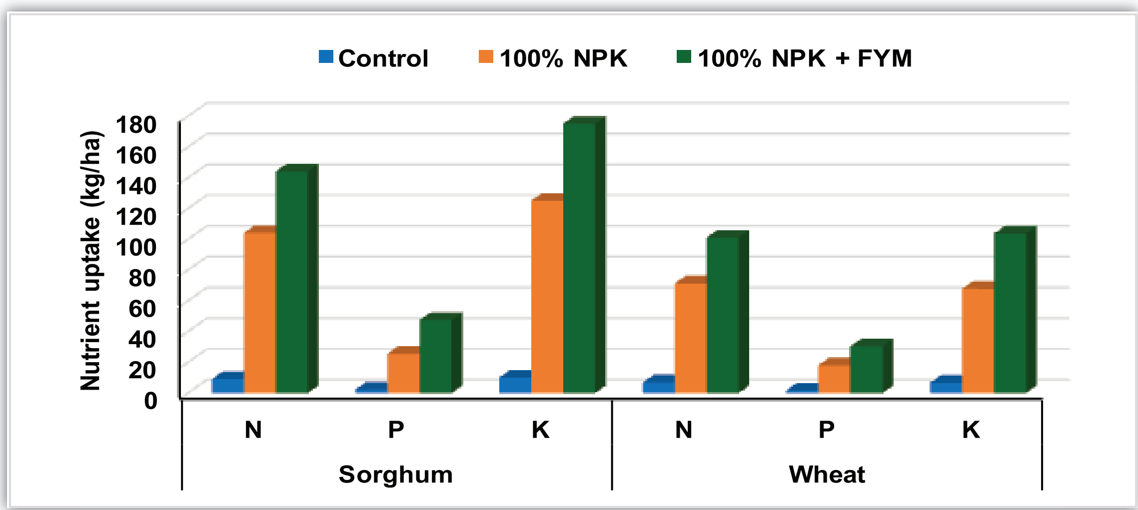


Figure 5.1 Nutrient uptake pattern in sorghum and wheat in LTFE at Akola

5.2 Bangalore

5.2.1 Finger millet

The long-term nutrient options influenced the nutrient uptake pattern in finger millet (**Table 5.3 and 5.4**). The uptake of N, P and K was maximum with 150% NPK and lowest under control. Similar to major nutrients, secondary nutrients viz. S, Ca, and Mg uptake was highest in 150% NPK application. Reduction in S uptake was noticed in 100% NPK (S-free) where DAP was applied as P source compared to SSP. Micronutrient uptake of Zn, Fe, Cu and Mn was highest in 150% NPK treatment followed by 100% NPK+ FYM + Lime application (**Table 5.4**). The imbalanced nutrient application has drastically reduced the removal of minerals such as Ca and Mg in finger millet (**Figure 5.2**).

Table 5.3 Effect of long term application of fertilizers on primary and secondary nutrient uptake by finger millet in LTFE at Bangalore (2018-19)

Treatment	Nutrient uptake (kg ha^{-1})					
	N	P	K	S	Ca	Mg
Control	13.3	2.9	13.0	1.1	5.1	4.7
100% N	14.0	1.9	9.8	0.8	4.9	4.3
100% NP	15.9	3.6	13.6	1.4	6.1	5.1
50% NPK	46.4	9.0	32.5	3.4	15.7	11.7
100% NPK	78.8	15.8	100.0	6.8	29.6	25.1
150% NPK	126.8	28.8	164.2	12.4	42.4	35.0
100% NPK (S-free)	77.7	19.2	85.7	6.0	25.9	23.6
100% NPK+HW	84.8	18.8	105.9	7.8	32.2	28.1
100% NPK+lime	76.6	16.7	90.6	7.8	36.4	26.5
100% NPK+FYM	106.0	26.7	115.5	9.6	38.8	32.5
100% NPK+FYM+lime	120.0	26.4	111.8	11.1	35.9	34.8

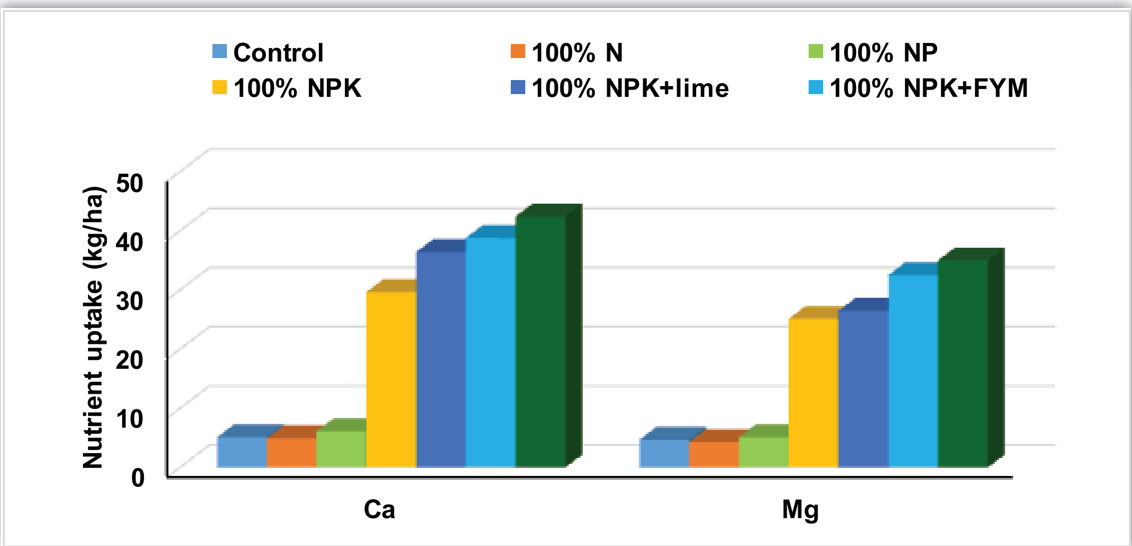


Figure 5.2 Mineral (Ca & Mg) constituent in finger millet as influenced by imbalanced and balanced nutrient use in LTFE at Bangalore

Table 5.4 Effect of long term application of fertilizers on micronutrient uptake by finger millet in LTFE at Bangalore (2018-19)

Treatment	Micronutrient uptake (g ha^{-1})			
	Zn	Fe	Cu	Mn
Control	45	158	23	137
100% N	44	140	22	228
100% NP	53	185	25	269
50% NPK	140	499	70	514
100% NPK	239	772	121	1090
150% NPK	394	1141	192	1551
100% NPK (S-free)	222	815	114	1033
100% NPK+HW	251	767	138	963
100% NPK+ Lime	222	691	120	643
100% NPK+FYM	278	874	155	1113
100% NPK+FYM+lime	269	893	151	858

5.2.2 Maize

The highest uptake of N, P and K was recorded with an application of 100% NPK + FYM + lime followed by 100% NPK+FYM (**Table 5.5**). The lowest uptake of N, P and K was observed in 100% N treatment. The uptake of secondary and micronutrient followed the similar trend to that of primary nutrients (**Table 5.6**). Further, micronutrient uptake of Zn, Fe, Cu and Mn was enhanced due to application of FYM, lime and higher dose of fertilizer (150% NPK) (**Figure 5.3**) and significantly reduced at sub-optimal and imbalanced dose of fertilizer application.

Table 5.5 Effect of long term application of fertilizers on primary and secondary nutrient uptake by maize in LTFE at Bangalore (2018-19)

Treatment	Nutrient uptake (kg ha^{-1})					
	N	P	K	S	Ca	Mg
Control	28.5	4.9	28.5	4.7	17.3	9.9
100% N	7.9	1.4	7.8	1.4	6.1	3.3
100% NP	33.0	6.6	32.5	6.1	24.8	12.8
50% NPK	66.6	12.7	60.5	10.5	41.8	21.5
100% NPK	85.1	16.5	77.9	13.8	51.3	27.8
150% NPK	104.6	20.6	107.4	16.5	69.9	35.2
100% NPK+HW	92.5	18.1	97.8	14.7	55.8	28.8
100% NPK+lime	92.2	17.6	87.0	14.4	64.6	28.4
100% NPK+FYM	104.1	22.9	114.5	16.3	71.4	43.0
100% NPK (S-free)	84.9	16.6	78.5	11.8	47.8	30.8
100% NPK+FYM+lime	120.6	24.6	132.9	19.3	76.7	44.2

Table 5.6 Effect of long term application of fertilizers on micronutrient uptake by maize in LTFE at Bangalore (2018-19)

Treatment	Micronutrient uptake (g ha^{-1})			
	Zn	Fe	Cu	Mn
Control	71	109	22	131
100% N	34	39	14	56
100% NP	96	131	53	201
50% NPK	163	268	67	286
100% NPK	205	350	76	379
150% NPK	258	469	161	561
100% NPK+HW	214	412	112	479
100% NPK+lime	265	425	100	420
100% NPK+FYM	274	475	115	480
100% NPK (S-free)	223	319	88	383
100% NPK+FYM+lime	312	551	119	527

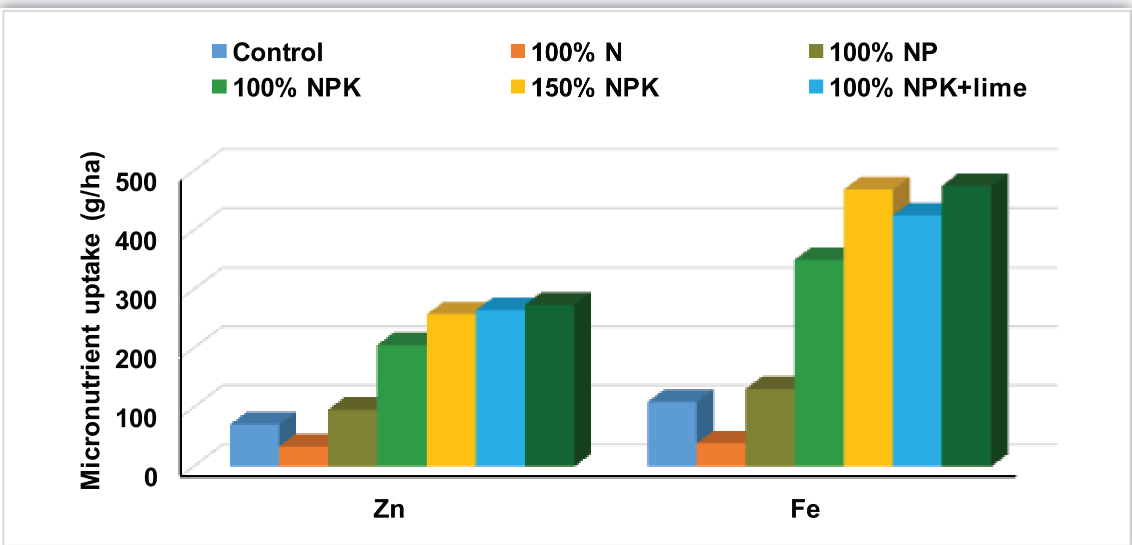


Figure 5.3 Zinc and iron removal by maize as influenced by imbalanced and balanced nutrient use in LTFE at Bangalore

5.3 Bhubaneswar

Nutrient uptake by rice crop reflects the status/availability of the nutrient in soil and interaction effect with other nutrients. Uptake in control plot shows the uptake from soils native source only. However, in other treatments, it comprises of both native and fertilizer source. The N, P and S supply from soil source in rabi season was less than that in kharif season (**Table 5.7** & **Figure 5.4**). With increase in dose, the uptake increased under balanced nutrient application and highest uptake of N, P, K and S was recorded with 100% NPK + FYM and 100% NPK + Lime + FYM followed by 150% NPK recommended dose.

Table 5.7 Effect of long term manuring on average nutrient uptake in rice and rice at Bhubaneswar (2016-2019)

Treatment	Rice (Kharif)				Rice (Rabi)			
	Nutrient uptake (kg ha^{-1})							
	N	P	K	S	N	P	K	S
Control	25.2	4.6	23.8	7.4	15.0	2.8	21.3	3.2
100% N	45.4	8.2	43.2	8.4	22.6	4.1	29.1	4.5
100% NP	64.2	11.3	53.5	11.5	36.1	6.2	41.1	7.1
100% PK	46.0	9.2	63.8	8.6	30.8	6.1	43.0	6.6
100% NPK	68.4	13.9	83.1	11.9	44.6	7.9	60.6	8.9
150% NPK	85.9	16.9	106.2	13.6	67.5	11.4	72.6	10.3
100% NPK +Zn	67.1	13.6	79.2	11.3	48.6	7.1	51.6	8.9
100% NPK + B + Zn	67.3	14.6	91.2	12.3	45.3	7.9	56.7	8.3
100% NPK + S + Zn	65.3	13.0	81.2	13.4	50.1	8.7	60.1	13.0
100% NPK + Lime	75.9	15.4	73.8	14.5	58.0	9.3	63.3	11.5
100% NPK +FYM	99.3	21.5	123.3	16.5	85.2	14.1	97.5	15.0
100% NPK+Lime+FYM	98.6	20.7	105.0	17.4	82.1	14.4	94.5	14.8
CD (0.05)	8.5	1.9	11.9	2.8	6.4	1.1	7.9	1.3

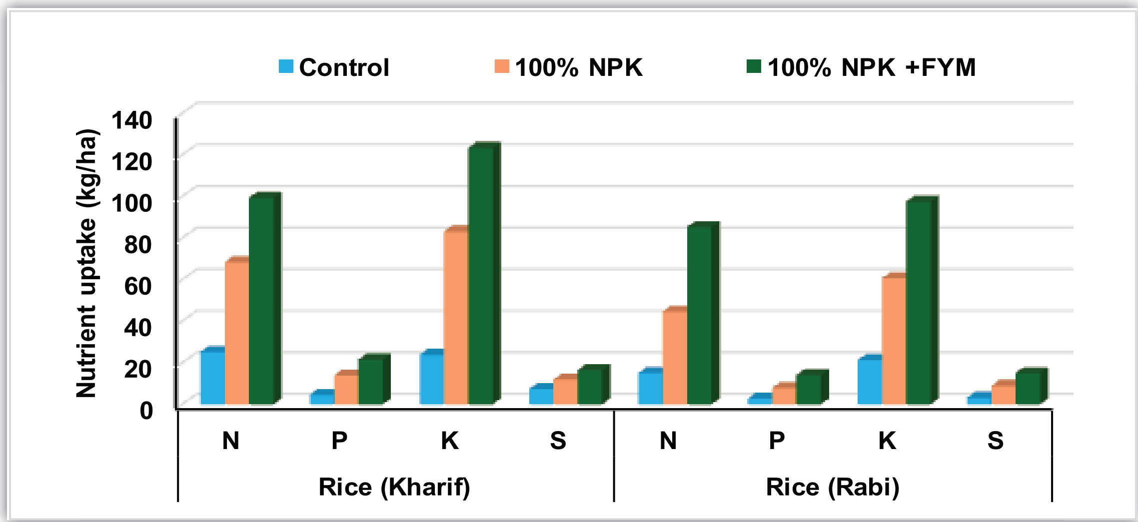


Figure 5.4 Nutrient (N, P, K and S) removal by rice during kharif and rabi season in LTFE at Bhubaneswar

5.4 Coimbatore

Application of fertilizers under INM (100% NPK+ FYM) influenced N uptake greatly in finger millet and maize over the years (**Table 5.8**). The inclusion of FYM in INM resulted in increased N uptake. Significant progressive increase in N uptake was recorded when fertilizers doses were gradually increased from 50, 100 and 150% NPK (**Figure 5.5)**. Omission of K in 100% NP and omission of PK in 100% N significantly reduced N uptake. Overall, N uptake was highest under INM (**Table 5.8**). The similar pattern of P and K uptake was noticed in maize and finger millet in LTFE at Coimbatore.

Table 5.8 Nutrient uptake by fingermillet and maize in LTFE at Coimbatore (2018-19)

Treatment	Finger millet			Maize		
	Nutrient uptake (kg ha^{-1})					
	N	P	K	N	P	K
Control	31.5	2.8	31.9	49.5	9.5	63.0
100% N	43.2	4.6	45.4	75.7	14.8	98.0
100% NP	58.2	5.6	67.3	102.1	20.2	132.0
50% NPK	50.9	5.1	54.3	86.1	16.3	104.0
100% NPK	61.8	6.4	72.8	110.4	20.6	143.0
150% NPK	74.5	8.4	83.9	127.3	25.1	165.0
100% NPK (-S)	58.9	6.1	65.2	102.7	21.1	136.0
100% NPK + HW	59.7	5.9	69.2	109.0	20.7	133.0
100% NPK + Zn	66.5	6.8	79.1	121.5	22.8	152.0
100% NPK + FYM	88.0	9.9	94.7	144.3	27.5	187.0
CD (0.05)	2.6	0.3	2.8	5.1	0.8	6.0

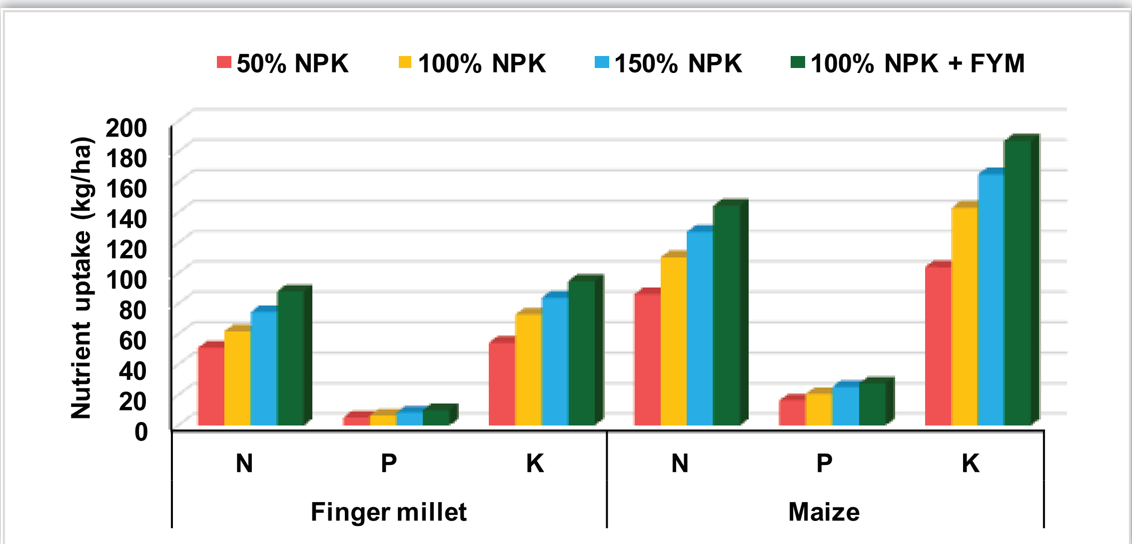


Figure 5.5 Impact of graded dose of fertilizers and INM on nutrient (N, P and K) removal by finger millet and maize in LTFE at Coimbatore

5.5 Jabalpur

The effect of fertilizer and manure addition on nutrient uptake by crops revealed that the significant difference was observed with varying fertilizer application on crop growth and yield. The increasing trend with higher uptake of N, P, K, S and Zn by soybean was obtained with successive application of fertilizer over control and the maximum uptake of nutrients was recorded with 100% NPK+FYM application (**Table 5.9**). The uptake of N, P, K and S recorded with application of 100% N alone was lowest except control and increased due to inclusion of P (100% NP) (**Figure 5.6**). Also, inclusion of K with 100% NP i.e. (100% NPK) had resulted in slight increase in the uptake of N, P, K, S and Zn nutrients. Further, the maximum uptake of nutrients was found with 100% NPK+FYM followed by 150% NPK while, minimum was in control. A similar, trend was also observed in wheat and the data indicated that highest uptake of N, P, K, S and Zn in 100% NPK +

FYM followed by 150% NPK (**Table 5.9**). Further, the uptake of Zn by wheat was found to be maximum in 100% NPK+FYM followed by 150% NPK and minimum in control (**Figure 5.7**). This indicated that P is one of the important factors governing the yield in soybean and wheat. It was also noticed that higher amount of nutrients were harvested by wheat in comparison to the nutrient removal in soybean.

Table 5.9 Nutrient uptake by soybean and wheat in LTFE at Jabalpur (2018-19)

Treatment	Soybean					Wheat				
	Nutrient uptake (kg ha^{-1})				Zn ($g\ ha^{-1}$)	Nutrient uptake (kg ha^{-1})				Zn ($g\ ha^{-1}$)
	N	P	K	S		N	P	K	S	
Control	61.9	2.3	48	2.1	41	55.5	5.0	52	4.3	74
100% N	85.5	3.9	59	3.6	61	79.7	9.2	80	8.2	113
100% NP	144.5	9.2	89	8.2	119	163.2	18.3	138	21.3	238
50% NPK	120.4	7.4	91	6.9	96	152.0	16.7	166	19.1	215
100% NPK	170.8	12.5	135	11.2	152	208.4	30.7	222	30.7	338
150% NPK	214.3	15.1	164	14.9	182	239.6	37.8	277	36.4	455
100% NPK-S	147.3	9.8	113	6.3	120	180.2	22.6	185	17.5	257
100% NPK+HW	161.5	11.1	125	9.7	148	202.5	26.5	205	27.1	328
100% NPK+Zn	163.9	11.7	130	10.2	193	210.9	28.6	217	28.9	482
100% NPK+FYM	235.7	17.2	189	17.2	226	252.4	41.2	319	42.2	504
CD (0.05)	17.0	1.5	14	1.1	17	23.0	3.5	25	3.8	46

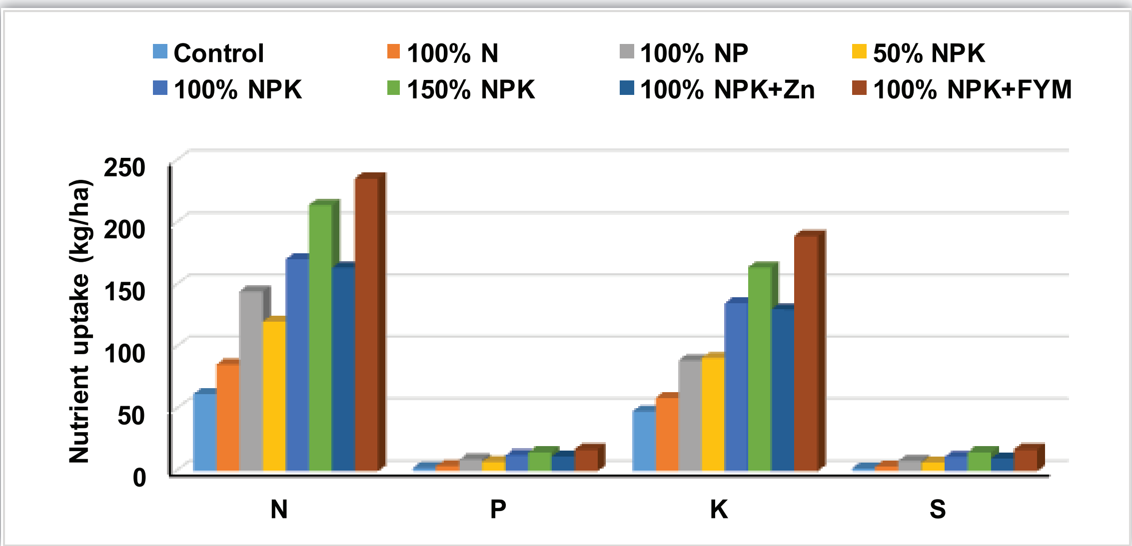


Figure 5.6 Impact of fertilizer and manure and INM on nutrient (N, P and K) removal by soybean in LTFE at Jabalpur

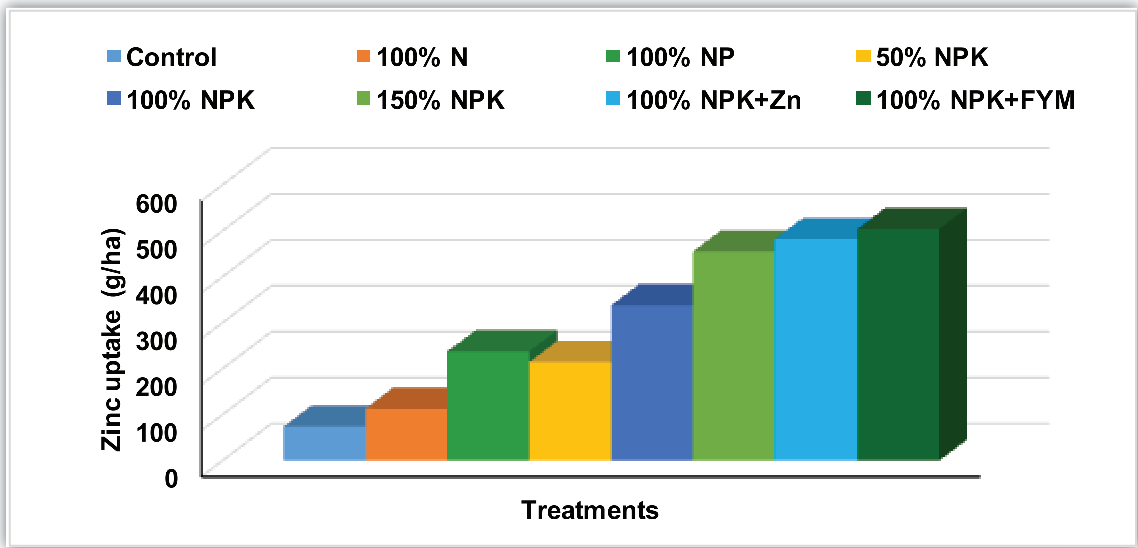


Figure 5.7 Impact of fertilizer and manure and INM on Zn uptake by wheat in LTFE at Jabalpur

5.6 Jagtial

Data on N, P and K uptake by both kharif and rabi rice crop revealed that N and K uptake during both kharif and rabi season showed highest values with an application of 150% NPK followed by INM i.e., 100% NPK+FYM (**Table 5.10**). However, the P uptake for both in kharif and rabi seasons showed highest uptake under INM (100% NPK+FYM) followed by 150% NPK. The uptake pattern of these major nutrients drastically declined under 100% N alone.

Table 5.10 Influence of long-term fertilizers and manures on nutrient uptake by rice during kharif and rabi in LTFE at Jagtial (2018-19)

Treatment	Rice (Kharif)			Rice (Rabi)		
	Nutrient uptake (kg ha^{-1}					
	N	P	K	N	P	K
Control	20.5	5.6	6.8	31.0	5.3	25.8
100% N	36.1	4.8	11.3	32.2	4.3	26.5
100% NP	54.0	15.3	18.3	100.0	20.7	57.0
50% NPK	38.8	8.8	21.5	67.9	14.4	51.3
100% NPK	60.6	15.2	27.8	103.7	22.0	86.3
150% NPK	86.0	25.7	63.2	131.4	29.4	117.2
100% NPK – S	67.3	15.2	27.1	102.6	22.8	79.9
100% NPK + HW	73.0	14.7	26.7	82.1	21.7	81.9
100% NPK + Zn	65.1	13.2	33.0	93.3	19.1	89.4
100% NPK + FYM	81.3	22.4	50.5	128.1	30.4	106.7
FYM	54.1	17.1	24.4	96.4	22.4	63.3
CD (0.05)	11.2	3.4	11.1	14.3	14.1	13.7

5.7 Junagadh

The uptake of major and micronutrients was significantly influenced by long term nutrient management in groundnut (**Table 5.11**). The significantly highest uptake of N, P, K and S by groundnut was recorded with 50% NPK+10 Mg ha^{-1} FYM. Similarly, the maximum uptake of micronutrients i.e. Zn, Fe, Cu and Mn by groundnut were recorded with 50% NPK+ FYM, however, it was at par with only FYM @ 25 Mg ha^{-1} to groundnut and 150% NPK application.

Maximum uptake of N, P, K and S by wheat was recorded with 50% NPK+ FYM and FYM @ 25 Mg ha^{-1} only (**Table 5.12**). Similar results were also observed in case of uptake of micronutrients Zn, Fe, Cu and Mn and significantly highest total uptake was recorded with 50% NPK+ FYM.

Table 5.11 Uptake of nutrients by groundnut in LTFE at Junagadh (2017)

Treatment	Nutrient uptake (kg ha^{-1})				Micronutrient uptake (g ha^{-1})			
	N	P	K	S	Zn	Fe	Cu	Mn
Control	36.9	4.4	12.0	3.5	189	1221	108	164
100% N	34.4	4.2	10.6	3.4	160	1143	106	156
100% NP	43.0	6.0	12.5	4.5	217	1524	145	221
50% NPK	44.6	5.7	14.3	4.5	217	1638	140	223
100% NPK	55.3	7.3	17.6	5.2	270	2008	201	343
150% NPK	71.3	8.8	20.7	6.1	332	2167	287	490
100% NPK+ Zn	56.6	7.6	18.5	6.0	382	2098	236	412
100% NPK (as per soil test)	55.0	7.1	16.7	5.3	302	1888	233	416
100% NPK (P as SSP)	55.6	7.5	17.8	6.4	298	1888	242	427
50% NPK+ FYM*	74.0	9.7	26.5	7.0	428	2773	333	540
Only FYM @ 25 Mg ha^{-1}	64.8	9.0	24.7	6.2	410	2516	320	531
50% NPK +Rhizobium +PSM**	51.0	6.5	15.9	5.1	258	1815	170	303
CD (0.05)	7.9	0.9	2.0	0.8	48	372	42	59

**50% NPK+10 Mg ha^{-1} FYM to groundnut and 100% NPK to wheat; **Phosphate solubilizing bacteria*

Table 5.12 Uptake of nutrients by wheat in LTFE at Junagadh (2017-18)

Treatment	Nutrient uptake (kg ha^{-1})				Micronutrient uptake (g ha^{-1})			
	N	P	K	S	Zn	Fe	Cu	Mn
Control	34.2	5.0	21.0	5.9	213	848	255	338
100% N	39.7	5.2	18.2	6.3	244	816	210	347
100% NP	48.4	7.0	28.0	8.9	299	1090	396	536
50% NPK	54.1	8.0	31.4	8.5	297	1117	329	494
100% NPK	77.7	10.7	49.1	11.8	442	1465	519	742
150% NPK	96.1	12.8	56.6	13.4	552	1489	655	842
100% NPK+ Zn	80.5	10.3	46.1	11.9	606	1368	563	732
100% NPK (as per soil test)	69.3	9.6	44.8	10.7	407	1203	559	701

100% NPK (P as SSP)	68.0	9.9	43.8	12.5	391	1220	611	724
50% NPK+FYM	112.0	16.7	67.6	15.7	698	2028	845	1087
Only FYM @ 25 Mg ha^{-1}	96.8	15.8	65.1	13.6	679	2000	786	951
50% NPK+Rhizobium+PSM	69.5	10.0	40.1	10.7	425	1316	483	644
CD (0.05)	11.4	1.8	8.6	1.5	64	241	79	121

5.8 Palampur

Nutrient uptake (macro, secondary and micro nutrients) by maize and wheat followed similar trend to that of yields (**Table 5.13, 5.14, 5.15** & **5.16**). Nutrient uptake was influenced significantly by the long-term application of fertilizers alone or in combination with FYM and lime amendment. Maximum uptake of nutrients was recorded with 100% NPK along with FYM followed by 100% NPK + lime. Nutrients uptake was significantly lower in treatments wherein potassium and sulphur was not in fertilizer schedule. The 100% N alone resulted in no uptake of nutrients as there was no yield during that year in both the crops (**Figure 5.8 & 5.9**). However, the plots in which no fertilizer and manure (control) were supplied little bit nutrient uptake was obtained. Thus, application of N alone adversely affected the crop yield as well as uptake resulting to no nutrient uptake and found detrimental for both maize and wheat in these soils of Palampur. Therefore, imbalance nutrient application such as control, 100% N, 100% NP are not advisable in Alfisols group of soils.

Table 5.13 Long-term effect of fertilizers and amendments on nutrient uptake by maize in LTFE at Palampur (2017-18)

Treatment	Nutrient uptake (kg ha^{-1})					
	N	P	K	S	Ca	Mg
Control	12.8	2.0	6.5	1.6	3.6	1.0
100% N	0.0	0.0	0.0	0.0	0.0	0.0
100% NP	34.0	5.4	16.7	7.1	11.5	2.7
50% NPK	72.7	12.9	43.9	12.8	25.7	6.4
100% NPK	80.6	14.9	49.9	17.4	29.6	7.5
150% NPK	73.5	14.9	43.8	15.5	27.8	7.5
100% NPK (-S)	31.3	6.1	18.5	3.8	10.3	2.7
100% NPK +HW	96.6	18.1	57.5	20.7	36.3	8.9
100% NPK + Zn	74.9	12.5	44.4	15.3	27.5	6.2
100% NPK + Lime	114.9	23.0	68.1	26.4	47.9	12.0
100% NPK + FYM	136.2	28.7	84.0	32.9	52.8	13.5
CD (0.05)	8.3	1.7	5.9	2.5	3.5	0.9

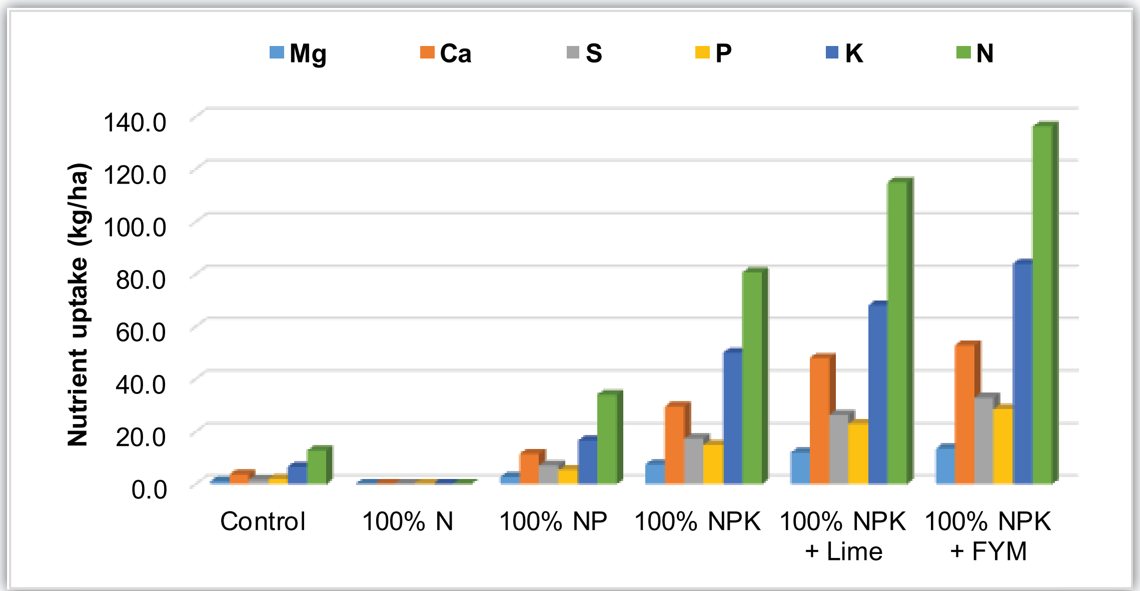


Figure 5.8 Impact of fertilizer and manure and INM on nutrient removal by maize in LTFE at Palampur

Table 5.14 Long-term effect of fertilizers and amendments on micronutrient uptake by maize in LTFE at Palampur (2017-18)

Treatment	Micronutrient uptake (g ha^{-1})			
	Zn	Fe	Cu	Mn
Control	36	122	36	58
100% N	0	0	0	0
100% NP	111	390	104	200
50% NPK	268	900	235	469
100% NPK	300	980	266	506
150% NPK	271	922	255	441
100% NPK (-S)	113	362	93	191
100% NPK +HW	367	1187	359	613
100% NPK + Zn	459	862	225	451
100% NPK + Lime	447	1364	416	725
100% NPK + FYM	549	1780	540	895
CD (0.05)	50.1	120.6	34.4	56.9

Table 5.15 Long-term effect of fertilizers and amendments on macro-nutrient uptake by wheat in LTFE at Palampur (2017-18)

Treatment	Nutrient uptake (kg ha^{-1})					
	N	P	K	S	Ca	Mg
Control	8.4	1.4	5.0	0.9	2.9	0.5
100% N	0.0	0.0	0.0	0.0	0.0	0.0
100% NP	20.5	3.8	10.0	2.6	6.8	1.5
50% NPK	40.8	8.3	26.4	5.6	14.6	3.0

100% NPK	44.0	9.3	28.9	6.6	15.0	3.2
150% NPK	37.4	9.5	24.7	5.8	11.3	2.9
100% NPK (-S)	19.7	4.2	13.1	1.9	7.5	1.4
100% NPK +HW	50.0	10.6	34.3	7.0	17.6	3.5
100% NPK + Zn	42.3	7.9	26.3	6.0	13.5	2.9
100% NPK + Lime	60.7	13.1	40.2	8.7	27.5	4.5
100% NPK + FYM	70.5	16.2	46.9	11.6	28.6	5.6
CD (0.05)	3.5	0.9	2.5	0.6	1.5	0.3

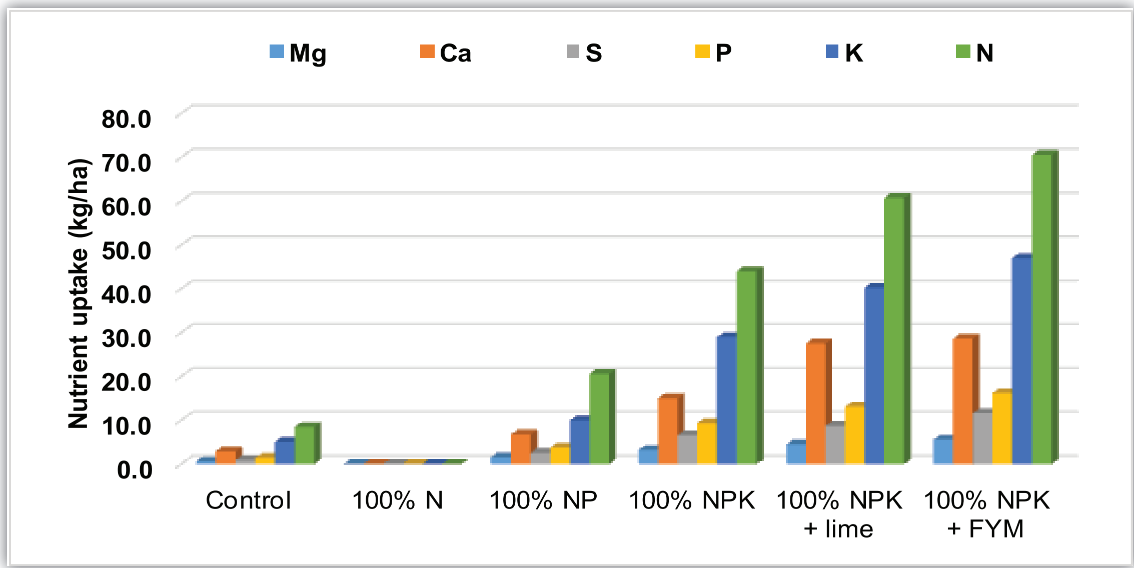


Figure 5.9 Impact of fertilizer and manure and INM on nutrient removal by wheat in LTFE at Palampur

Table 5.16 Long-term effect of fertilizers and amendments on micronutrient uptake by wheat in LTFE at Palampur (2017-18)

Treatment	Micronutrient uptake (g ha^{-1})			
	Zn	Fe	Cu	Mn
Control	29	82	37	48
100% N	0	0	0	0
100% NP	72	245	92	149
50% NPK	152	448	168	265
100% NPK	185	513	197	288
150% NPK	159	442	168	255
100% NPK (-S)	79	237	97	144
100% NPK +HW	218	551	227	354
100% NPK + Zn	278	473	180	282
100% NPK + Lime	263	656	295	434
100% NPK + FYM	300	798	329	461
CD (0.05)	16.9	42.5	17.0	24.4

5.9 Pantnagar

Nutrient uptake by rice and wheat crop were significantly influenced under different treatments (**Table 5.17**). Addition of FYM along with optimal NPK (100% NPK +FYM) removed maximum N from soil followed by 150% NPK. As compared to control, addition of N (100% N) significantly removed more P. The uptake of P was significantly increased by inclusion of P along with N (100% NP). Moreover, the conjoint use of optimal NPK and farmyard manure (100% NPK+FYM) removed the highest amount of P. The N and P removal was lowest under control which was at par with bio-fertilizer application alone treatment. Similarly, the K removal by rice and wheat was highest under 100% NPK+FYM and lowest under control. Addition of K along with N and P had significant influence on withdrawal of nutrients by crops (**Figure 5.10**).

Table 5.17 Nutrient uptake by rice and wheat in LTFE at Pantnagar (2018-19)

Treatment	Rice			Wheat		
	Nutrient uptake (kg ha^{-1})					
	N	P	K	N	P	K
Control	20.5	5.0	27.8	19.3	3.5	15.8
100% N +Zn	61.8	13.3	56.5	60.5	12.3	39.8
100% NP +Zn	77.8	21.5	68.0	69.5	15.8	44.5
50% NPK	58.5	16.5	66.0	55.0	11.5	41.5
100% NPK	76.3	18.7	79.3	68.7	15.7	54.0
150% NPK	84.3	24.0	91.0	75.3	17.7	63.3
100% NPK+HW+Zn	79.3	23.0	89.0	79.0	17.8	61.0
100% NPK+Zn	96.5	25.8	93.8	85.8	21.3	67.8
100% NPK-S+Zn	73.6	22.8	79.3	70.8	13.8	52.3
100% NPK+FYM	112.5	38.5	112.3	110.5	27.3	91.0
Biofertilizer	22.3	5.5	28.5	21.5	4.0	16.8
CD (0.05)	3.2	3.1	3.9	3.2	2.9	2.7

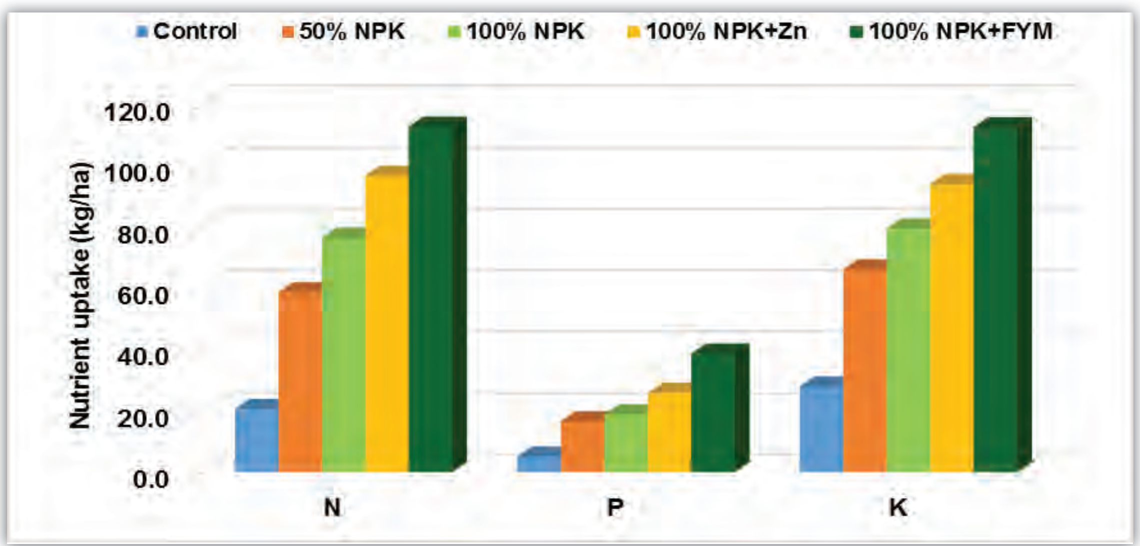


Figure 5.10 Impact of balanced fertilizer use and INM on nutrient removal by rice in LTFE at Pantnagar

5.10 Pattambi

The nutrient uptake data of both kharif and rabi rice crop revealed that the N, P and K uptake was highest under 100% NPK+FYM @ 5 Mg ha^{-1} followed by 100% NPK+green manuring (**Table 5.18** and **Figure 5.11**). The application of N alone i.e. 100% N had deleterious effect on the major nutrient uptake by rice. However, inclusion of P along with N had improved the nutrient uptake subsequently.

Table 5.18 Nutrient uptake by rice (kharif) and rice (Rabi) in LTFE at Pattambi

Treatment	Rice (Kharif)			Rice (Rabi)		
	Nutrient uptake (kg ha^{-1})					
	N	P	K	N	P	K
Control	41.7	7.1	57.5	34.3	5.9	47.8
100% N	36.0	6.8	58.2	32.5	6.3	46.1
100% NP	44.1	8.8	66.5	39.7	8.0	61.6
50% NPK	45.6	8.1	70.1	39.3	7.0	61.8
100% NPK	45.4	8.7	74.1	40.8	7.8	63.6
150% NPK	48.4	10.3	78.6	42.9	9.1	70.8
100% NPK +Lime	48.5	10.1	68.0	41.3	8.5	57.9
100% NPK-$CuSO_4$	44.2	8.2	72.8	38.7	7.2	60.5
50% NPK+ Green manure	48.5	9.4	77.8	40.5	7.9	63.6
50% NPK+FYM @ 5 Mg ha^{-1}	49.3	8.8	73.4	43.2	7.7	65.4
100% NPK + Green manure	54.0	10.1	82.8	51.1	9.5	76.3
100% NPK+FYM @ 5 Mg ha^{-1}	60.1	12.3	88.7	56.8	11.6	83.3

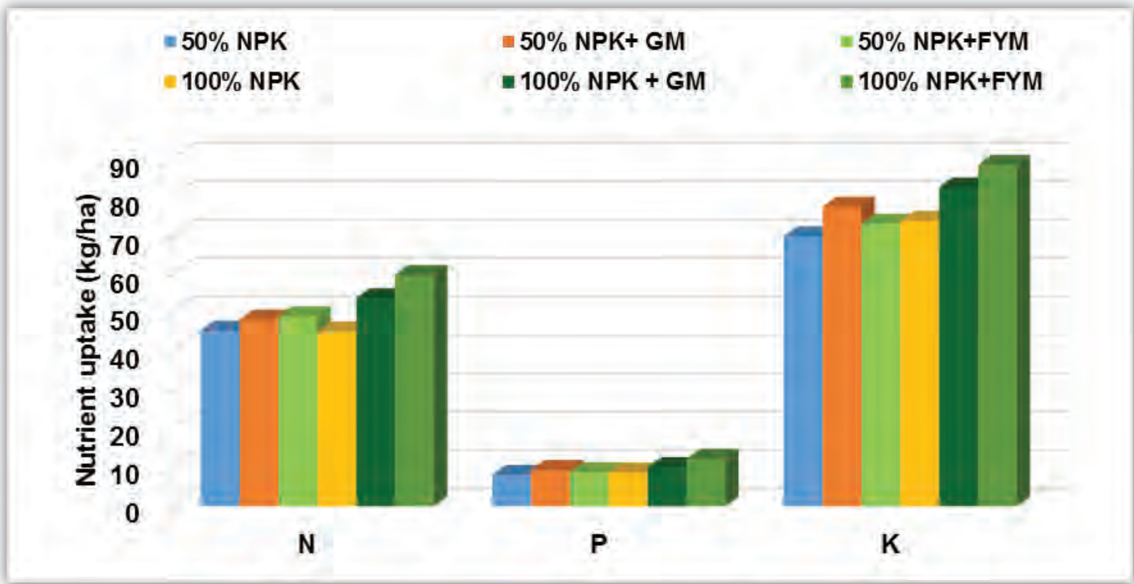


Figure 5.11 Impact of green manuring and FYM on nutrient withdrawal by rice in LTFE at Pattambi

5.11 Ludhiana

5.11.1 Maize

The nutrient uptake (N, P and K) by maize recorded a significant variation amongst the nutrient management options (**Table 5.19**). A significant increase in uptake of N, P and K was recorded with 100% NPK as compared to 50% NPK. The application of 150% of the recommended NPK showed higher uptake of N, P and K as compared to 100% recommended NPK. Similarly, a significant increase in uptake of these nutrients was recorded with 100% N only as compared to the control. Further, results indicated that the increase in nutrient uptake was recorded with application of 100% NP as compared to 100% N only. The effect of FYM application along with 100% NPK showed significant increase in total N, P and K uptake as compared to 100% recommended NPK (**Figure 5.12** & **Figure 5.13**). The micronutrients (Zn, Cu, Fe and Mn) uptake data also revealed significant difference amongst nutrient management options (**Table 5.19**). A significant increase in uptake of Zn, Cu, Fe and Mn was recorded with 100% NPK as compared 50% NPK. The application of 150% NPK recorded higher uptake of Zn, Cu, Fe and Mn as compared to 100% recommended NPK.

Table 5.19 Effect of long-term fertilizer application on major and micronutrient uptake by maize in LTFE at Ludhiana

Treatment	Nutrient uptake (kg ha^{-1})			Micronutrient uptake (g ha^{-1})			
	N	P	K	Zn	Cu	Fe	Mn
Control	26.6	4.2	16.5	119	19	213	158
100% N	69.9	10.8	38.2	300	42	479	354
100% NP	97.9	17.2	53.7	354	55	652	494
50% NPK	82.4	16.0	49.6	335	45	649	409
100% NPK	118.0	22.0	75.5	469	73	910	575
100% NPK-S	116.4	19.5	60.7	413	59	779	537
100% NPK+Zn	119.6	21.6	70.1	505	65	923	598
100% NPK+W	121.7	23.6	72.3	479	68	869	587
150% NPK	132.6	24.7	83.0	509	75	994	680
100% NPK+FYM	149.0	30.0	99.3	587	85	1177	776

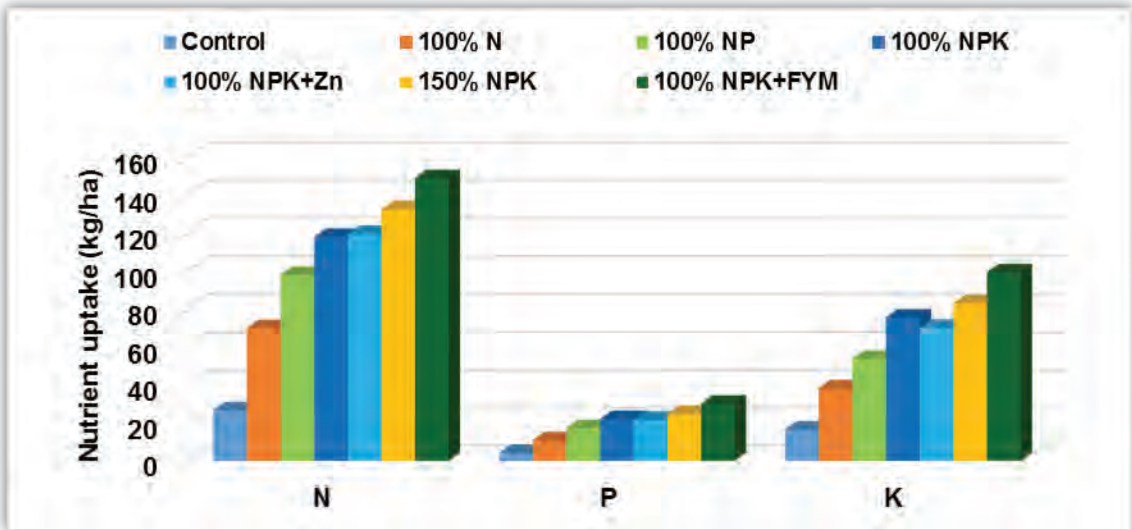


Figure 5.12 Impact of imbalanced and balanced and INM on nutrient withdrawal by maize in LTFE at Ludhiana

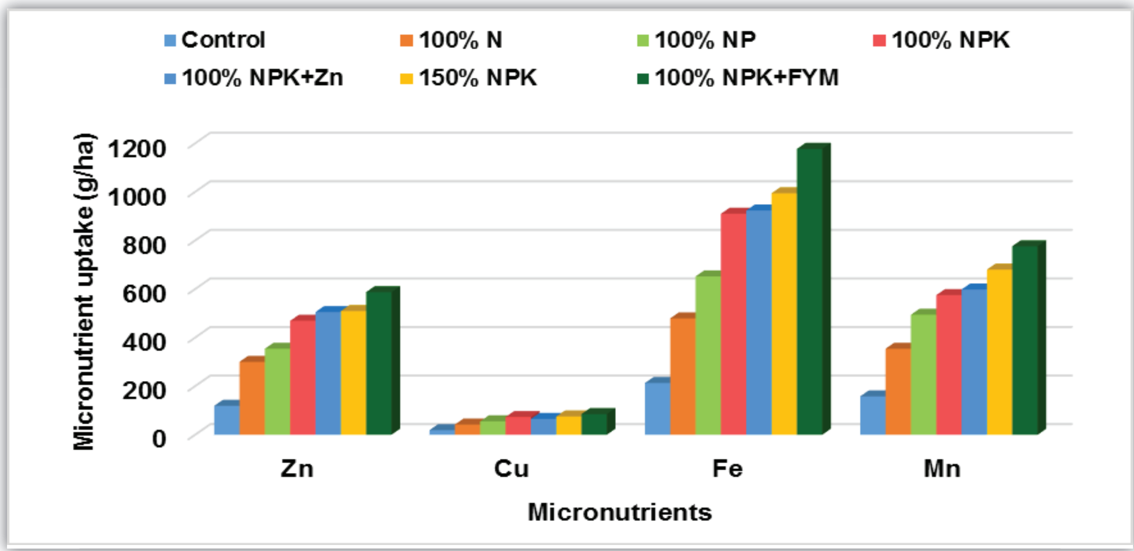


Figure 5.13 Impact of imbalanced and balanced and INM on micronutrient withdrawal by maize in LTFE at Ludhiana

5.11.2 Wheat

The N, P and K uptake by wheat during r*abi* showed a significant variation amongst the treatments (**Table 5.20**). The uptake of N, P and K with 100% NPK was higher compared to 50% of the recommended NPK. The application of 150% of the recommended NPK showed higher total uptake of N, P and K which was higher as compared to 100% recommended NPK. Almost similar trend was observed for nutrient uptake pattern in case of wheat to that of maize. A significant increase for uptake of Zn, Cu, Fe and Mn was recorded with 100% NPK as compared to 50% of the recommended NPK. The application of 150% of the recommended NPK showed improvement in uptake of Zn, Cu, Fe and Mn as compared to the plots that received 100% recommended NPK. The integrated nutrient management i.e. 100% NPK +FYM found to remove the maximum amount of nutrients.

Table 5.20 Effect of long-term fertilizer application on major and micronutrient uptake by wheat in LTFE at Ludhiana

Treatment	Nutrient uptake (kg ha^{-1})			Micronutrient uptake (g ha^{-1})			
	N	P	K	Zn	Cu	Fe	Mn
Control	26	5.3	15	43	9.5	631	53
100% N	62	12.2	46	128	26.3	1742	160
100% NP	83	15.2	59	161	31.9	2217	209
50% NPK	67	13.0	51	128	25.4	1687	170
100% NPK-S	95	19.5	72	186	35.5	2531	239
100% NPK	91	17.9	67	184	34.9	2492	238
100% NPK+W	104	21.6	71	195	38.0	2581	260
100% NPK+Zn	107	19.7	77	216	39.4	2784	264
150% NPK	114	25.2	78	234	41.7	2853	310
100% NPK+FYM	127	26.4	94	271	50.6	3418	394

5.12 Ranchi

The nutrient (N, P and K) uptake by the crops under soybean-wheat cropping system indicated the highest N uptake for both the crops under integrated use of organics along with balanced fertilizer use (**Table 5.21)**. The lowest N uptake was recorded in the treatment where N alone was applied through urea only over the years for both soybean (**Figure 5.14**) and wheat which was even lower than control. Application of higher dose of NPK i.e. 150% NPK although could utilize nitrogen similar that of optimal dose of NPK as there was no significant difference for grain yield of crops between optimal and super optimal dose of the recommended fertilizers.

Table 5.21 Nutrient uptake by soybean and wheat in LTFE at Ranchi (2018-19)

Treatment	Soybean			Wheat		
	Nutrient uptake (kg ha^{-1})					
	N	P	K	N	P	K
Control	48.7	4.3	11.3	8.8	3.5	7.7
100% N	34.0	2.7	7.4	18.4	5.0	13.9
100% NP	61.0	8.1	13.5	53.5	15.6	47.6
50% NPK	78.0	8.2	19.0	36.9	11.6	35.9
100% NPK	107.9	14.7	28.3	54.8	14.6	51.6
100% NPK+HW	92.9	11.5	25.3	52.6	17.3	48.5
150% NPK	112.3	14.1	29.8	59.4	21.3	50.9
100% N (S) PK	123.8	11.7	29.6	56.9	18.3	46.4
100% NPK + Lime	138.1	17.5	36.8	61.0	20.6	60.5
100% NPK + FYM	145.9	21.1	30.0	63.8	23.1	58.9
CD (0.05)	19.4	2.9	5.3	9.5	6.4	7.3

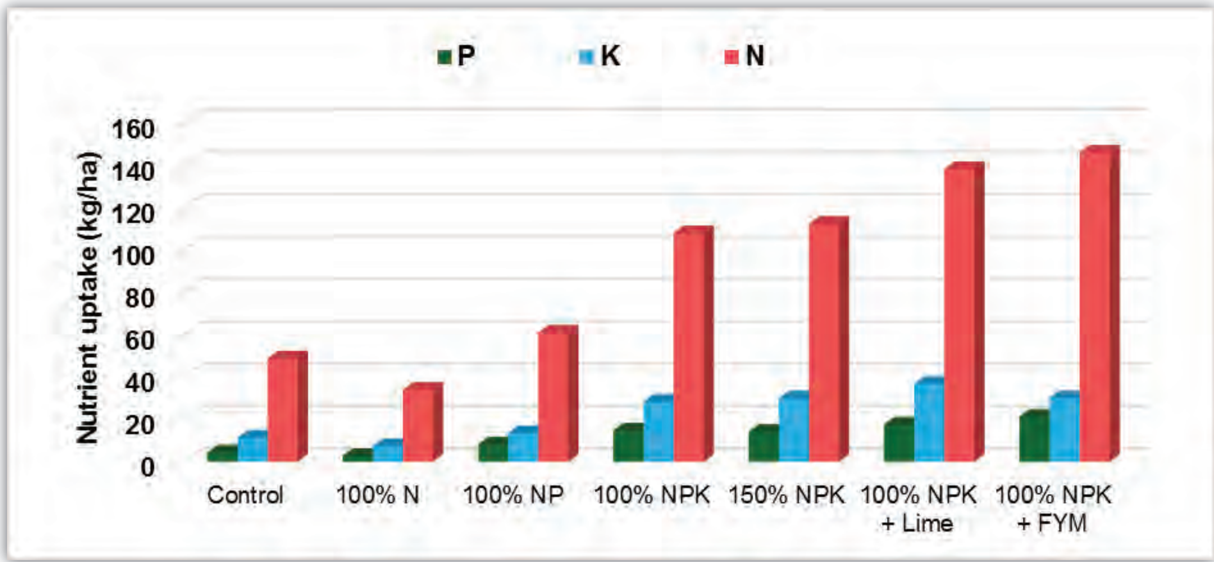


Figure 5.14 Impact of imbalanced and balanced and INM on nutrient removal by soybean in LTFE at Ranchi

5.13 Udaipur

The uptake of nutrients followed similar trend as that of yield being maximum with NPK + FYM followed by 150% NPK and lowest in control. The uptake of N, P and K by maize and wheat followed similar trend (**Table 5.22** & **5.23**). The uptake of nutrients was in order of K > N > P > S > Zn for maize and N > K > P > S > Zn for wheat.

Table 5.22 Long term effect of fertilizer, manure and their combinations on average nutrient uptake by maize in LTFE at Udaipur (2018-19)

Treatment	Nutrient uptake (kg ha^{-1})				Micronutrient uptake (g ha^{-1})
	N	P	K	S	Zn
Control	23.5	5.2	30.2	3.4	54
100% N	41.4	8.9	55.8	6.5	88
100% NP	56.9	13.9	69.2	9.2	113
100% NPK	69.2	16.2	80.9	17.2	135
100% NPK + Zn	72.7	16.8	83.3	11.6	172
100% NPK+ S	75.2	16.2	82.8	14.4	148
100% NPK+ Zn + S	76.6	17.6	86.2	15.6	176
100% NPK + *Azotobacter*	77.5	17.9	85.6	11.8	136
100% NPK + FYM 10 Mg ha^{-1}	90.8	20.9	120.4	16.2	188
FYM*	77.5	17.5	94.1	13.4	158
150% NPK	87.3	22.1	120.0	12.9	161
FYM @ 20 Mg ha^{-1}	44.0	11.3	54.0	8.5	93
CD (0.05)	6.1	0.7	3.8	1.0	9.2

** FYM 10 Mg ha^{-1} + 100% NPK (-NPK of FYM)*

Table 5.23 Long term effect of fertilizer, manure and their combinations on average nutrient uptake by wheat in LTFE at Udaipur (2018-19)

Treatment	Nutrient uptake (kg ha^{-1})				Micronutrient uptake (g ha^{-1})
	N	P	K	S	Zn
Control	25.8	5.1	26.9	3.6	54
100% N	55.9	10.7	52.8	8.1	103
100% NP	68.9	15.4	65.3	11.0	128
100% NPK	90.1	19.4	81.9	22.3	162
100% NPK + Zn	94.4	19.7	84.3	14.4	189
100% NPK+ S	92.9	19.4	83.7	18.7	169
100% NPK+ Zn + S	97.1	20.5	87.0	20.1	197
100% NPK + Azotobacter	96.4	20.0	88.2	15.0	171
100% NPK + FYM 10 Mg ha^{-1}	110.6	24.1	100.0	19.9	204
FYM*	100.5	21.7	96.0	18.0	190
150% NPK	106.0	23.7	98.6	15.0	180
FYM @ 20 Mg ha^{-1}	61.6	13.9	56.2	11.0	114
CD (0.05)	3.9	0.8	6.3	0.6	7.3

** FYM 10 Mg ha^{-1} + 100% NPK (-NPK of FYM)*

5.14 Parbhani

5.14.1 Soybean

Data revealed that the nutrient uptake of N, P, K, S and Zn was maximum with 100% NPK+FYM @ 5 Mg ha^{-1} followed by 150% NPK and 100% NPK + Zn (**Table 5.24**). The lowest nutrient uptake was noticed in control treatment followed by 100% N application. It was also observed that the sulphur uptake was drastically declined in 100% N treatment and control as well as 100% NPK - S treatment also recorded drastic reduction in S uptake as compared to 100% NPK treatment. Data on Zn uptake indicated maximum values with INM i.e. 100% NPK+FYM @ 5 Mg ha^{-1}. It was also noticed that 100% NPK+Zn recorded higher zinc uptake as compared to other treatments.

5.14.2 Safflower

Almost similar nutrient uptake trend was found in safflower to that of soybean. Data revealed that the uptake of N, P, K, S and Zn was maximum with 100% NPK+FYM @ 5 Mg ha^{-1} wchich was at par with 150% NPK and 100% NPK + Zn (**Table 5.25**). The lowest nutrient uptake (N, P, K, S and Zn) was noticed in 100% N and control (no fertilizer and manure). Like soybean, the sulphur uptake declined in 100% N treatment and control. In addition, the 100% NPK-S treatment also recorded significant reduction in S uptake as compared to 100% NPK application. Data on Zn uptake indicated maximum uptake with 100% NPK along with FYM @ 5 Mg ha^{-1}. However, 100% NPK+Zn application recorded maximum Zn uptake as compared to other nutrient management options **(Figure 5.15).**

Table 5.24 Long term effect of fertilizer, manure and their combinations on nutrient uptake by soybean in LTFE at Parbhani (2018-19)

Treatment	Nutrient uptake (kg ha^{-1})				Micronutrient uptake (g ha^{-1})
	N	P	K	S	Zn
Control	37.5	6.1	16.6	3.5	64
100% N	30.2	4.5	12.4	2.7	50
100% NP	119.3	22.1	50.1	12.5	203
50% NPK	89.9	14.8	38.8	9.1	154
100% NPK	111.4	18.9	46.2	11.6	195
150% NPK	137.0	26.1	56.3	15.4	231
100% NPK+hand weeding	123.6	21.6	52.1	11.7	216
100% NPK+Zn	123.6	22.8	52.0	13.2	257
100% NPK+FYM @ 5 Mg ha^{-1}	137.1	27.2	58.8	16.1	257
100% NPK-Sulphur	116.8	22.4	49.5	10.9	218
Only FYM @ 10 Mg ha^{-1}	115.9	21.8	48.6	11.6	212
CD (0.05)	24.2	3.5	9.1	2.3	38.7

Table 5.25 Long term effect of fertilizer and manure on nutrient uptake by safflower in LTFE at Parbhani (2018-19)

Treatment	Nutrient uptake (kg ha^{-1})				Micronutrient uptake (g ha^{-1})
	N	P	K	S	Zn
Control	33.2	9.0	45.7	4.8	87
100% N	32.8	8.2	42.5	4.6	81
100% NP	80.1	27.3	104.5	14.3	209
50% NPK	67.1	20.8	92.5	10.3	183
100% NPK	80.6	24.4	104.1	14.3	220
150% NPK	89.2	33.9	113.8	18.4	243
100% NPK+ hand weeding	75.5	23.6	98.0	13.7	201
100% NPK+Zn	90.8	30.8	118.0	17.7	267
100% NPK+FYM @ 5 Mg ha^{-1}	98.0	35.3	126.6	19.3	289
100% NPK-Sulphur	73.3	24.1	97.8	11.5	211
Only FYM @10 Mg ha^{-1}	75.6	24.4	94.3	13.5	207
CD (0.05)	12.7	4.3	16.0	2.2	35.3

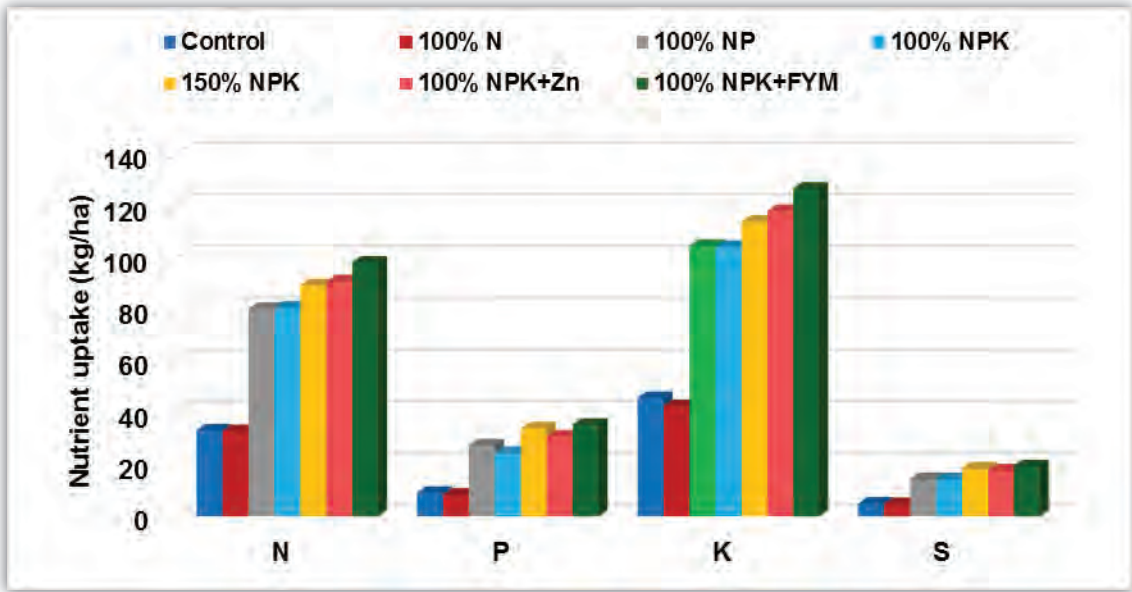


Figure 5.15 Impact of imbalanced and balanced nutrient management on nutrient uptake by safflower in LTFE at Parbhani

5.15 Barrackpore

Nutrient uptake by rice, wheat and jute was higher in fertilized plots as compared to the unfertilized control. Application of 100% NPK+FYM resulted in higher uptake of N, P in rice and jute (**Figure 5.16** & **5.18**). The N, P and K uptake by rice, wheat and jute increased with increasing dose of fertilizer. Total K uptake varied from 37 to 67 kg ha^{-1} in rice and 19 to 92 kg ha^{-1} in wheat and 60 to 120 kg ha^{-1} in jute, respectively (**Figure 5.16, 5.17** & **5.18**). The highest K uptake was found in 100% NPK+FYM, followed by 150% NPK in rice and wheat, while maximum K uptake in jute was found in 150% NPK. The lowest K uptake was observed in control in these crops.

Table 5.26 Long term effect of fertilizer and manure on nutrient uptake in LTFE at Barrackpore (2017-18)

Treatment	Rice			Wheat			Jute		
	Nutrient uptake (kg ha^{-1})								
	N	P	K	N	P	K	N	P	K
Control	22.8	14.5	22.2	18.0	13.2	22.3	43.2	15.6	52.6
100% N	42.8	16.2	30.3	52.5	17.2	54.2	48.4	14.4	54.5
100% NP	47.3	18.1	35.6	56.4	19.1	61.2	64.4	24.3	72.1
50% NPK	39.6	17.0	30.5	44.5	17.5	54.9	64.7	20.0	71.9
100% NPK	50.0	19.9	42.7	64.5	19.9	75.5	80.1	24.6	102.6
100% NPK+HW	53.1	18.8	40.8	61.0	20.7	70.9	87.9	29.7	103.1
100% NPK+Zn	55.7	18.6	42.9	68.8	19.2	74.7	91.9	27.6	104.9
100% NPK-S	50.1	18.9	38.2	62.1	18.3	72.6	66.1	24.7	87.7
150% NPK	65.5	21.2	50.0	82.8	21.7	88.5	103.1	36.1	118.4
100% NPK+FYM	64.6	22.1	50.4	78.3	22.9	81.7	113.6	33.4	117.5
CD (0.05)	2.95	2.13	4.84	6.41	2.96	7.67	23.45	3.59	10.23

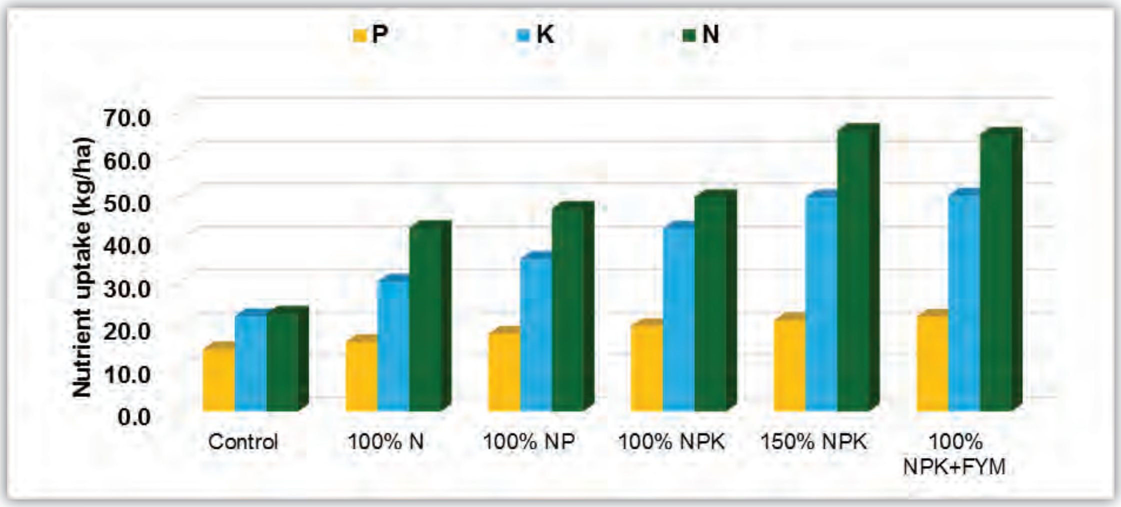


Figure 5.16 Impact of nutrient management on nutrient uptake by rice in LTFE at Barrackpore

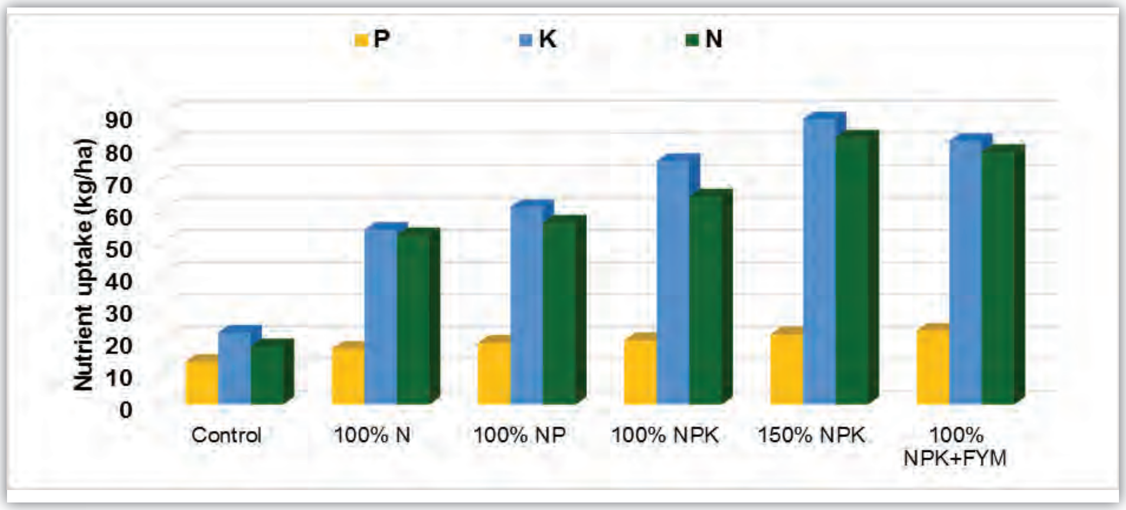


Figure 5.17 Impact of nutrient management on nutrient uptake by wheat in LTFE at Barrackpore

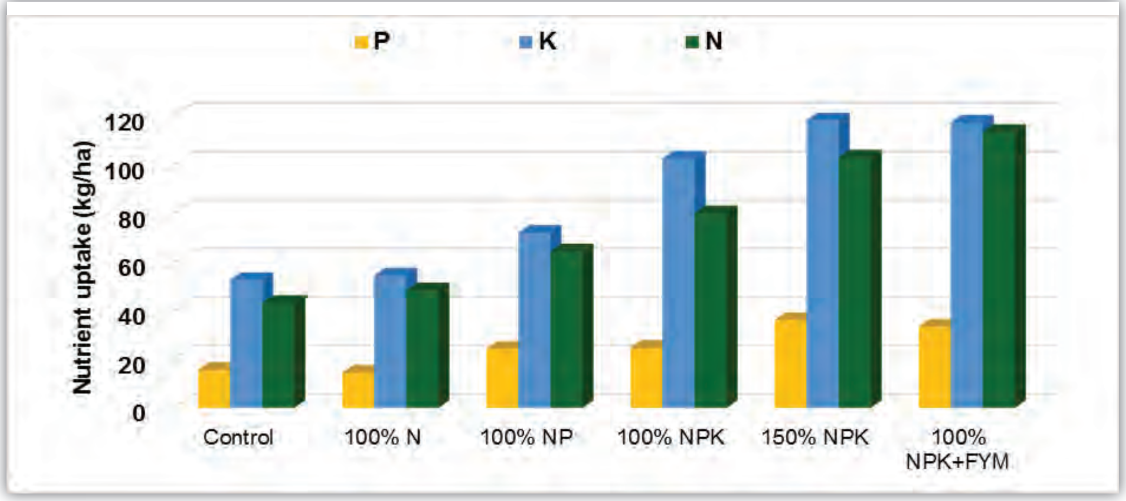


Figure 5.18 Impact of nutrient management on nutrient uptake by jute in LTFE at Barrackpore

5.16 Raipur

Data on nutrient uptake for rice and wheat under LTFE at Raipur indicated that recommended dose of fertilizer through inorganic fertilizer (100% NPK) or INM or 150% NPK, 100% NPK+FYM recorded significantly higher nutrient uptake than imbalanced application (100% N alone). Absence of P fertilizer in cropping (100% N alone and control) reduced the nutrient uptake which indicates reduced ability of crops to acquire N (**Table 5.27**). Application of 50% NPK+GM significantly improved the N-uptake over sole application of 100% N. Slightly higher P-uptake were observed by rice than wheat. The K uptake data revealed that both rice and wheat registered maximum uptake of K than N and P indicating luxury consumption of K.

Table 5.27 Long term effect of fertilizer, manure and their combinations on nutrient uptake by rice and wheat in LTFE at Raipur (2018-19)

Treatment	Rice			Wheat		
	Nutrient uptake (kg ha^{-1})					
	N	P	K	N	P	K
Control	34.3	6.8	67.3	33.0	4.8	48.8
100% N	54.9	8.9	119.9	51.1	6.5	68.9
100% NP	80.3	15.4	179.5	80.4	9.8	103.9
50% NPK	62.7	11.5	130.1	65.4	8.6	83.5
100% NPK	75.9	13.6	166.1	82.8	11.3	104.0
150% NPK	82.4	16.2	169.0	91.8	13.3	111.7
100% NPK+Zn	77.1	14.4	161.9	80.0	10.5	103.2
100%NPK+ FYM	83.4	16.0	172.4	91.3	12.2	111.0
50% NPK+ BGA	60.6	11.8	132.4	65.6	8.3	86.3
50% NPK+ GM	66.5	11.9	142.9	72.4	9.3	93.3
CD (0.05)	10.1	2.7	19.7	13.7	2.6	16.9

Thus, balanced use of fertilizers enhanced nutrient uptake of major and micronutrients in crops cultivated under long term fertilizer experiments (LTFEs) across all sites of AICRP-LTFE. The uptake further improved with 100% NPK + lime in majority of crops grown on Alfisols. Similarly, NPK+green manuring also equally improved the crop growth and thereby nutrient uptake. However, 100% NPK+FYM resulted in maximum uptake of major and micronutrients in almost all crops across different soils under LTFEs.

6. NUTRIENT DYNAMICS

NUTRIENT TRANSFORMATION is a continuous process that occurs in soil which are mediated through chemical and biochemical processes. One form of nutrient is converted into another and the conversion is termed as nutrient dynamics. Studies conducted on nutrient dynamics are given hereunder.

6.1 Akola (Vertisols)

6.1.1 Nitrogen

Nitrogen (N) mineralization in soil is a key process needed to be fully understood and taken into account while meeting the N demand of crops. The inorganic N fractions increased significantly with the application of balanced dose of fertilizer along with organic manure (100% NPK + FYM) (**Table 6.1**). Both the forms of N (NH_4^+-N & NO_3^--N) increased with increase in recommended dose of balanced chemical fertilizers. However, higher inorganic N fractions were observed with the combined application of manures and fertilizers (**Figure 6.1a** & **6.1b**). The NO_3-N was higher as against ammonium N after harvest of sorghum and wheat. It was noted that both the forms of N were higher after harvest of wheat.

Table 6.1 Long term effect of fertilizer and manure application on inorganic N fractions in soil at Akola (0-15 cm soil depth) (2017-18)

Treatment	Inorganic N fractions (mg kg^{-1})			
	Sorghum		Wheat	
	NH_4-N	NO_3-N	NH_4-N	NO_3-N
Control	13.1	19.7	16.2	21.9
100% N	18.8	27.6	23.6	31.1
100% NP	20.6	28.0	24.1	31.5
50% NPK	16.2	24.9	21.0	28.9
100% NPK	21.4	29.3	25.4	32.4
150% NPK	23.6	35.4	28.9	35.0
100% NPK S free	21.4	28.0	24.5	32.4
100% NPK + Zn @ 2.5 kg ha^{-1}	22.3	28.9	24.9	32.4
100% NPK + FYM @ 5 Mg ha^{-1}	26.7	38.9	32.8	37.2
100% NPK + 37.5 kg S ha^{-1}	22.3	28.9	24.9	32.4
FYM @ 10 Mg ha^{-1}	25.8	29.3	28.4	33.7
75% NPK + 25% N through FYM	22.8	27.1	26.7	32.4
CD (0.05)	1.90	1.87	1.62	2.40

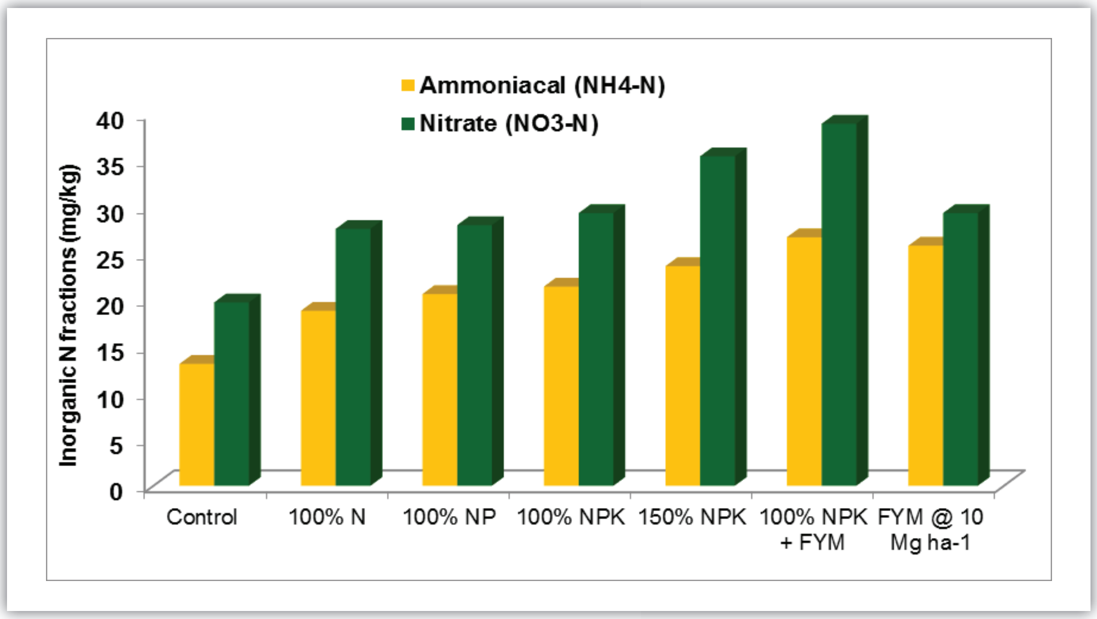


Figure 6.1 (a) Impact of long term fertilizer and manure application on inorganic forms of N in LTFE (Sorghum) at Akola (Vertisols)

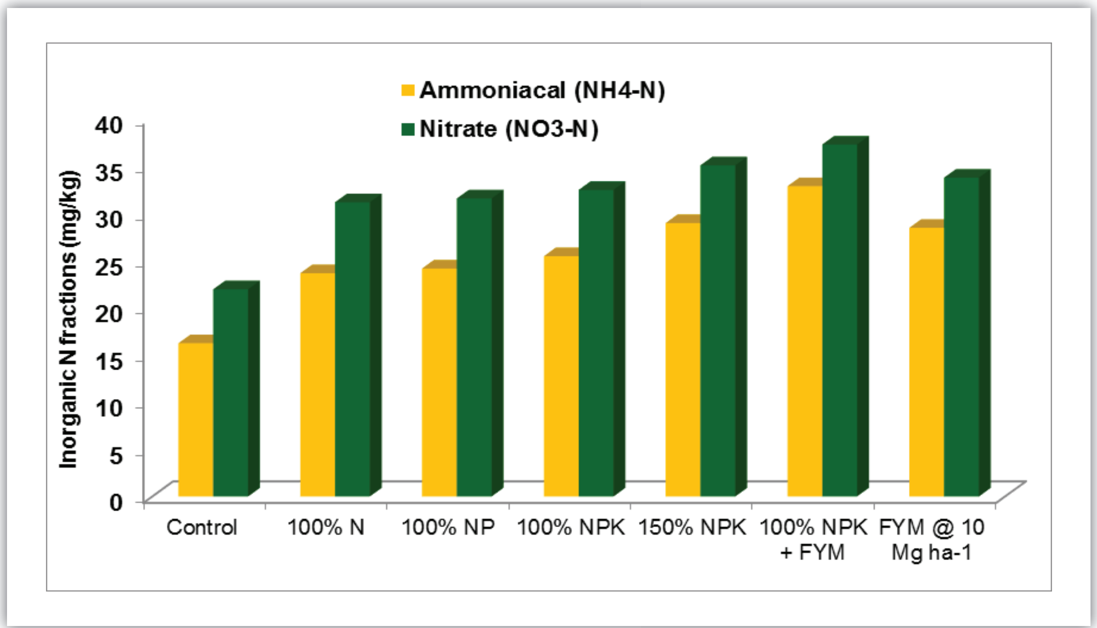


Figure 6.1 (b) Impact of long term fertilizer and manure application on inorganic forms of N in LTFE (Wheat) at Akola (Vertisols)

6.1.2 Potassium

Significantly highest water soluble, exchangeable and non-exchangeable K was recorded with the application of 100% NPK + FYM @ 5 Mg ha^{-1} followed by 150% NPK as compared to other treatments (**Table 6.2**). The lattice K ranged from 6982 to 18461 mg kg^{-1} and highest value was recorded under 100% NPK along with FYM @ 5 Mg ha^{-1} followed by 150% NPK treatment The sequential order of dominance of different forms of K were water soluble K<exchangeable K< non-exchangeable K < lattice K, which corresponds to 0.11, 0.97, 6 and 92% contributes to total K, respectively.

Table 6.2 Long term effect of treatments on forms of potassium at Akola (2017-18)

Treatment	Potassium forms (mg kg^{-1})				
	Water soluble	Exchangeable	Non-exchangeable	Lattice	Total
Control	10.8	64	610	9189	9874
100% N	11.8	78	651	9561	10302
100% NP	13.3	89	692	10030	10824
50% NPK	14.1	96	758	9823	10691
100% NPK	16.0	156	836	9931	10939
150% NPK	18.1	192	968	10017	11195
100% NPK S free	15.5	152	821	9897	10885
100% NPK + Zn @ 2.5 kg ha^{-1}	15.9	153	869	9856	10894
100% NPK + FYM @ 5 Mg ha^{-1}	18.5	199	992	10139	11348
100% NPK + 37.5 kg S ha^{-1}	16.1	156	879	9974	11025
FYM @ 10 Mg ha^{-1}	14.9	104	788	9806	10713
75% NPK + 25% N through FYM	16.4	123	843	9986	10968
CD (0.05)	1.03	9.90	77.4	NS	NS

6.2 Bangalore (Alfisols)

6.2.1 Calcium

Calcium fractionation study indicated that all fractions i.e. Exchangeable, organic complexed, acid soluble and mineral forms differs significantly due to long tern manure and fertilizer application. Exchangeable calcium content in soil showed increasing trend over the years in all the treatments (**Table 6.3**). However,

Table 6.3 Effect of long term manuring on fractions of calcium in soil after the harvest of maize at Bangalore (2017)

Treatment	Calcium Fractions (c mol (p$^+$) kg^{-1})				
	Exchangeable	Organic	Acid soluble	Mineral	Total
Control	3.70	1.22	11.2	20.2	37.9
100% N	3.75	1.25	10.2	19.1	40.8
100% NP	4.48	1.40	13.1	20.4	45.8
50% NPK	4.05	1.35	12.3	21.3	42.2
100% NPK	4.22	1.40	11.9	21.8	41.1
150% NPK	4.58	1.42	12.3	21.9	42.9
100% NPK(S-free)	3.55	1.27	10.7	16.3	35.7
100% NPK+HW	4.12	1.38	11.7	21.3	39.3
100% NPK+Lime	5.43	1.47	16.2	26.8	54.1
100% NPK+FYM	4.52	1.65	13.3	25.3	47.4
100% NPK+FYM+Lime	5.58	1.75	16.3	27.0	55.4
CD (0.05)	0.12	0.08	0.6	0.8	0.9

extent of increase over 31 years was found maximum in 100% NPK+FYM+lime followed by 100% NPK+lime which received fertilizer as Ca source. Treatments, which received single super phosphate (SSP) as P source, maintained higher exchangeable Ca over the years. Exchangeable calcium content was found to be lower and increase over the years was minimum in NPK-S followed by 100% N and control, which received neither lime nor any calcium source fertilizer. This might be due to release of calcium from native soil nutrient reserve (non-exchangeable Ca source).Similar trend was found with for other Ca fractions i.e. Organic complexed, acid soluble, mineral and total Ca.

6.2.2 Magnesium

Exchangeable magnesium (Mg) content in soil found maximum in 100% NPK+FYM+Lime followed by 100% NPK+Lime (**Table 6.4**). Exchangeable magnesium content was found to be significantly lower in 100% NPK (S free) in that which received DAP as a source of P followed by 100% N. Exchangeable magnesium content in 100% N and control has increased over the initial exchangeable Mg even though they have not received any Mg source. It might be due to release of Mg from native soil nutrient reserve (non exchangeable Mg source). A similar trend was found with respect to organic complexed, acid soluble, mineral and total fraction of Mg.

Table 6.4 Effect of long term manuring on different fractions of Mg in soil after the harvest of maize at Bangalore (2017)

Treatment	Magnesium fractions (c mol (p^+) kg^{-1})				
	Exchangeable	Organic complexed	Acid Soluble	Mineral	Total
Control	2.33	0.58	4.87	16.2	24.3
100% N	1.73	0.60	4.33	14.8	26.3
100% NP	2.12	0.60	4.43	16.3	27.2
50% NPK	2.35	0.58	4.63	15.2	23.8
100% NPK	1.92	0.67	4.60	16.1	23.8
150% NPK	1.90	0.67	4.67	14.0	23.8
100% NPK+HW	1.97	0.63	5.57	15.0	25.5
100% NPK(S-free)	1.58	0.62	5.10	12.1	22.2
100% NPK+Lime	2.62	0.70	7.30	15.2	28.8
100% NPK+FYM	2.38	0.73	4.77	15.3	26.3
100% NPK+FYM+Lime	2.78	0.78	7.30	18.3	32.0
CD (0.05)	0.21	0.10	0.24	0.8	0.9

6.2.3 Sulphur

The water soluble sulphur (S) content in soil found maximum in 100% NPK+FYM+Lime followed by 100% NPK+FYM (**Table 6.5**). Treatments which receives single super phosphate (SSP) as a P source maintained higher water soluble S. Water soluble S was found to be lower in 100% NPK (S free) which received S free phosphatic fertilizer (DAP) followed by 100% N. Available sulphur content in soil found maximum in 100% NPK+FYM+Lime followed by 150% NPK as sulphur source. Increase in available sulphur content was found to be negligible in treatment 100% NPK+FYM which received S free P fertilizer (DAP) followed by 100% N which received only nitrogenous fertilizer. Available S content did not increase over the years compared to initial. It might be due to continuous cropping without addition of any S containing fertilizer or organic sources. Available S was lower in 100% NPK (S free) followed by 100% N. A similar trend was found with respect to inorganic S, organic S, residual and total S. However, in case of residual S content in 100% NPK (S free) and 100% N has increased over the years compared to initial inorganic S content might be due to continuous cropping without addition of any S containing fertilizer or organic sources and also due to release of S from the non-available fractions to exchangeable pool.

Table 6.5 Effect of long term manuring on different fractions of sulphur content in soil after the harvest of maize at Bangalore (2017)

Treatment	Sulphur fractions (mg kg^{-1})					
	Water soluble	Available	Inorganic	Organic	Residual	Total
Control	14.1	10.5	20	225	36	306
100% N	9.2	8.6	19	223	36	295
100% NP	25.3	21.3	26	231	43	348
50% NPK	17.2	14.5	23	229	43	327
100% NPK	25.9	18.7	29	231	43	347
150% NPK	28.1	22.1	32	234	45	362
100% NPK+HW	25.6	19.3	28	233	43	349
100% NPK(S-free)	7.7	7.4	18	220	35	288
100% NPK+Lime	27.7	20.7	30	233	44	355
100% NPK+FYM	30.4	20.4	31	247	45	373
100% NPK+FYM+Lime	29.1	19.6	31	246	44	369
CD (0.05)	2.4	1.8	2.7	20.6	4.3	35.4

6.3 Bhubaneswar (Inceptisols)

6.3.1 Nitrogen (Organic) fractions

Soil organic nitrogen (N) fraction comprised of two parts i.e. hydrolysable-N and non-hydrolysable-N (NHN). Hydrolysable ammonia-N (HAN), amino acid N (AAN), amino sugar N (ASN), unidentified hydrolysable-N (UHN) together known as total hydrolysable-N (THN). Soil organic N comprised of 91.75 to 96.82% of total N (**Table 6.6**). Total N content was maximum with 100% NPK+ FYM. The contribution of THN in the total N in surface layer is about 72.9 to 88.7%. Among the various hydrolysable N fractions, the lowest N content was recorded in the ASN fraction and highest in the UHN fraction. On an average, ammonia-N, amino acid-N, amino sugar-N, and hydrolysable unknown N constituted 23.8, 22.2, 4.2 and 49.9% of the total hydrolysable-N after rice harvest, respectively. Long-term application of mineral fertilizer and organic manure resulted in a significant build-up of HAN, AAN, ASN content over the unfertilized control.

Table 6.6 Effect of long term fertilizer and manure application on total and organic forms of N in soils (0-15 cm) in rice-rice cropping system at Bhubaneswar

Treatment	Total N (mg kg^{-1})	Organic form of N (mg kg^{-1})					
		THN	HAN	AAN	ASN	UHN	NHN
Control	608	471	116	94	14.2	248	112
100% N	639	546	123	120	19.7	284	50
100% NP	716	557	133	134	20.3	269	113
100% PK	699	513	129	105	18.0	261	140
100% NPK	729	622	134	126	32.3	330	50
150% NPK	752	667	145	157	28.1	327	16
100% NPK+Zn	762	579	145	141	21.5	271	137
100% NPK+FYM	1045	762	190	174	38.0	361	198
100% NPK+FYM+lime	975	765	186	174	35.0	370	129
100% NPK+Zn+B	740	544	141	128	27.8	248	139
100% NPK+Zn+S	764	627	147	132	22.5	325	72
100% NPK+lime	801	703	150	147	30.0	376	34
CD (0.05)	17.9	15.8	4.9	6.5	4.3	18.6	26.1

Total hydrolysable-N (THN); Hydrolysable ammonia-N (HAN); amino acid N (AAN); amino sugar N (ASN); unidentified hydrolysable-N (UHN); non hydrolysable-N (NHN)

6.3.2 Potassium

Under different nutrient-management treatments, the concentration of water soluble-K in the surface soil ranged from 16.7 to 29.6 kg ha^{-1} (**Table 6.7**).

Table 6.7 Effect of long term manurial practices on forms of K in soils (0-15 cm) in rice- rice cropping system at Bhubaneswar

Treatment	Potassium forms (kg ha^{-1})			
	Water soluble	Exchangeable	Non-exchangeable	Available
Control	16.7	76.3	219	93
100% N	15.9	75.1	238	91
100% NP	18.5	78.5	244	97
100% PK	23.8	75.2	239	99
100% NPK	21.9	81.1	240	103
150% NPK	28.7	86.3	266	115
100% NPK+Zn	21.0	81.0	249	102
100% NPK+FYM	27.5	125.5	286	153
100% NPK+FYM+Lime	29.6	124.4	291	154
100% NPK+Zn+B	20.8	81.2	247	102
100% NPK+Zn+S	22.0	77.0	250	99
100% NPK+lime	23.9	90.1	280	114
CD (0.05)	1.6	5.74	17.4	8.02

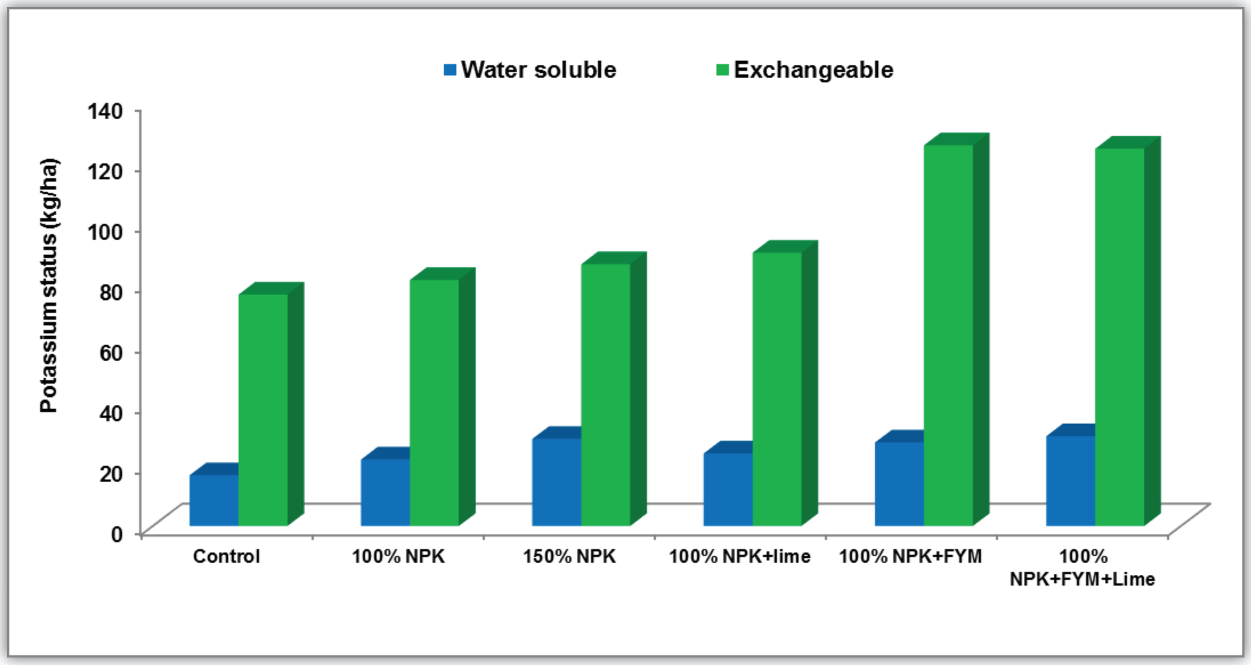


Figure 6.2 Impact of long term fertilizer and manure on K status in LTFE at Bhubaneswar

The water soluble K in the fertilized (NPK) plots were significantly higher than those of the unfertilized control plots and there was increase in the water soluble K under the FYM amended plots over the 100% NPK treated plots. The 100% NPK+FYM+lime resulted in highest water soluble K which was at par with 100% NPK+ FYM (**Figure 6.2**). The exchangeable K content ranged from 75.1 to 125.5 kg ha^{-1}. The lowest exchangeable K concentration in surface soil was observed under 100% N and highest in 100% NPK+FYM. Application of 150% NPK resulted in a significant increase in the exchangeable K content over control, 100% N, 100% NP, 100% NPK and 100% PK. Non exchangeable K content varied from 218.6 to 291.2 kg ha^{-1} in surface soil and 100% NPK+FYM+Lime resulted in significantly greater non exchangeable K over all other treatments except 100% NPK+FYM.

6.3.3 Soil organic carbon fraction

Results indicated that cultivation with balanced fertilization led to increase total organic carbon (TOC) by 30% over control (**Table 6.8**). Further FYM application significantly improved TOC by 16% over balanced mineral fertilization. Cultivation with balanced fertilization (NPK) and C supplementation (NPK+FYM) increased the oxidizable organic carbon by 20% and 36% respectively as compared to control. Characterization of organic matter liability using a gradient of oxidizing condition showed that the irrespective of the treatment, the very liable organic carbon fraction (VLC) comprised a larger pool of SOC than the other three fractions (**Table 6.8**). The carbon content of very labile, labile and less labile, however, constituted on an average about 53.0, 34.30, and 10.95% respectively of the amount of oxidisable organic carbon (**Figure 6.3**). Compared to control, 100% NPK and 100% NPK+FYM improved the very labile organic C fraction by 31% and 47%, respectively. The labile fraction also responded to FYM application in a similar manner to the very labile fraction. The less labile fraction under different treatments did not differ significantly. Addition of FYM enhanced the non-labile organic carbon fraction by 164% compared to control. However, active pool (very labile + labile) constituted about 79%, passive pool (less labile + non labile) represented 20% of the TOC. The Carbon Management Index (CMI) was in the ascending order of control < 100% NP < 100% N< 100% < NPK< 100% NPK+FYM.

Soils with higher CMI values are considered as better managed soil. The CMI significantly enhanced by FYM application compared to balanced or imbalanced fertilization. This is due to increase in annual C input and the good quality organic matter. Compared to a single measure such as SOC, CMI can be used as one of the sensitive indicator of the rate of change of SOC in response to soil management practices.

Table 6.8 Soil organic carbon fractions of varying oxidizability and their relationship with total soil organic carbon contents at Bhubaneswar

Treatment	Carbon fractions (Mg ha^{-1})								CMI
	TOC	Oxidizable organic	Very labile	Lablie	Less labile	Non labile	Active pool	Passive pool	
Control	8.6	8.25	4.16	2.81	0.92	0.67	6.97	1.59	100
100% N	10.0	9.58	4.86	3.35	0.96	0.87	8.21	1.83	109
100% NP	10.5	9.55	5.18	3.31	1.05	0.91	8.49	1.96	108
100% NPK	11.2	9.94	5.45	3.34	1.14	1.26	8.79	2.40	118
100% NPK+FYM	13.0	11.24	6.12	3.85	1.25	1.77	9.97	3.02	151
CD (0.05)	0.52	0.31	0.17	0.24	0.13	0.46	-	-	11.6

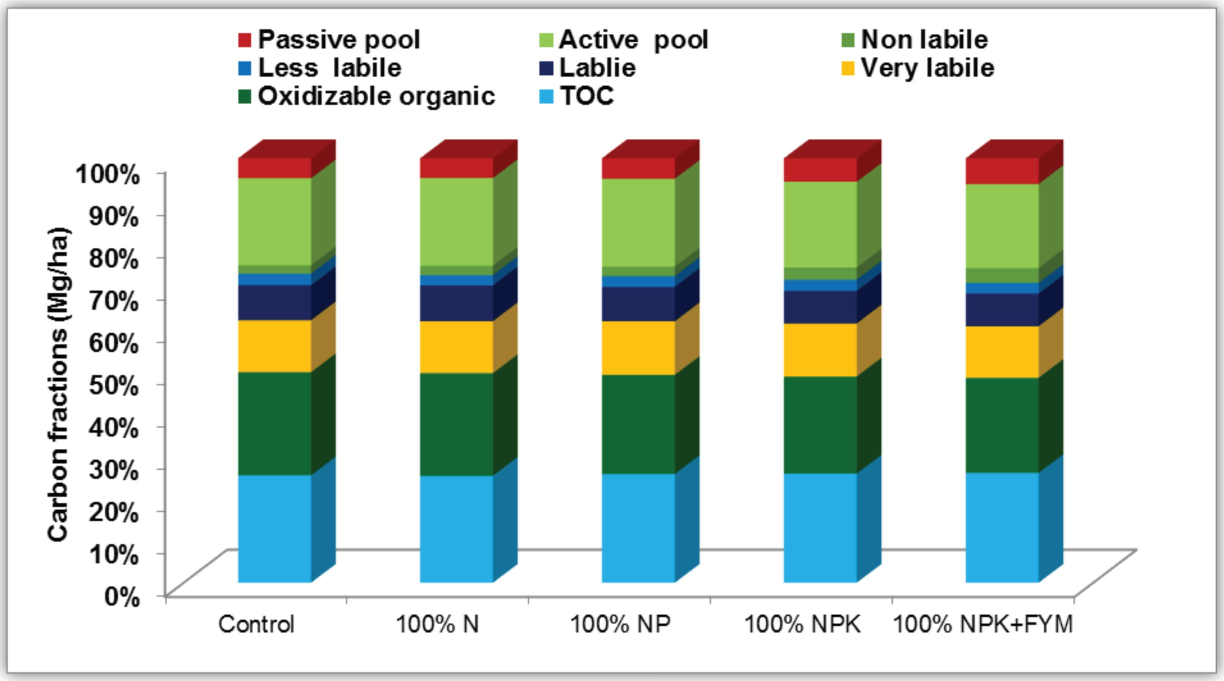


Figure 6.3 Impact of long term nutrient application on K forms in LTFE at Bhubaneswar (Inceptisols)

6.4 Coimbatore (Inceptisols)

6.4.1 Nitrogen

Among the inorganic N fractions, fixed ammonium N content was highest and it varied from 18.6 to 29.9 mg kg^{-1} (**Table 6.9**). Application of 100% NPK along with FYM recorded the highest inorganic N fractions of 8.2, 13.9 and 29.9 mg kg^{-1} for the exchangeable NH_4–N, NO_3–N and fixed NH_4–N respectively which was at par with 150% NPK and least being observed in control plot. There was a marked increase in inorganic

N fractions with increase in fertilizer level from 50% to 150% of optimal NPK. Among the various organic N fractions, the total hydrolysable N contributed much towards organic N pool. An increase in dosage of fertilizer from sub optimal (50% NPK) to super optimal (150% NPK) level has resulted in significant increase in the content of total hydrolysable N. The organic N fractions in post harvest soil of maize were found to be higher in 100% NPK+FYM and least was obtained in control plot.

Table 6.9 Nitrogen fractions in post harvest soil of maize in Inceptisols of Coimbatore

Treatment	Inorganic N fractions (mg kg^{-1})			Organic N fractions (mg kg^{-1})					
	Exch. NH_4-N	NO_3-N	Fixed NH_4-N	THN	Hydro lysable NH_4-N	Hexos amine N	Amino acid N	UHN	UNHN
Control	3.2	8.2	18.6	213	95	21.4	71.2	33.7	74.6
100% N	6.5	11.4	26.1	265	113	25.1	84.9	67.7	128.5
100% NP	6.2	11.7	26.6	270	117	25.9	87.1	69.5	178.1
50% NPK	5.1	9.6	22.9	252	106	23.9	79.0	54.0	101.1
100% NPK	6.3	11.2	26.3	269	126	27.5	94.3	68.7	181.2
150% NPK	7.1	13.1	29.4	291	132	28.7	99.5	81.5	212.3
100% NPK + HW	6.6	11.5	26.7	266	122	27.2	93.8	67.4	183.4
100% NPK + Zn	6.4	11.6	26.1	264	123	26.9	91.2	70.3	184.7
100% NPK + FYM	8.2	13.9	29.9	311	136	29.3	102.7	83.1	217.9
100% NPK (-S)	6.6	11.4	26.4	263	121	26.8	91.7	68.7	171.8
CD (0.05)	0.27	0.58	1.02	11.08	5.04	1.08	4.12	4.53	8.06

UHN- Unidentified hydrolysable N, THN- Total hydrolysable N, UNHN- Unidentified non hydrolysable N

6.4.2 Phosphorus

The saloid P was highest in 100% NPK+FYM followed by 150% NPK and least being observed in control (**Table 6.10**). There was a marked increase in this form of P with increase in fertilizer level from 50% to 150%

Table. 6.10 Phosphorus and potassium fractions in post harvest soil of maize at Coimbatore

Treatment	Inorganic P fractions (mg kg^{-1})					OP (mg kg^{-1})	Potassium fractions (mg kg^{-1})			
	SP	Fe - P	Al - P	Ca - P	RSP		WSK	Exchangable	Non Ex.	Lattice
Control	6.7	14.6	13.8	51	13.8	257	20.9	76	182	2181
100% N	8.8	20.2	14.2	55	15.5	291	21.5	80	189	2304
100% NP	11.5	24.7	18.6	106	19.5	354	21.9	82	194	2257
50% NPK	9.7	22.1	17.4	77	17.6	304	22.7	87	220	2405
100% NPK	11.9	24.6	19.7	106	19.9	359	25.2	92	235	2473
150% NPK	17.8	30.8	20.3	135	23.0	411	26.1	101	253	2718
100% NPK + HW	12.1	24.1	20.8	108	19.8	366	24.8	93	230	2539
100% NPK + Zn	12.2	24.0	20.1	103	19.7	375	23.5	92	227	2591
100% NPK + FYM	17.7	31.3	21.7	141	23.6	420	26.7	103	251	2758
100% NPK (-S)	11.6	24.1	19.4	98	19.6	357	24.1	95	226	2629
CD (0.05)	0.67	1.97	0.72	6.01	0.82	18.9	0.75	4.4	9.3	99.3

RSP- Reductant soluble P; OP- Organic P; WSK- Water Soluble K; SP-Saloid P, Ex.- Exchangable of optimal NPK. Supplemental management practices such as 100% NPK+hand weeding, 100% NPK+$ZnSO_4$, 100% NPK (S free) recorded at par values of saloid P. The 50% NPK recorded lower value of iron-P content than 100% NP and 100% NPK. The iron-P content was found to be maximum with 100% NPK+FYM followed by 150% NPK. The least iron-P content was under the manured control plot. A similar trend was observed in case of aluminium P, calcium P, reductant soluble P, and organic P content in post-harvest soil of maize.

6.4.3 Potassium

The water soluble K fraction was the least among the K fractions evaluated (**Table 6.10)**. The 100% NPK +FYM and 150% NPK were statistical superior over rest of the treatments. The water soluble K increased with increasing NPK level from 50 to 150% NPK. A similar trend was observed w.r.t. exchangeable, non-exchangeable and lattice K.

6.5 Jabalpur (Vertisols)

6.5.1 Nitrogen

Total N content in soil increased successively as the dose of fertilizer increased from 50%, 100% and 150% NPK (**Table 6.11**). The highest total N was recorded with 100% NPK+FYM and the lowest in control. It is equal to sum of total hydrolysable-N and non-hydrolysable-N. A similar trend was found in case of inorganic N, total hydrolysable-N, Hydrolysable ammonical-N, hexose amine and hydrolysable ammonical-N, Amino acid-N, Unidentified hydrolysable-N. The value of unidentified hydrolysable-N was slightly higher in 100% NP than 100% N. The highest value of unidentified hydrolysable-N was recorded with 100% NPK+FYM. While, the lowest value of unidentified hydrolysable-N was observed in control 421 kg ha^{-1}. Non-hydrolysable-N increased with levels of fertilizer increased from 50%, 100% and 150% NPK. The maximum value of non-hydrolysable N was recorded with 100% NPK+FYM treatment. While, the lowest value of non- hydrolysable-N was observed control.

Table 6.11 Effect of long term application of fertilizers and manure on total nitrogen and nitrogen fractions in LTFE at Jabalpur

Treatment	Total N (kg ha^{-1})	Nitrogen fractions (kg ha^{-1})							
		IN	THN	HyAN	HA & HAN	HeAN	AN	UHN-N	NHN
Control	1306	122	939	259	277	18.2	241	420	367
100% N	1513	143	1088	281	310	29.1	289	489	425
100% NP	1540	148	1131	288	315	27.4	295	521	409
50% NPK	1463	142	1011	274	297	23.0	279	435	453
100% NPK	1621	152	1208	293	323	29.6	296	589	413
150% NPK	1723	174	1288	307	341	34.6	328	618	435
100% NPK+FYM	1819	188	1371	341	378	37.2	357	637	447
100% NPK-S	1568	151	1165	291	319	29.3	300	545	404
CD (0.05)	181.2	10.5	123.8	46.9	45.2	5.5	44.3	45.7	NS

IN-Inorganic-N (NH4-N+NO3-N); THN-Total Hydrolysable N; HyAN-Hydrolysable Ammonical N; HA & HyAN- Hexose amine and hydrolysable Ammonical N; HeAN- Hexose amine N; AN-Amino acid N; UHN- Unidentified Hydrolysable N; NHN-Non-hydrolysable N

6.5.2 Phosphorus

Phosphorous fractionation study showed that Ca-P form is the most dominant one (**Table 6.12)**. Use of P increased the P fractions while absence of P resulted in decline of Ca-P, available-P, Fe-P, Al-P, saloid–P, occluded-P fractions (**Figure 6.4**). It means P fractions are in equilibrium and responsible to maintain supply of P to plant.

Table 6.12 Effect of long term application of fertilizers and manure on distribution of phosphorus fractions in LTFE at Jabalpur

Treatment	Phosphorus fractions (mg kg^{-1})				
	Saloid-P	Al-P	Fe-P	Occluded-P	Ca-P
Control	3.1	7.4	10.2	4.2	89
100% N	4.0	10.1	14.3	5.4	96
100% NP	18.9	33.9	52.2	16.3	166
50% NPK	16.4	32.1	43.1	13.7	143
100% NPK	19.2	37.9	54.6	18.5	193
150% NPK	21.7	42.8	63.2	22.3	221
100% NPK-S	14.9	24.3	52.7	14.4	181
100% NPK+FYM	25.3	43.9	68.7	22.8	216
CD (0.05)	2.2	3.5	7.2	2.6	24.5

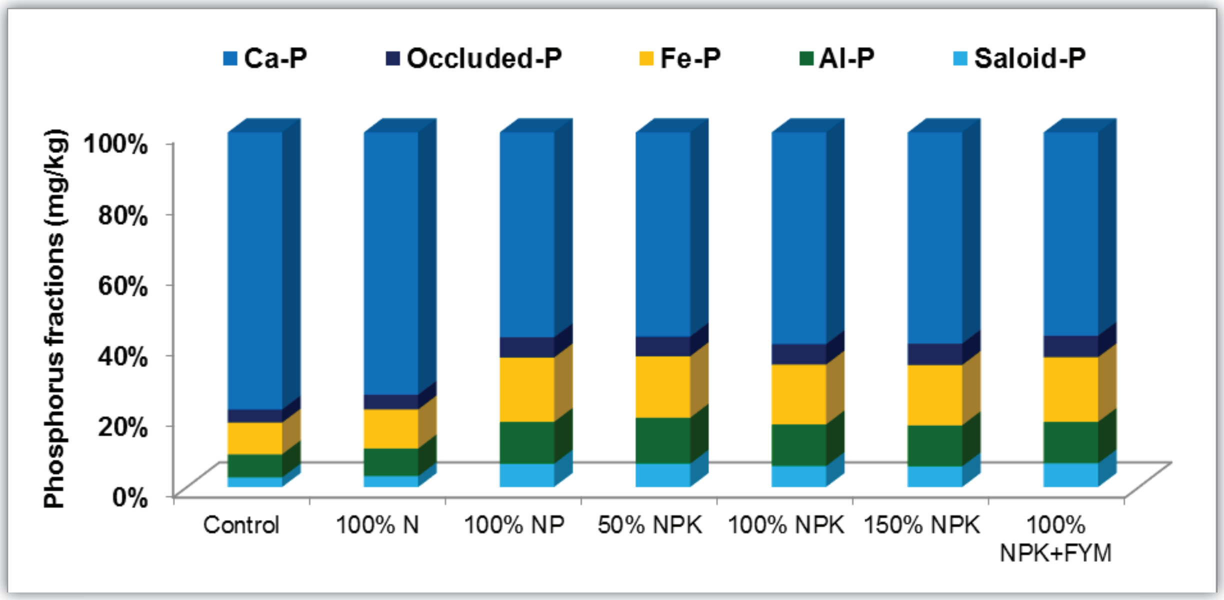


Figure 6.4 Impact of long term fertilizer and manure application on P fractions in LTFE at Jabalpur (Vertisols)

6.5.3 Potassium

The data (**Table 6.13**) showed that the water soluble-K increased successively and significantly from 100% N to 50% NPK, 100% NPK and 150% NPK. The maximum status was found in 100% NPK+FYM (**Figure 6.5**). While the lowest content of water soluble-K was confined in 100% N followed by 100% NP and control.

Statistically the treatments 100% N, 100% NP and control were at par with each other. Similar trend was found for exchangeable, non-exchangeable, lattice and total K content in soil. The contribution of different K fractions studied was in order of total-K> lattice K > non-exchangeable K > exchangeable K > water soluble K. Thus, findings indicated that the depleting K reserves due to mining of soil pool.

Table 6.13 Effect of different treatments on available K and its fractions in soil (mg kg^{-1}) in LTFE at Jabalpur

Treatment	Potassium forms (mg kg^{-1})					
	Available	Water soluble	Exchange-able	Non- Exchange-able	Lattice	Total
Control	105	15.9	89	737	3814	4655
100% N	96	15.2	86	730	3777	4608
100% NP	98	15.4	88	734	3792	4629
50% NPK	113	19.4	107	752	3892	4769
100% NPK	129	22.6	115	779	3990	4907
150% NPK	141	23.8	123	821	4306	5273
100% NPK + HW	127	22.4	112	780	3994	4909
100% NPK - S	128	22.2	113	776	3996	4908
100% NPK + Zn	129	22.5	115	781	3995	4914
100% NPK + FYM	142	25.1	126	860	4357	5368
CD (0.05)	11.3	4.1	9.4	78.2	371.3	411.5

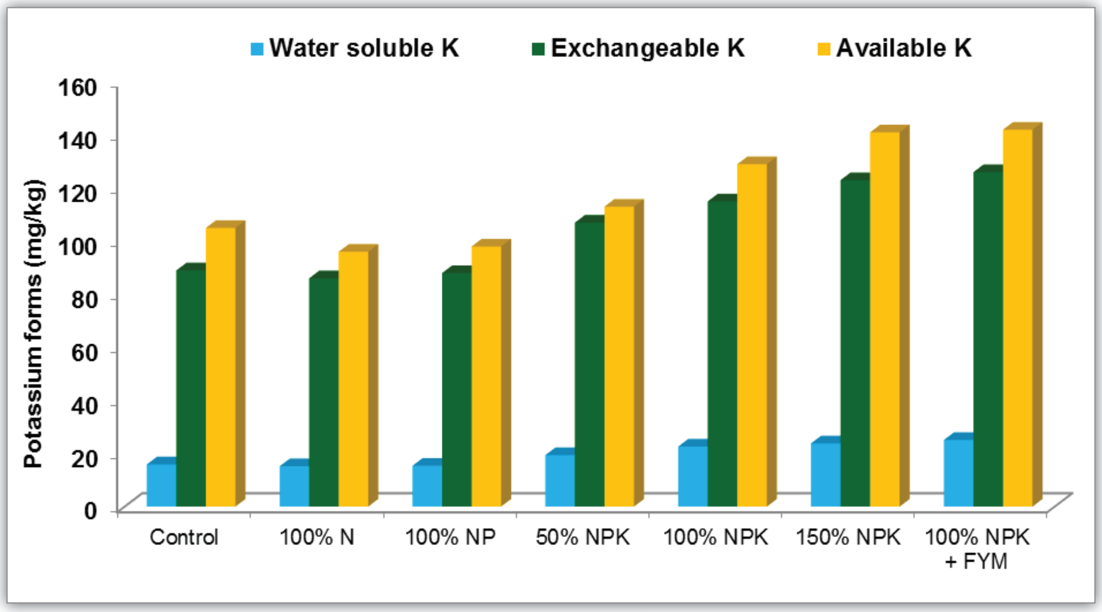


Figure 6.5 Impact of long term fertilizer and manure application on K forms in LTFE at Jabalpur (Vertisols)

6.5.4 Sulphur

Results indicated (**Table 6.14**) that the available S in soils gave lowest value of available S in control whereas the highest was in 100% NPK + FYM. The content of available S was found significantly higher in 100% NPK as compared to 100% NPK-S whereas the content of available S was found to be higher in 100% NP as compared to 50% NPK. A similar trend was seen for water soluble, heat soluble, organic and total S content in soil.

Table 6.14 Impact of long term addition of fertilizer and manure on distribution of Sulphur fractions in LTFE at Jabalpur

Treatment	Sulphur fractions (kg ha^{-1})				
	Available	Water soluble	Heat soluble	Organic	Total
Control	11.0	10.4	24.2	39.3	150
100% N	11.1	10.2	24.0	39.0	152
100% NP	29.0	24.5	37.0	55.3	209
50% NPK	22.1	15.6	34.6	65.1	195
100% NPK	31.2	26.1	38.6	71.2	211
150% NPK	35.1	31.7	41.1	73.1	217
100%NPK+HW	30.1	25.5	35.0	68.1	207
100% NPK – S	11.1	11.3	25.3	44.8	153
100% NPK +Zn	30.1	25.6	36.0	69.0	209
100% NPK+FYM	37.0	32.0	48.1	79.3	234
CD (0.05)	2.86	3.55	5.43	6.93	16.3

6.5.5 Zinc

The distribution of various fractions of Zn were found to be higher in 0-20 cm soil layer and continued to decrease with depth in all the treatments (**Table 6.15)**.

Table 6.15 Effect of continuous application of fertilizers and manure on Zn fractions in soil in LTFE at Jabalpur

Treatment	Zn fractions (mg kg^{-1})							
	Available	Water soluble	Exchangeable	Complexed	Organically bound	Occluded	Residual	Total
Control	0.32	0.04	0.13	0.19	0.50	0.52	49.7	51.1
100% N	0.48	0.05	0.14	0.19	0.55	0.58	50.8	52.3
100% NP	0.81	0.08	0.15	0.20	0.87	0.97	61.6	63.9
50% NPK	0.67	0.07	0.16	0.22	0.73	0.81	53.1	55.1
100% NPK	0.83	0.08	0.17	0.23	0.91	0.99	62.9	65.3
150% NPK	0.92	0.09	0.18	0.25	1.02	1.10	68.7	71.3
100% NPK+HW	0.65	0.07	0.16	0.22	1.01	0.78	53.7	55.9
100% NPK – S	0.59	0.06	0.15	0.21	0.65	0.70	51.5	53.3
100% NPK+Zn	1.19	0.12	0.26	0.37	1.28	1.43	76.1	79.6
100% NPK+FYM	1.09	0.11	0.24	0.34	1.19	1.30	69.6	72.7
CD (0.05)	0.13	0.01	0.03	0.04	0.15	0.15	8.04	8.18

Further, the water soluble, exchangeable, occluded and organically bound-Zn fractions jointly contributed only 5.3% part to the total-Zn, whereas the rest 94.7% was left in the residual fraction.

6.5.6 Humus

Application of fertilizer resulted increase in humin content in soil in absolute content, which means humin is most resident fraction of soil carbon. However, application of nutrient may alter the humin content to some extent. Application of nutrient resulted change in humin content from 3.63 g kg^{-1} in control to 6.52 g kg^{-1} in NPK+FYM (**Table 6.16**). Critical observation of data further revealed a decline in humin content with imbalance application of nutrient (N alone) and control. Incorporation of FYM over and above NPK further increased the humin content. However, similar trend was found for humin content on application of fertilizer, was due to decline in organic carbon. Humic acid is another important fraction of carbon which is relatively less resistant compared to humin. A similar trend was noted in case of humic and fulvic acid fractions of C. Fulvic acid is the third important fraction of soil carbon (**Figure 6.6**). Data on fulvic acid fraction soil carbon revealed that like humic acid and humin, increase in fulvic acid content on application of nutrient was observed. Absence of nutrient continuously for long time led to decline in absolute amount of fulvic acid content in soil. The lowest fulvic acid content in control plot recorded was 0.24 g kg^{-1} soil. Thus, 100% NPK+FYM improved humin, humic and fulvic acid content in Vertisols of Jabalpur. This could be the reason that it helps in sustaining crop productivity over the years.

Table 6.16 Impact of long term addition of fertilizer and manure on humus fractions in Vertisols of Jabalpur

Treatment	Humus fractions (g kg^{-1} soil)			HA:FA ratio
	Humin	Humic	Fulvic acid	
Control	3.63	0.32	0.24	1.30
100% N	4.51	0.41	0.31	1.29
100% NP	5.62	0.67	0.47	1.42
50% NPK	4.96	0.55	0.37	1.47
100% NPK	5.92	0.94	0.57	1.65
150% NPK	6.64	1.23	0.99	1.27
100% NPK+HW	6.02	0.92	0.56	1.65
100% NPK – S	6.09	0.64	0.47	1.38
100% NPK+Zn	6.07	0.95	0.58	1.66
100% NPK+FYM	6.52	1.35	1.10	1.24
CD (0.05)	1.38	1.62	1.20	0.263

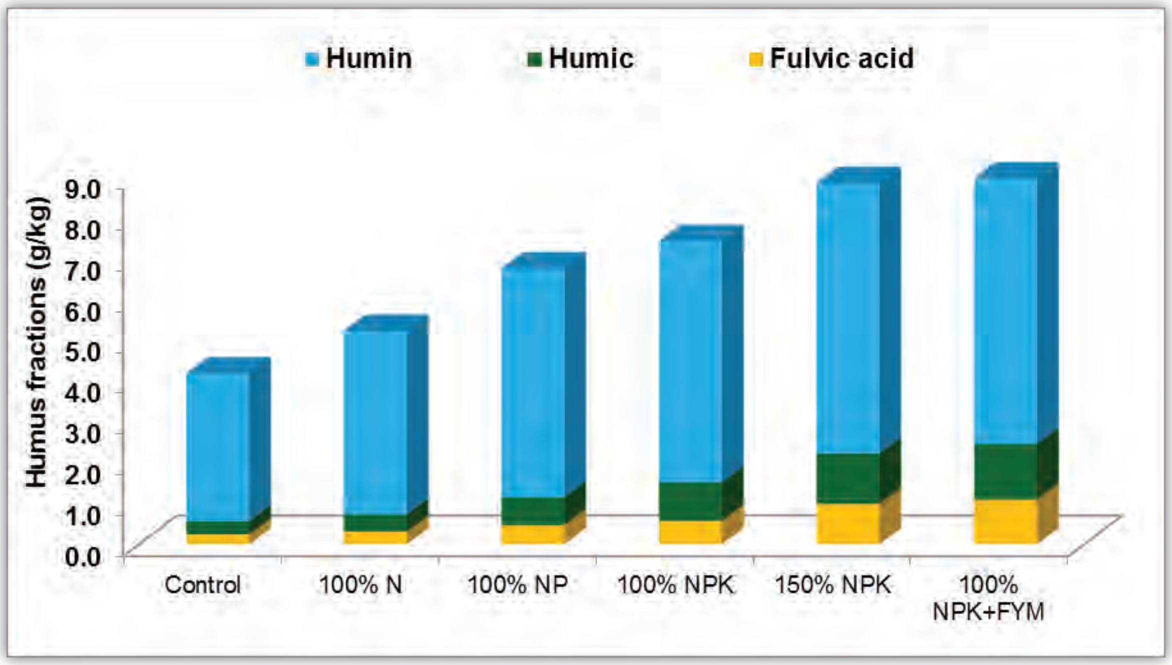


Figure 6.6 Impact of long term fertilizer and manure application on K forms in LTFE at Jabalpur (Vertisols)

6.6 IARI, New Delhi

6.6.1 Potassium

Soil samples were collected from the LTFEs at Ranchi (Alfisols), Delhi (Inceptisols) and Jabalpur (Vertisols) after harvest of *rabi* crops at 0-15 cm depth and analyzed for nutrient content.

6.6.1.1 Water soluble and exchangeable K

In Alfisols from Ranchi, highest water soluble K (WSK) was observed under NPK+FYM, followed by 150% NPK and lowest WSK under NP followed by N at 0–15 soil depths (**Table 6.17**). In the Inceptisols from Delhi, significantly higher WSK was observed at surface layer after long-term cultivation with 150% NPK than control, N and NP.

Table 6.17 Water soluble and exchangeable K in different soils as affected by nutrient supply options (0-15 cm depth)

Treatment	Water soluble K (kg ha^{-1})			Exchangeable K (kg ha^{-1})		
	Alfisols	Inceptisols	Vertisols	Alfisols	Inceptisols	Vertisols
Control	8.20	37.2	20.4	111	208	187
100% N	8.09	28.9	19.5	97	201	176
100% NP	7.10	34.7	16.6	85	189	169
100% NPK	14.6	38.8	23.5	104	237	244
100% 150% NPK	16.0	44.1	24.4	110	244	251
100% NPK+FYM	17.4	39.0	24.0	118	253	257
Mean	11.9	37.1	21.4	*104*	*222*	*214*
Uncultivated soil	19.8	39.9	38.1	161	274	308

In the Vertisols from Jabalpur, significantly higher WSK under NPK, 150% NPK and NPK+FYM was observed than unbalanced fertilization options *i.e.,* N and NP at 0–15 cm depth. Application of FYM along with recommended NPK significantly increased the WSK content over NPK alone. In the Alfisols (Ranchi), Inceptisols (Delhi) and Vertisols (Jabalpur), significant variations in exchangeable K (EK) were observed (**Table 6.17**). Irrespective of soil type and depth, NP showed the lowest EK contents, which were significantly lower than the K-fertilized treatments.

Table 6.18 The HNO_3-K and non-exchangeable K (NEK_{NaTPB}) in different soils as affected by nutrient supply options (0-15 cm depth)

Treatment	HNO_3-K (kg ha^{-1})			NEK_{NaTPB} (kg ha^{-1})		
	Alfisols	Inceptisols	Vertisols	Alfisols	Inceptisols	Vertisols
Control	1174	3096	1830	934	1779	1035
100% N	1214	2946	1725	907	1476	970
100% NP	1160	2916	1720	833	1425	916
100% NPK	1308	3356	1947	925	1743	907
150% NPK	1384	3414	2016	979	1765	945
100% NPK+FYM	1425	3456	2164	961	1839	930
Uncultivated soil	1212	3465	2238	914	1886	1136

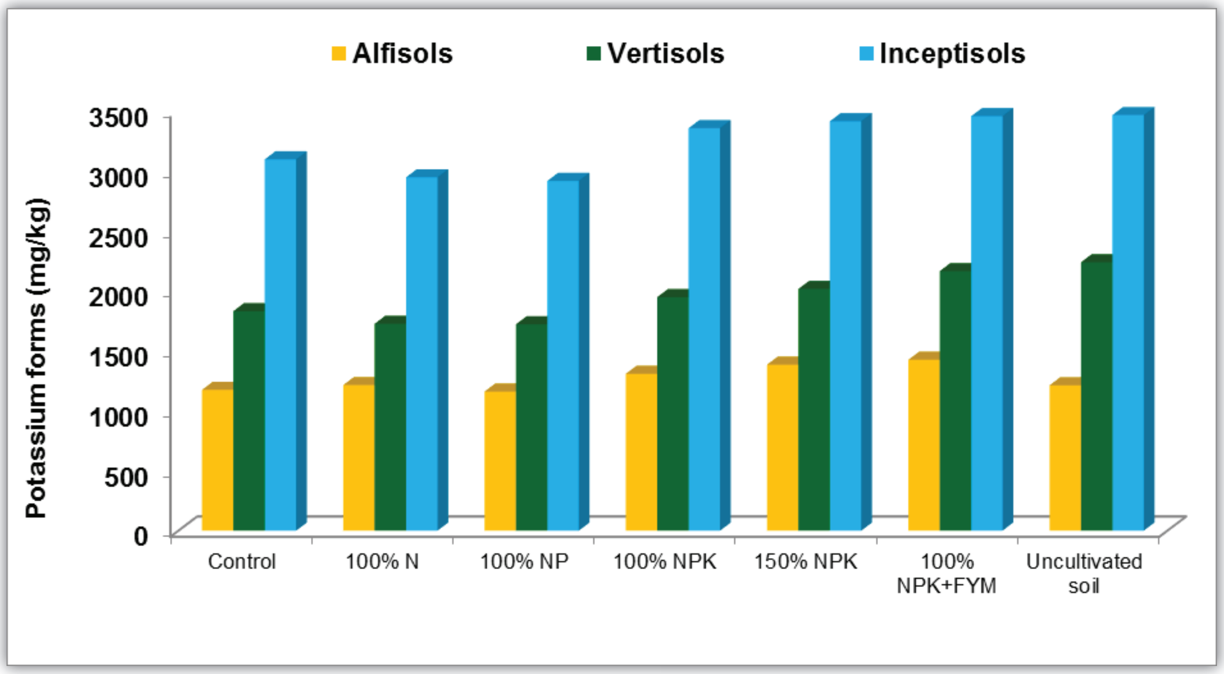


Figure 6.7 Impact of long term fertilizer and manure application on Nitric acid-K (HNO_3-K)

6.6.1.2 Nitric acid extractable K and non-exchangeable K

After more than four decades of intensive cultivation, clear negative influence of cropping without K fertilization on HNO_3-K was observed in surface as well as sub-surface soil layers across the soil types (**Table 6.18**). The NaTPB (NEK_{NaTPB}) was used for extraction of non-exchangeable K (NEK) with a contact time of five minutes and observed the effect of long-term cultivation with different fertilization options on NEK in soils (**Table 6.18**). Except the surface layer of Alfisols, treatment effects on NEK_{NaTPB} were significant (**Figure 6.7**). In the Alfisols and Inceptisols, unbalanced fertilization (without K) led to lowest contents of NEK, whereas K addition especially at more than recommended rates maintained higher NEK. The Vertisols did not show any positive influence of K fertilization over no fertilization or imbalanced fertilization on NEK.

6.6.1.3 Quantity/Intensity (Q/I) parameters

Study on Quantity/intensity (Q/I) parameters of soil K in LTFE of Alfisol at Ranchi was done and the results found from the study are presented as under:

Equilibrium activity ratio (AR_e^K) and free energy of exchange (ΔG^0)

At both depths, 150% NPK followed by NPK+FYM showed the highest AR_e^K values, whereas 100% NP showed the lowest values (**Table 6.19**). In surface soil, AR_e^K values under 150% NPK and NPK+FYM were significantly higher than the rest of the treatments. AR_e^K values were lower in cultivated than uncultivated soil. The mean AR_e^K values across six treatments were 44% and 32% lower than those under uncultivated soil at 0–15 and 15–30 cm depths, respectively.

Labile K fractions

Labile K was divided into non-specifically held K ($-\Delta K_0$) and specifically held K (K_s) (**Table 6.19**). The lowest $-\Delta K_0$ (3.26 mg kg^{-1}) among the treatments in surface soil. The values of $-\Delta K_0$ under control, N and NPK were at par, but significantly lower than 150% NPK and 100% NPK+FYM. Like AR_e^K, mean $-\Delta K_0$ across the treatments was lower in surface (8.97 mg kg^{-1}). Uncultivated soil showed higher values of $-\Delta K_0$ than the cultivated soils at both soil depths. Treatment effect on K_s was not significant in the surface soil, although the content under imbalanced fertilization (N and NP) tended to be lower than control and K-fertilized treatments.

Potential buffering capacity

Across the treatments, significant variations were observed in PBC^K (**Table 6.19**). The PBC^K ranged from 14.1 to 18.5 cmol$_c$ kg^{-1} at 0–15 cm and 16 to 19.1 cmol$_c$ kg^{-1} at 15–30 cm depth. The treatment 100% NP showed greater PBC^K than the K-fertilized treatments. The cropped soils invariably showed higher PBC^K than uncultivated soil.

Equilibrium solution K (CK_0), equilibrium exchangeable K (EK_0) and minimum exchangeable K (EK_{min})

At 0–15 cm, the equilibrium solution K concentration (CK_0) was as low as 2.01 mg L^{-1} in 100% NP (**Table 6.19**). The CK_0 under control, N and NPK were at par, but significantly greater than that under 100% NP and significantly lower than that under 150% NPK and NPK+FYM. The uncultivated soil showed greater CK_0 than the cropped soils. EK_0 of NP was significantly lower than the rest of the treatments. The same under 150% NPK and NPK+FYM were significantly greater than control, N, NP and NPK. Long-term cultivation with different nutrient management options resulted in significant variations in minimum exchangeable K (EK_{min}) (**Table 6.19**). At 0–15 cm, the K-fertilized treatments were at par with respect to EK_{min}. The EK_{min} under NP (23.6 mg L^{-1}) was significantly lower than other treatments. EK_0 and EK_{min} were very close under NP (3.1 mg kg^{-1}), moderately close under control (6.7 mg kg^{-1}), N (6.6 mg kg^{-1}) and NPK (6.5 mg kg^{-1}), whereas considerably much distant under 150% NPK (12.8 mg kg^{-1}) and NPK+FYM (10.3 mg kg^{-1}).

Table 6.19 Quantity/Intensity (Q/I) parameters of soil K under different nutrient management options

Treatment	$CK_0^{\#}$ (mg L^{-1})	AR_e^K ×10^4	$-\Delta K_0$ (mg kg^{-1})	K_s (mg kg^{-1})	EK_{min} (mg kg^{-1})	EK_0 (mg kg^{-1})	PBC^K ($cmol_c$ kg^{-1})	ΔG^0 (cal mol^{-1})
Control	4.51	11.1	7.98	45.3	27.2	33.9	18.5	–4035
100% N	5.44	13.3	8.10	38.7	29.9	36.5	15.7	–3924
100% NP	2.01	4.76	3.26	37.9	23.6	26.7	17.8	–4541
100% NPK	4.95	12.4	8.15	44.9	31.4	37.9	17.1	–3982
150% NPK	9.29	23.8	13.1	43.3	30.4	43.2	14.1	–3577
100% NPK+FYM	8.33	21.3	13.3	46.9	31.2	41.5	16.0	–3643
Mean	*5.75*	*14.4*	*8.97*	*42.8*	*28.9*	*36.6*	*16.5*	*–3950*
Uncultivated soil	9.75	25.8	13.4	67.4	34.5	45.3	13.3	–3530

#CK_0- equilibrium K concentration; AR_e^K- equilibrium activity ratio; $-\Delta K_0$- non-specifically held K; K_s- specifically held K; EK_{min}- minimum exchangeable K; EK_0- equilibrium exchangeable K; PBC^K- potential buffering capacity; ΔG^0- standard free energy of exchange

6.6.2 Zinc

Soil samples (0-15 cm) were collected from AICRP-LTFE, Delhi centre after harvest of wheat (2018) to study the long-term effect of fertilization and manuring on soil Zn fractions and sorption-desorption of Zn in soil.

6.6.2.1 Zn fractions

On an average, the water soluble plus exchangeable (Zn_{WSE}), carbonate bound ($Zn_{carbonate}$), oxide bound (Zn_{oxide}), organically bound ($Zn_{organic}$) and residual Zn ($Zn_{residual}$) contributed 0.26 to 0.58%, 0.34 to 0.82%, 1.87 to 3.81%, 5.4 to 9.2%, 86 to 90% of total Zn, respectively (**Figure 6.8**). Value of Zn_{WSE} was highest in NPK+Zn (0.80 mg kg^{-1}) whereas lowest with control (0.32 mg kg^{-1}). Application of FYM along with NPK resulted in significantly higher value of Zn_{WSE} which was ~ 62% and ~ 44% higher than the control and NPK, respectively. Carbonate bound Zn ranged between 0.40 to 1.14 mg kg^{-1}. Treatment with integrated nutrient management (NPK+FYM) showed lowest $Zn_{carbonate}$ which was ~ 45% lower than that of control. The NPK+ Zn registered ~ 50% higher $Zn_{carbonate}$ than that under control. Continuous application of fertilizers with or without FYM under intensive cropping caused significant decrease in Zn_{oxide} in all treatments compared to control, except NPK+Zn which registered highest Zn_{oxide} among all treatments. Integrated use of FYM along with the NPK caused ~ 30% reduction of oxide-bound Zn compared to control followed by 16.8% in 150% NPK treated plots. Application of Zn or FYM with NPK significantly improved $Zn_{organic}$ fraction. The $Zn_{organic}$ was highest under NPK+FYM (4.40 mg kg^{-1}) which was significantly greater than NPK+ Zn (3.67 mg kg^{-1}). The application of NPK+Zn and NPK+FYM registered ~ 12% and ~ 38% higher $Zn_{organic}$ as compared to NPK, respectively. The residual Zn varied from 96.7 to 119 mg kg^{-1} under 150% NPK and NPK+Zn respectively. The Zn-treated plots had significantly higher $Zn_{residual}$ than all other treatments, whereas the values were similar under N, NP, NPK, 150% NPK and NPK + FYM. The Zn_{Total} varied from 108 mg kg^{-1} under 150% NPK to 138.48 mg kg^{-1} under NPK + Zn.

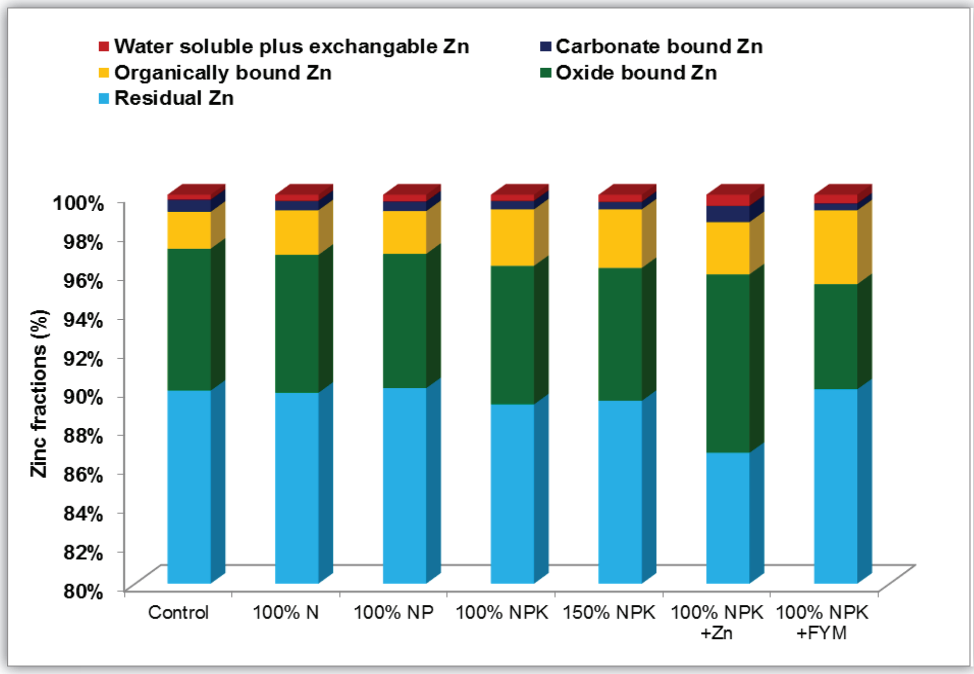


Figure 6.8 Effect of long-term nutrient management options on distribution of Zn fractions in surface soil

6.6.2.2 Inter-relationship between different fractions of Zn

The Zn_{WSE} was significantly and positively correlated with $Zn_{carbonate}$ (r = 0.73**), Zn_{oxide} (r = 0.68**), $Zn_{organic}$ (r= 0.53*), $Zn_{residual}$ (r= 0.71**) as well as Zn_{Total} (r = 0.77**). $Zn_{carbonate}$ showed positive correlation with the Zn_{oxide} (r = 0.91**), $Zn_{residual}$ (r = 0.69**) and Zn_{Total} (r = 0.76**). A significant correlation was observed between oxide-bound Zn and residual Zn (r = 0.69**) as well as between oxide bound Zn and total Zn (r = 0.77**). On the other hand, organically bound Zn did not show any significant correlation with total or residual Zn. A strong positive correlation was observed between total and residual Zn (r = 0.98**) (**Table 6.20**). Amongst different fractions, water soluble plus exchangeable Zn and organically bound Zn were positively correlated with the total Zn uptake, whereas grain yield of wheat showed significant correlations only with organically bound Zn (r = 0.67**).

Table 6.20 Correlation coefficient amongst different fractions of Zn, and with total Zn uptake and grain yield of wheat

Fractions	Zn_{WSE}	$Zn_{carbonate}$	Zn_{oxide}	$Zn_{organic}$	$Zn_{residual}$	Zn_{Total}
Zn_{WSE}	1					
$Zn_{carbonate}$	0.73**	1				
Zn_{oxide}	0.68**	0.91**	1			
$Zn_{organic}$	0.53*	-0.066	-0.001	1		
$Zn_{residual}$	0.71**	0.69**	0.69**	0.21	1	
Zn_{Total}	0.77**	0.76**	0.77**	0.25	0.98**	1
Zn_{uptake}	0.59*	0.13	0.22	0.73**	0.14	0.21
Y_{grain}	0.28	-0.19	-0.08	0.67**	-0.12	-0.06

6.6.2.3 Zinc adsorption and desorption

Adsorption of Zn

Adsorption of Zn was markedly varied among various nutrient management options. Amongst various fertilizer treatments, Zn adsorption was maximum under control followed by N alone, whereas minimum adsorption of Zn was registered under NPK+Zn treatment followed by NPK+FYM. The Zn adsorption continuously increased with increasing Zn concentration of added solution even at 40 µg mL^{-1} indicating that adsorption maxima was not achieved. Results further underlined that with increased in Zn concentration of added solution, adsorption of Zn was increased from 198 to 760 µg g^{-1} in control followed by 198 to 750 µg g^{-1} in N alone treatment which showed the maximum adsorption, and from 197 to 690 µg g^{-1} in NPK+Zn treatment followed by 192 to 702 µg g^{-1} in NPK+FYM where adsorption of Zn was minimum. Adsorption and desorption data obtained from the experiment was fitted to different adsorption isotherms.

Langmuir adsorption isotherm

Langmuir constant (adsorption maxima and affinity coefficient) and regression equation obtained by fitting adsorption data in the linear form of Langmuir equation are given in (**Table 6.21)**. The adsorption data fitted well in Langmuir equation.

Table 6.21 Effect of long-term nutrient management options on Zn adsorption as fitted to Langmuir adsorption equations

Treatment	Equation	b	k	MBC
Control	C/X = 0.001127 C + 0.000455	886	2.52	2230
100% N	C/X = 0.001197 C + 0.000444	839	2.70	2258
100% NP	C/X = 0.001282 C + 0.000587	779	2.20	1712
100% NPK	C/X = 0.001279 C + 0.000638	782	2.01	1571
150% NPK	C/X = 0.001273 C + 0.000816	785	1.57	1233
100% NPK+Zn	C/X = 0.001379 C + 0.001013	724	1.37	994
100% NPK+FYM	C/X = 0.001337 C + 0.000935	746	1.46	1084

The value of adsorption maxima ‘b’ ranged from 724 to 886 µg g^{-1} among different nutrient management options (**Table 6.21**). Adsorption maxima were highest under the control (886 µg g^{-1}) and were significantly greater, compared with all other treatments. On the other hand, the lowest value of ‘b’ was obtained under NPK+Zn which was statistically at par with NPK+FYM treatment, with the values being significantly lower compared with other treatments. On the other hand, ‘b’ in NPK and 150% NPK treatments were similar, and the values were significantly lower than N alone plot. Affinity coefficient or bonding energy represented by ‘k’ was highest (2.70 mL µg^{-1}) under NP, which was statistically at par with control. On the contrary, Zn treated plot showed the minimum value of ‘k’ (1.37 mL µg^{-1}) that statistically at par with NPK+FYM and NPK (**Table 6.21**). The maximum buffering capacity (MBC) was calculated from Langmuir adsorption isotherm. Minimum and maximum values of buffering capacity (MBC) were documented under NPK+Zn and N alone with corresponding value of 994 and 2258, respectively.

Freundlich adsorption isotherm

Freundlich constant (‘1/n’ and ‘a’) and regression equation was obtained by fitting adsorption data in the linear form of Freundlich equation (**Table 6.22**).

The value of slope (1/n) was highest under control (0.42) and lowest under NPK+Zn (0.31) and NPK+FYM (0.32), respectively. Freundlich slope under NPK and 150% NPK was statistically at par with NP treated plots (**Table 6.22**). Nutrient management options significantly affected the 'a' value of the Freundlich equation. It ranged from 379 to 578 among treatments. Control registered maximum value of 'a' which was significantly higher than all other treatments. The lowest 'a' value was recorded under NPK+Zn and NPK+FYM, with the values being ~ 34% and ~ 28% lower than control, respectively.

Table 6.22 Effect of long-term nutrient management options on Freundlich adsorption parameters

Treatment	Equation	1/n	A
Control	Log x = 0.418 Log c + 2.762	0.42	578
100% N	Log x = 0.387 Log c + 2.734	0.39	546
100% NP	Log x = 0.339 Log c + 2.665	0.34	464
100% NPK	Log x = 0.347 Log c + 2.651	0.35	448
150% NPK	Log x = 0.363 Log c + 2.618	0.36	418
100% NPK+Zn	Log x = 0.307 Log c + 2.578	0.31	379
100% NPK+FYM	Log x = 0.318 Log c + 2.596	0.32	396

Coefficient of determination value (R^2) for different adsorption equation

Coefficients of determination (R^2) varied from 0.95 to 0.99 in case of both Langmuir, and Freundlich isotherms (**Table 6.23**).

Table 6.23 Coefficient of determination value (R^2) for different adsorption equation

Treatment	Langmuir Equation	Freundlich Equation
Control	0.98	0.99
100% N	0.98	0.98
100% NP	0.99	0.95
100% NPK	0.99	0.99
150% NPK	0.99	0.99
100% NPK + Zinc	0.95	0.99
100% NPK + FYM	0.95	0.98

Among the seven treatments, N alone, NPK and 150% NPK were well fitted to both equations compared with other treatments. Treatments NPK+ FYM and NPK+ Zn were well-fitted to Freundlich equation followed by Langmuir equation.

Inter-relationship among the different adsorption parameters

All the adsorption parameters were positively and significantly correlated with each other with r^2 value ranged between r = 0.67** for Langmuir k and Freundlich "1/n" to r = 0.99** for Temkin b and Freundlich a parameters (**Table 6.24**)

Desorption of adsorbed Zn

Cumulative desorption of added Zn was highest under 100% NPK+FYM followed by 100% NPK+Zn. Similar type desorption was found under 100% NP, 100% NPK and 150% NPK whereas least desorption was

Table 6.24 Correlation coefficient among different adsorption parameters

Parameters	Langmuir b	Langmuir k	Freundlich a	Freundlich (1/n)
Langmuir b	1			
Langmuir k	0.74**	1		
Freundlich a	0.94**	0.91**	1	
Freundlich (1/n)	0.95**	0.67**	.83**	1
Temkin-a	0.96**	0.68**	0.86**	0.99**
Temkin-b	0.93**	0.92**	0.99**	0.83**

recorded under control. Desorption of Zn was higher at initial desorption step which reduced significantly at later stage. Maximum value of cumulative desorption of Zn during 4 stage of desorption was 55.5 µg g^{-1} under 100% NPK+FYM followed by 50.4 µg g^{-1} under 100% NPK+FYM which showed maximum cumulative desorption. Minimum value of cumulative desorption was 18.3 µg g^{-1} under control followed by 22 µg g^{-1} under N alone. Data obtained from 4 desorption steps was fitted into Freundlich equation, from which Freundlich constants for desorption as well as desorption index was calculated (**Table 6.25**).

Table 6.25 Effect of long-term nutrient management options on Freundlich desorption parameters with respect to desorption of added Zn

Treatments	Equation	Equation parameters		Desorption index	r^2
		1/n	a		
Control	Log x = 0.008 Log c + 2.878	0.008	756	61.3	0.8
100% N	Log x = 0.016 Log c + 2.869	0.016	740	30.7	0.97
100% NP	Log x = 0.028 Log c + 2.833	0.028	682	12.8	0.96
100% NPK	Log x = 0.028 Log c + 2.833	0.028	679	12.7	0.96
150% NPK	Log x = 0.028 Log c + 2.817	0.028	654	12.9	0.94
100% NPK+Zn	Log x = 0.033 Log c + 2.812	0.033	650	9.5	0.95
100% NPK+FYM	Log x = 0.039 Log c + 2.819	0.039	659	8.5	0.98

Highest slope of Freundlich desorption isotherm was observed under 100% NPK+FYM and 100% NPK+Zn treated plots with the value of 0.039 and 0.033, respectively, while minimum value was obtained under control (0.008) and 100% N alone (0.016) (**Table 6.25**). Treatments NPK and 150% NPK had similar values of '1/n', which were significantly higher than control and significantly lower than 100% NPK+FYM. The desorption index (DI) was comparatively higher in control or imbalanced fertilization. Control registered highest DI (61.3) whereas it was lowest under 100% NPK+FYM (8.5). Treatments 100% NPK, 150% NPK, 100% NPK+Zn and 100% NPK+FYM registered statistically similar DI.

6.7 Pantnagar (Mollisols)

6.7.1 Nitrogen

Data generated on N fractions after 48 years revealed that incorporation of FYM in combination with fertilizer resulted in significant increase of total N, available N, NH_4- N and NO_3 -N as compared to control (**Table 6.26**). However, continuous use of organic manure in combination with inorganic fertilizers significantly increased total N, available N, NH_4-N and NO_3-N in comparison to other treatments. A balanced use of nutrient fertilizers increase total N, available N, NH_4-N and NO_3-N over imbalanced use of fertilizers. Improvement in total N, available N, NH_4-N and NO_3-N could be attributed to the higher microorganisms population and beneficial effect of organic matter decomposition into the soil nitrogen.

Table 6.26 Effect of fertilizers and manure on N fractions (0-15 cm) in LTFE at Pantnagar (2018-19)

Treatment	Nitrogen fractions (kg ha^{-1})			
	Available N	Total N	NO_3-N	NH_4-N
Control	172	563	7.21	16.23
100% N + Zn	232	751	11.68	21.25
100% NP + Zn	238	833	10.87	21.08
50% NPK + Zn	233	640	12.00	12.23
100% NPK	242	809	14.50	24.15
150% NPK	307	852	18.10	27.18
100% NPK + HW + Zn	244	876	15.58	26.35
100% NPK-S + Zn	213	886	13.43	23.14
100% NPK + Zn	235	857	16.60	26.75
100% NPK + FYM	337	982	10.56	20.14
Fallow	280	907	12.60	25.36
CD (0.05)	11.4	13.0	0.40	1.84

6.7.2 Phosphorus

Data generated on P fractions after 48 years revealed that incorporation of FYM in combination with fertilizer resulted significant increase in total P, saloid P, available P, Fe-P, Al-P and Ca -P as compared to all other fertilizer treatments and control (**Table 6.27**). The total P, saloid P, available P, Fe-P, Al-P and Ca -P might be due to addition of P through fertilizer as well as organic matter which in turn increased the availability in soil.

Table 6.27 Effect of fertilizers and manure on P fractions (0-15 cm) in LTFE at Pantnagar (2017-18)

Treatment	P fractions (kg ha^{-1})					
	Available P	Total P	Ca-P	Saloid-P	Fe-P	Al-P
Control	7.5	310	111	10.9	16.6	7.0
100% N + Zn	12.2	418	105	10.5	16.9	9.5
100% NP + Zn	19.4	443	140	17.9	25.8	12.3
50% NPK + Zn	15.1	436	134	17.1	23.1	12.5
100% NPK	18.7	435	135	18.2	23.3	12.9
150% NPK	34.3	459	146	21.4	24.9	15.3
100% NPK + HW + Zn	18.5	429	133	17.8	22.7	12.2
100% NPK + Zn	20.1	437	134	17.3	23.1	12.7
100% NPK + FYM	35.8	560	144	21.8	25.4	15.5
100% NPK-S + Zn	20.5	444	120	17.7	23.9	13.1
Fallow	22.0	450	150	20.0	23.5	12.5
CD (0.05)	6.4	16.0	14.4	3.01	3.43	2.01

6.7.3 Potassium

Data generated on K forms after 48 years revealed that incorporation of FYM in combination with fertilizer resulted significant increase in total K, exchangeable K. soluble K and fixed K as compared to all other fertilizer treatments and control (**Table 6.28**). However, continuous use of organic manure in combination with inorganic fertilizers significantly increased total K, exchangeable K, soluble K and fixed K in comparison to all other fertilizer treatments. The increase in total K, exchangeable K, soluble K and fixed K might be due to addition of K through fertilizer as well as organic matter which in turn increase the availability in soil. Balanced use of nutrient fertilizers increase total K, exchangeable K, soluble K and fixed K over unbalanced use of fertilizers.

Table 6.28 Effect of fertilizers and manure on K fractions (0-15 cm) in LTFE at Pantnagar (2018-19)

Treatment	K fractions (kg ha^{-1})			
	Available	Exchangeable	Non-exchangeable	Total
Control	91	204.2	1510	12397
100% N + Zn	95	232.1	1508	14248
100% NP + Zn	97	230.3	1500	15672
50% NPK + Zn	129	246.9	1607	15735
100% NPK	135	248.9	1638	16447
150% NPK	152	280.8	1753	28780
100% NPK + H.W. + Zn	134	253.1	1640	25003
100% NPK + Zn	129	247.8	1622	24011
100% NPK + FYM	159	292.2	1758	29937
100% NPK-S + Zn	137	258.5	1611	24567
Fallow	150	299.9	1760	24551
CD (0.05)	17.4	12.4	190.1	490.0

6.8 Parbhani (Vertisols)

6.8.1 Soil carbon

Soil carbon forms as influenced by long term use of organic and inorganic fertilizers were recorded and results indicated that the maximum carbon forms were observed in the treatment receiving organic with inorganic nutrient sources i.e. 100% NPK+FYM @ 5 Mg ha^{-1} followed by only organic manuring treatment as FYM @ 10 Mg ha^{-1} (**Table 6.29**). However, lowest were recorded in the control followed by imbalance use of inorganic fertilizers i.e. only 100% N. Forms of different carbon were increasing with increasing inorganic fertilizers dose, results showed that 150% NPK fertilizer dose recorded higher carbon forms as compare to 50% NPK and 100% NPK fertilizer dose.

Table 6.29 Forms of soil carbon as influenced by long term use of organic manure and inorganic fertilizers under soybean-safflower cropping sequence (2016-17)

Treatment	Organic carbon (g kg^{-1})	Inorganic carbon (g kg^{-1})	Total organic carbon (g kg^{-1})	Labile carbon (mg kg^{-1})	Water soluble carbon (mg kg^{-1})	Carbohydrate carbon (mg kg^{-1})
Control	5.6	7.7	13.2	242	13.3	13.3
100% N	5.7	8.4	14.1	262	18.9	18.9
100% NP	5.9	8.9	14.8	287	20.8	20.8
50% NPK	6.0	9.0	15.0	268	20.5	20.5
100% NPK	6.4	9.3	15.7	289	25.3	25.3
150% NPK	6.6	10.4	17.0	350	29.9	29.9
100% NPK+HW	6.5	9.4	15.9	273	25.0	25.0
100% NPK+Zn	6.6	10.0	16.6	292	26.3	26.3
100% NPK-Sulphur	5.8	9.2	15.0	285	23.5	23.5
FYM @10 Mg ha^{-1}	6.7	11.1	17.8	379	31.1	31.1
100% NPK+FYM @ 5 Mg ha^{-1}	7.1	11.4	18.5	387	32.6	32.6
Fallow	5.7	8.7	14.4	261	18.6	18.6
CD (0.05)	0.28	0.77	1.18	17.9	2.76	2.76

6.8.2 Sulphur

Soil sulphur forms as influenced by long term use of different inorganic and organic fertilizers differed significantly were recorded and presented in (**Table 6.30**).

Table 6.30 Forms of sulphur as influenced by long term use of organic manure and fertilizers under LTFE at Parbhani (2017-18)

Treatment	Sulphur fractions (mg kg^{-1})				
	Organic	Sulphur	Water	Heat Soluble	Total
Control	29	113	10.5	1.27	142
100% N	31	113	10.8	1.31	145
100% NP	32	121	11.0	1.38	149
50% NPK	31	114	10.9	1.24	146
100% NPK	31	115	10.9	1.25	148
150% NPK	33	116	12.5	1.34	150
100% NPK+HW	32	115	11.2	1.47	147
100% NPK-S	30	114	11.2	1.22	138
100% NPK+Zn	34	116	11.0	1.49	150
FYM @ 10 Mg ha^{-1}	35	118	11.3	1.45	152
100% NPK+FYM @ 5 Mg ha^{-1}	37	118	12.3	1.46	154
Fallow	28	117	10.2	1.19	143
CD (0.05)	3.8	3.9	0.6	0.1	6.7

Results indicated that the maximum values of S forms were observed in the 100% NPK+FYM @ 5 Mg ha^{-1} followed by FYM @ 10 Mg ha^{-1}. Lowest soil S forms were recorded in the control. Forms of different S were increased with increasing inorganic fertilizers dose, results showed that 150% NPK fertilizer dose recorded higher S forms as compared to 50% NPK and 100% NPK application.

6.9 Ludhiana (Inceptisols)

6.9.1 Zinc

The water soluble + exchangeable Zn (Ws+Ex-Zn) and specifically adsorbed Zn (SpAd-Zn) varied from 0.47 to 1.34 and 0.83 to 1.72 mg kg^{-1} in control and 100% NPK + Zn treated plots, respectively (**Table 6.31**). The Carb-Zn varied from 1.25 to 2.83 mg kg^{-1} in 150% NPK and 100% NPK + Zn treatment. The organically bound Zn was highest in Zn treated plots and lowest in control with the values of 2.14 and 4.04 mg kg^{-1}, respectively. Manganese oxide bound (MnOx-Zn) ranged from 1.38 to 3.13 mg kg^{-1} in control and Zn amended plots, respectively. Result indicated that Amor Fe-Zn ranged from 2.0 mg kg^{-1} in 150% NPK to 4.21 mg kg^{-1} in Zn treated plots. Crystalline Fe oxide bound Zn (Cryst Fe-Zn) ranged from 21.2 mg kg^{-1} in plots receiving 150% NPK to 32.0 mg kg^{-1} in control after 43 years since inception of the experiment. Application of chemical fertilizers alone or in combination with FYM showed a significant decline in Cryst Fe-Zn as compared to control.

The Res-Zn content varied from 27.5 to 53.0 mg kg^{-1} in control and Zn treated treatments, respectively. Res-Zn was 0.35 mg kg^{-1} higher in 150% NPK plots while 5.75 mg kg^{-1} lower in 50% NPK treatment as compared to 100% NPK treatment. Total-Zn was highest in the plots under NPK+Zn treatment. The total-Zn in soil varied from 68.7 mg kg^{-1} in control to 92.7 mg kg^{-1} in Zn amended plots. Total-Zn in FYM treated plots was higher by 6.5% over 100 per cent NPK alone treatment. The total-Zn in soils increased with the application of fertilizers and amendments as compared to zero-fertilization over the years (**Table 6.31**).

Table 6.31 Effect of long-term application of farmyard manure and chemical fertilizers on zinc fractions (2017-18)

Treatment	Zinc fractions (mg kg^{-1})								
	WS+Ex	SpAd	Carb	OM	MnOx	Amor Fe	Cryst Fe	Res	Total
Control	0.47	0.83	2.45	2.14	1.38	3.22	32.0	26.3	68.8
100% N	0.69	0.90	1.44	2.77	1.43	2.45	23.0	38.3	70.9
100% NP	0.67	0.87	1.65	2.76	1.41	2.59	23.6	38.2	71.8
50% NPK	0.64	0.87	1.48	2.75	1.88	2.63	24.7	34.5	69.4
100% NPK + W	0.76	0.90	1.35	3.16	2.19	2.13	21.9	46.5	78.9
150% NPK	0.79	0.95	1.25	3.19	1.46	2.00	21.2	43.8	74.7
100% NPK	0.77	0.91	1.36	3.18	2.09	2.20	22.1	44.7	77.3
100% NPK + Zn	1.34	1.72	2.83	4.04	3.13	4.21	25.6	49.8	92.7
100% NPK + FYM	0.97	1.37	2.22	3.66	2.61	2.93	28.5	40.0	82.2
100% NPK (-S)	0.72	0.90	1.61	3.08	1.93	2.25	22.5	40.2	73.1

6.9.2 Carbon dynamics and sequestration

6.9.2.1 Potassium permanganate oxidisable carbon ($KMnO_4$-C)

The continuous application of fertilizers for 46 years in maize-wheat cropping system resulted in significant effect on $KMnO_4$-C (**Table 6.32**). In the surface soil (0-15 cm), $KMnO_4$-C ranged from 1.34 g kg^{-1} under control to 2.02 g kg^{-1} under 100% NPK+FYM. The $KMnO_4$-C is the sensitive fraction of SOC, which can be easily influenced by management practices. Determination of $KMnO_4$-C is a vital tool for studying the impact of management practices on SOC on short-term basis. In the present study, the $KMnO_4$-C significantly improved under the application of fertilizer compared to control. The improvement of $KMnO_4$-C was 12% under 100% N, 28% under 100% NP, 37% under 100% NPK and 44% under 150% NPK in comparison to control. The conjunctive use of fertilizer along with FYM resulted in significantly higher $KMnO_4$-LC, which was 51% and 10% higher compared to control and 100% NPK, respectively. In the sub-surface soil, $KMnO_4$-C ranged from 1.06 g kg^{-1} under control to 1.51g kg^{-1} under 100% NPK+FYM. The $KMnO_4$-C was significantly higher under 100% NPK, 150% NPK and 100% NPK+FYM treatments, but the effect was statistically at par.

6.9.2.2 Oxidizable soil organic carbon fractions

Data related to the effect of long-term fertilizer application on oxidizable fractions of SOC i.e. very labile (C_{frac1}), labile (C_{frac2}), less labile (C_{frac3}) and recalcitrant (C_{frac4}) C fraction are illustrated in (**Table 6.32**). The data revealed that the stability of improved SOC is not uniform under different fertilizer treatments. Very labile and labile C fractions of SOC are highly responsive to fertilizer managements compared to less labile and recalcitrant fractions. The concentrations of C_{frac1}, C_{frac2}, C_{frac3} and C_{frac4} (g kg^{-1}) in the surface soil ranged at 1.16-2.64, 0.97-1.62, 0.65-1.37 and 0.56-1.14, respectively, and in the sub-surface soil, ranged 0.90-2.11, 0.81-0.92, 0.70-1.40 and 0.61-1.32, respectively.

Irrespective of the fertilizer management, the mean concentrations of different fractions of SOC was followed the order as $C_{frac1} > C_{frac2} > C_{frac3} > C_{frac4}$. The NPK+FYM treatments had higher values over control for all the fractions in both surface and sub-surface soils. There was a greater accumulation of C_{frac1} and C_{frac2} in the surface soils and C_{frac3} and C_{frac4} in the sub-surface soils. The first two most easily oxidizable fractions, C_{frac1} and C_{frac2}, together constituted about 73% and 59% of the SOC and TOC, respectively.

Table 6.32 Effect of long-term application of inorganic fertilizer and manure on oxidizable soil organic carbon fractions (0-15 cm) in LTFE at Ludhiana (2017-18)

Treatment	Carbon fractions (g kg^{-1})				
	Very labile fraction	Labile fraction	Less labile fraction	Recalcitrant fraction	$KMnO_4$-C
Control	1.16	0.97	0.65	0.56	1.34
100% N	1.24	1.06	0.98	0.86	1.50
100% NP	1.45	1.09	1.04	0.87	1.72
100% NPK	1.90	1.17	1.23	0.97	1.83
150% NPK	1.98	1.17	1.23	1.13	1.93
100% NPK+FYM	2.64	1.62	1.37	1.14	2.02

6.10 Raipur (Vertisols)

6.10.1 Nitrogen

Nutrients both natives as well as applied either through chemical fertilizers or by way of organic amendments undergo a series of transformation and due to continuous manuring and cropping which in turn may have substantial impact on their availability to crops. Results with respect to different forms of nitrogen in relation to long-term addition of inorganic fertilizers alone or in combination with FYM under different treatment have been presented in **Table 6.33**.

Table 6.33 Nitrogen fractions in Vertisols of Raipur (2017-18)

Treatment	Nitrogen fractions (mg kg^{-1})	
	Ammonical – N	Nitrate – N
Control	51	130
100% N	94	159
100% NP	107	170
50% NPK	91	159
100% NPK	114	179
150% NPK	142	215
100% NPK+Zn	119	190
100% NPK+FYM	135	217
50% NPK+Blue Green Algae (BGA)	96	160
50% NPK+Green Manure (GM)	114	189
CD (0.05)	12	22

Application of fertilizers alone or in combination with FYM resulted in a significant build up of ammonical nitrogen over control (**Table 6.33**). Data showed that ammonical N of the soil varied from 51 to 142 mg kg^{-1} amongst various treatments at 0-15 cm depth.

Table 6.34 Sulphur fractions in Vertisols of Raipur (2018-19)

Treatment	Sulphur fractions (kg ha^{-1})			
	Sulphate	Organic	Heat soluble	Water soluble
Control	12.6	66	51	16.1
100% N	18.0	68	51	20.8
100% NP	26.4	74	67	26.0
50% NPK	23.1	73	68	23.4
100% NPK	25.9	80	73	27.0
150% NPK	36.4	86	80	35.0
100% NPK+Zn	35.0	86	79	33.4
100% NPK+FYM	30.1	82	77	32.5
50% NPK+BGA	23.1	79	73	22.4
50% NPK+GM	23.8	80	74	26.0
CD (0.05)	4.9	2.2	2.0	5.0

Application of 150% NPK had highest ammonical nitrogen. Data also revealed that the highest ammonical N (142 mg kg^{-1}) in 150% NPK followed by 135 mg kg^{-1} in 100% NPK+FYM as compared to 51 mg kg^{-1} under control was obtained. Nitrate nitrogen content of the soil at 0-15 cm depth varied from 130 to 217 mg kg^{-1} amongst various treatments. The higher NO_3-N was recorded in 100% NPK+FYM i.e. 217 mg kg^{-1} at 0-15 cm depth followed by 150% NPK i.e. 215 mg kg^{-1}. Whereas, the lowest value was recorded in control 130 mg kg^{-1} plot after twentieth crop cycle.

6.10.2 Sulphur

The sulfate sulphur (S) in soil differed significantly among the various treatments (**Table 6.34**). The findings indicated that sulphate S in soil varied from 12.6 to 36.4 kg ha^{-1} amongst the various treatments in surface soil. The significant increase in sulphate S in all the inorganic fertilizers and integrated nutrient management practices was measured over control. Significantly higher sulphate S, 36.4 kg ha^{-1} was recorded in 150% NPK followed by 100% NPK+ Zn (35.0 kg ha^{-1}). However, significantly lower sulphate S was noted in control. The sulphate S as influenced by Zn application ranged from 35.0 kg ha^{-1} surface soil. A similar trend was found in case of organic S, heat soluble S and water soluble S. The organic S in soil significantly differs amongst the various treatments of LTFE experiment. It ranged between 66 to 86 kg ha^{-1} in surface soil. The heat soluble sulphur irrespective of the nutrients application treatments ranged between 51 to 80 kg ha^{-1} at surface soil. The water soluble sulphur in soil irrespective of the nutrients application treatments ranged between 16.1 to 35.0 kg ha^{-1} in surface soil.

6.10.3 Zinc

Data on the Zn fractions recorded at harvest of wheat was found to be maximum in the balanced fertilizer and integrated nutrient management practices (**Table 6.35**). Application of inorganic fertilizers alone in balanced way or in combination with FYM showed significant build up of almost all forms of Zn over control.

Table 6.35 Zinc fractions in Vertisols of Raipur (2018-19)

Treatment	Zinc fractions (mg kg^{-1})				
	WSEX-Zn	Org-Zn	AMOX-Zn	CRYOX-Zn	Res-Zn
Control	0.24	0.22	0.52	0.48	59.84
100% N	0.27	0.52	0.59	0.63	63.81
100% NP	0.29	0.54	0.60	0.67	65.18
50% NPK	0.27	0.49	0.58	0.65	62.88
100% NPK	0.41	0.55	0.63	0.78	71.19
150% NPK	0.43	0.67	0.65	0.91	72.30
100% NPK+Zn	0.63	0.78	0.89	1.86	74.84
100% NPK+FYM	0.55	0.68	0.72	0.98	72.80
50% NPK+BGA	0.25	0.44	0.55	0.61	62.15
50% NPK+GM	0.33	0.54	0.62	0.72	67.40
CD (0.05)	0.10	0.20	0.05	0.19	11.20

WSEX-Zn: water soluble plus exchangeable zinc; Org-Zn: Organically bound Zn; AMOX-Zn: Amorphous sesquioxide bound Zn; CRYOX-Zn: Crystalline sesquioxide bound Zn and Res-Zn: Residual Zn

Data on fractions of Zn in soil namely water soluble plus exchangeable Zn (WSEX-Zn), organically bound Zn (Org-Zn), amorphous sesquioxide bound Zn (AMOX-Zn), crystalline sesquioxide bound Zn (CRYOX-Zn) and residual Zn (Res-Zn) showed similar trend indicating maximum values in 100% NPK+FYM. The highest content of these fractions were recorded in 100% NPK+Zn in 0-15 cm soil depth. While, the lowest of all were recorded in control.

6.11 Udaipur (Inceptisols)

6.11.1 Organic Carbon pools

6.11.1.1 Water soluble organic carbon

Data with respect to long-term effect of organic and inorganic fertilization on water soluble organic carbon (WS-OC) revealed that soil WS-OC was minimum in control and maximum in FYM @ 20 Mg ha^{-1}. The highest WS-OC was recorded with FYM 20 Mg ha^{-1} application which was significantly at par with 100% NPK+FYM and 150% NPK and significantly superior over rest of the treatments (**Table 6.36**). Application of balanced dose of chemical fertilizers (100% NPK) either alone or combination significantly increased WS-OC content as compared to the control. Application of optimal and super optimal dose of NPK *viz;* 100 and 150% NPK increased the WS-OC by 45.97 and 97.41 per cent, respectively over the control. WS-OC content in 100% NPK was found to be significantly higher than treatment receiving 100% NP and 100% N. This indicated that imbalanced application of fertilizers exerted adverse effect on WS-OC. A similar trend was observed w.r.t. water soluble carbohydrate, potassium permanganate oxidisable carbon (KMnO4-C), Particulate organic carbon (POC), and Light fraction organic carbon (LFOC).

6.11.1.2 Water soluble carbohydrate

Application of optimal and super optimal dose of NPK viz, 100 and 150% NPK increased the water soluble carbohydrate (WS-CHO) by 32.65 and 95.80%, respectively over the control (**Table 6.36**). WS-CHO content in 100% NPK was found to be significantly higher than 100% NP and 100% N. The WS-CHO content in 100% N, 100% NP and 100% NPK treatments was higher by 7.14, 21.65 and 32.65%, respectively over the control. Similarly, application of 100% NPK + FYM and 100% NPK (-NPK of FYM) showed significant increase in the content of WS-CHO by 93.67 and 89.40%, respectively over 100% NPK alone.

6.11.1.3 Potassium permanganate oxidizable carbon

Application of optimal and super optimal dose of NPK viz, 100 and 150% NPK increased the potassium permanganate oxidizable carbon ($KMnO_4$-C) by 70.95 and 71.92%, respectively over the control (**Table 6.36**). The $KMnO_4$-C content in 100% N, 100% NP and 100% NPK treatments was higher by 29.18, 42.32 and 70.95%, respectively over the control. Application of 100% NPK + FYM and 100% NPK (-NPK of FYM) showed significant increase in the content of $KMnO_4$-C by 30.17 and 29.36 per cent, respectively over 100% NPK alone.

6.11.1.4 Particulate organic carbon

The particulate organic carbon (POC) content in 100% N, 100% NP and 100% NPK treatments was higher by 4.04, 7.35 and 41.17%, respectively over the control (**Table 6.36**). Application of optimal and super optimal dose of NPK *viz;* 100 and 150% NPK increased the POC by 41.17 and 58.45%, respectively over the control. Similarly, application of 100% NPK + FYM and 100% NPK (-NPK of FYM) showed significant increase in the content of POC by 29.68 and 25.0%, respectively over 100% NPK alone.

6.11.1.5 Light fraction organic carbon

The light fraction organic carbon (LFOC) content in 100% N, 100% NP and 100% NPK treatments was higher by 26.79, 33.98 and 72.22%, respectively over the control (**Table 6.36**). Application of optimal and super optimal dose of NPK viz, 100 and 150% NPK increased the LFOC by 46.1 and 54.7%, respectively over the control. Application of 100% NPK + FYM and 100% NPK (-NPK of FYM) showed significant increase in the content of LFOC over 100% NPK alone. However, 100% NPK, 100% NPK + Zn, 100% NPK + S, 100% NPK + Zn + S and 100% NPK + *Azotobacter* treatments were at par with each other.

Table 6.36 Effect of organic and inorganic fertilization on C fractions of soil after harvest of maize under wheat- maize cropping sequence in LTFE at Udaipur (2018-19)

Treatment	WS-OC (mg kg^{-1})	WS-CHO (mg kg^{-1})	$KMnO_4$-C (g kg^{-1})	POC (g kg^{-1})	LFOC (mg kg^{-1})
Control	168	432	0.72	1.35	150
100% N	185	465	0.94	1.41	193
100% NP	225	548	1.07	1.47	206
100% NPK	278	595	1.25	1.94	268
100% NPK + Zn	282	610	1.25	1.99	271
100% NPK+ S	287	617	1.25	1.95	269
100% NPK+ Zn + S	279	607	1.25	1.96	273
100% NPK + Biofertilizer	281	615	1.25	1.98	271
100% NPK-FYM	482	1140	1.62	2.45	359
150% NPK	352	890	1.25	2.17	317
FYM @ 20 Mg ha^{-1}	495	1260	1.89	2.95	405
100% NPK + FYM	492	1170	1.64	2.52	365
CD (0.05)	25.0	59.9	0.1	0.1	19.7

6.11.2 Nitrogen

There is considerable build-up of organic and inorganic nitrogen fractions *viz.,* total N, total hydrolysable-N, amino sugar-N, amino acid -N, NH_4-N and NO_3-N on application of fertilizer, manure and their combination (**Table 6.37**). However, the effect of chemical fertilizers on inorganic nitrogen fractions was more pronounced than on organic nitrogen fractions. Application of N alone, NP and NPK increased almost all the N fractions in soil over the treatment neither receiving fertilizer nor manure. This increase in N fractions could due to continuous application of fertilizer which not only meets the immediate needed of the crop but also contributes substantially to all the forms of N. Combined application of chemical fertilizer and manure ensured higher NO_3-N thus enhanced nitrification.

Table 6.37 Long term effect of fertilizer, manure and their combination on N- fractions (0-15 cm) (2018-19)

Treatment	Nitrogen fractions (mg kg^{-1})					
	Amino acid N	NH_4-N	NO_3-N	Total N	Total hydrolysable N	Amino N
Control	82	16.2	7.2	644	482	24
100% N	90	21.3	9.7	705	505	33
100% NP	91	21.1	9.9	713	511	35
100% NPK	95	22.2	10.4	747	536	43
100% NPK + Zn	97	23.1	10.4	773	533	48
100% NPK + S	92	24.2	11.0	735	524	39
100% NPK + Zn + S	98	24.1	10.1	782	562	49
100% NPK + FYM	114	27.2	15.1	735	665	67
100% NPK – FYM	117	20.1	9.6	926	658	66
FYM	121	19.4	9.6	971	689	75
150% NPK	99	26.4	13.6	793	589	50
100% NPK + Biofertilizer	96	25.4	10.6	765	547	45
CD (0.05)	8.5	1.7	1.2	61.0	37.0	3.6

6.11.3 Soil Organic Matter Pools

The soil organic matter (SOM) pool comprises of active, intermediate and passive pools. The active pool generally contributes about 10-20% towards total SOM, whereas the stable passive pools have 50-90% towards total SOM.

6.11.3.1 Active pool

Use of FYM alone or in combination with chemical fertilizers significantly increased the soil microbial biomass carbon (SMBC) compared to the treatment receiving NPK alone (**Table 6.38**). The supply of additional mineralizable and readily hydrolysable C due to organic manure application might have resulted in higher microbial activity and in return higher microbial biomass carbon.

A similar trend was observed w.r.t. SMBC, SMBP, WSOC and DHA. Low content of SMB-P in 100% N alone was observed. Reason attributed is the reduction / death of microbial cells due to absence of any phosphate substrate. The addition of higher levels of phosphorus through external sources might have influenced the metabolism of microorganisms, which is probably responsible for higher levels of SMB-P.

Highest water soluble carbon was observed in treatment receiving FYM alone followed 100% NPK+FYM whereas the lowest in the control. A similar trend was observed w.r.t. water soluble carbohydrate (WSCHO) and dehydrogenase enzyme activities (DHA).

Table 6.38 Long term effect of fertilizer, manure on soil microbial parameters (2018-19)

Treatment	Carbon fractions (mg kg^{-1})					DHA
	Biomass-C	Biomass-N	Biomass-P	WS-OC	WS-CHO	(mg TPF kg^{-1} soil /24hr)
Control	168.0	23.2	3.0	42.7	25.8	4.12
100% N	177.2	29.0	3.2	51.8	31.1	4.27
100% NP	186.7	27.5	4.2	53.7	33.2	5.40
100% NPK	208.5	34.2	5.3	57.1	39.3	5.36
100% NPK + Zn	230.5	33.2	3.6	59.7	40.8	5.45
100% NPK + S	199.2	36.2	4.1	59.6	40.6	5.45
100% NPK + Zn + S	245.2	34.2	3.7	60.8	41.3	5.48
150% NPK	260.0	35.2	6.2	74.7	42.5	5.82
100% NPK – FYM	267.2	37.2	4.3	70.8	41.9	5.84
FYM	307.2	34.2	5.2	86.8	44.1	6.49
100% NPK + Biofertilizer	247.0	36.1	4.2	63.7	39.5	5.57
100% NPK + FYM	289.2	41.2	4.9	78.5	43.0	6.61
CD (0.05)	7.85	6.94	0.24	2.96	2.30	0.24

6.11.3.2 Passive pool

Humus fractions (humic acid, fulvic acid, humin)

Fractionation of the soil humus revealed that the humin content was highest amongst the humus fractions (**Table 6.39**). Humus content of soil organic matter was about 3.5 times of fulvic acid – C (FA-C) fraction and 1.5 times of humic acid – C (HA-C). All the humus fractions of the organic matter increased significantly with the application of fertilizer and more particularly with inclusion of FYM. The highest contents were observed in the treatment receiving FYM @ 20 Mg ha^{-1} (FYM) followed by NPK + FYM and NPK – FYM. Higher values of humin were observed in the treatment receiving FYM alone or in combination with fertilizer. No significant change in humin content of SOC was observed in the treatment where seeds of maize and wheat were treated with *Azotobacter* along with application of recommended NPK (NPK + Bio). Increase in contents of humin, HA-C and HF-C on application of FYM could be due to improved soil physical parameters and conducive environment for the formation of humic acid. In 150% NPK treatment addition of root residues consequent to higher biomass yield might have produced more amount of humus. Fulvic acid, although primarily considered to be humic acid precursor, may be humic acid degradation product as well. HA/FA ratio was recorded less with application of FYM due to positive association between fulvic acid and total organic matter.

Table 6.39 Long term effect of fertilizer, manure and their combinations on fractions of the soil humus at Udaipur (2018-19)

Treatment	Humus fractions (g kg^{-1})			HA/FA
	Humin	Humic acid	Fulvic acid	
Control	0.37	0.23	0.10	2.30
100% N	0.39	0.24	0.10	2.40
100% NP	0.47	0.26	0.12	2.17
100% NPK	0.46	0.28	0.12	2.33
100% NPK+Zn	0.46	0.26	0.13	2.00
100% NPK+S	0.46	0.27	0.13	2.08
100% NPK+Zn+S	0.47	0.27	0.13	2.08
100% NPK+FYM	0.54	0.31	0.19	1.63
100% NPK-FYM	0.51	0.30	0.17	1.76
FYM	0.57	0.32	0.20	1.59
150% NPK	0.51	0.30	0.17	1.77
100% NPK+ Biofertilizer	0.48	0.29	0.15	1.93
CD (0.05)	0.031	0.02	0.012	0.395

7. SUPERIMPOSITION

BASED ON RESULTS EMANATED from long term fertilizer experiments (LTFEs) over the years, some of the treatments were bifurcated and superimposed to address the issue such as nutritional imbalance, nutrient deficiency etc emerged during the course of experimentation.

7.1 Pantnagar

Response of nitrogen and other nutrients in superimposition treatments indicated that rice gave higher response to N, S, Zn and FYM as compared to wheat crop (**Table 7.1**). Remarkable response of S was seen in both rice as well as in wheat crops under 100% NPK with zinc application. In treatments without Zn fertilizers, there was incidence of Khaira disease in rice crops. Similarly, rice crop showed lower response to K and P in comparison to wheat crop in superimposition. The 100% NPK and 150% NPK in combination of S, Zn and FYM produced highest crop yields as compared to other treatments in which S and Zn was not applied. Sulphur and Zn application showed statistically at par response in both rice and wheat crops under 100% NPK and 150% NPK superimposed treatments **(Figure 7.1a** & **7.1b)**. There was marked response to S application when it was added indirectly through S containing fertilizers (Single super phosphate).

Table 7.1 Crop yields under superimposed treatments in Mollisols of Pantnagar (2017-19)

Treatment	100% NPK			150% NPK		
	2017-18	2018-19	Mean	2017-18	2018-19	Mean
Rice (kg ha^{-1})						
-S	3205	3405	3305	4219	4417	4318
+S	3559	3739	3649	4559	4639	4599
-S+Zn	3823	4123	3973	4423	4823	4623
+S+Zn	4843	4943	4893	5843	5643	5743
+S+Zn+FYM	5282	5652	5467	6559	6353	6456
Wheat (kg ha^{-1})						
-S	3032	3232	3132	3832	3932	3882
+S	3395	3495	3445	3995	3895	3945
-S+Zn	3578	3778	3678	3978	3878	3928
+S+Zn	4195	4295	4245	4865	4695	4780
+S+Zn+FYM	4414	4658	4536	5455	5657	5556

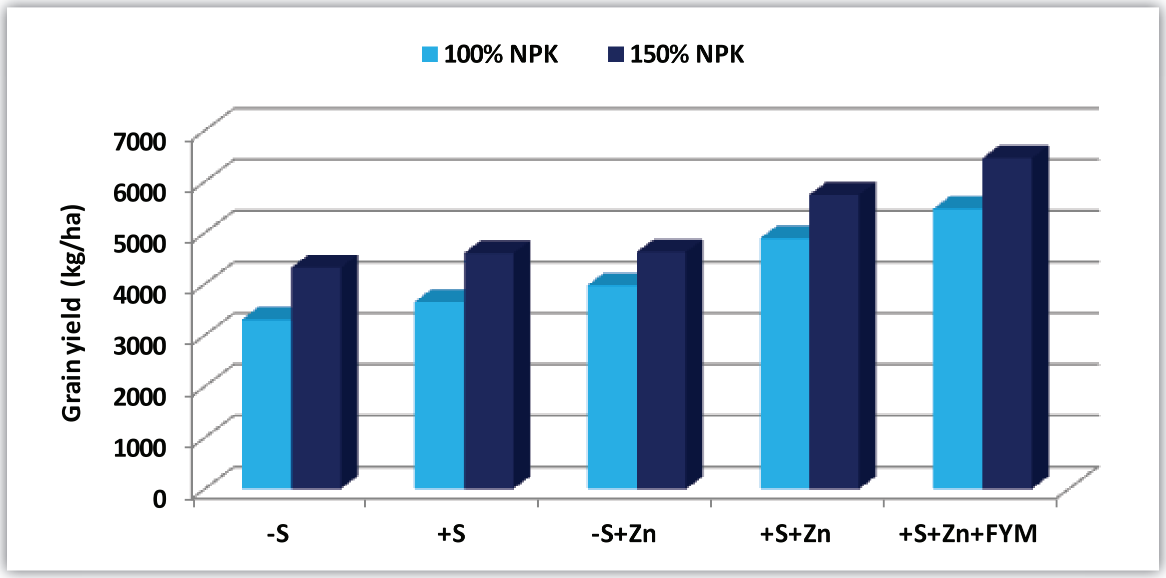


Figure 7.1a Impact of S and Zn on rice yield in Mollisols of Pantnagar

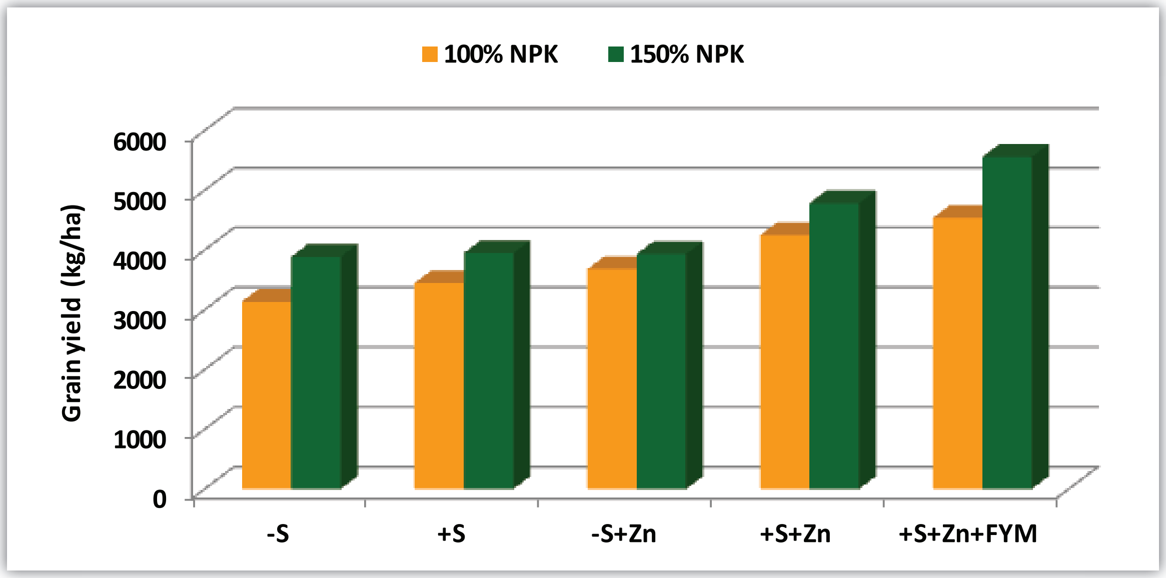


Figure 7.1b Impact of S and Zn on wheat yield in Mollisols of Pantnagar

7.2 PAU Ludhiana

7.2.1 Crop productivity

Grain yield was significantly higher with application of 100% NPK as compared to the application of 50% NPK (**Table 7.2**). The level of N increased from 50% to100% of the optimum level, the grain yield of maize increased significantly, although the dose of P and K remained at 50% of the optimum level and with application of Zn, there was non-significant difference. Similarly, there was no significant difference in maize grain yield amongst the treatments.

Yield was significantly higher in the plots that received 100% recommended NPK than those received 50% of recommended NPK (**Table 7.2**). The level of N increased from present 50% to 100% of the optimum level, the grain yield of wheat (3900 to 4800 kg ha^{-1}) increased significantly, although the dose of P and K remained at 50% of the optimum level and with application of Zn, there was non-significant difference. The recorded wheat grain yield showed the significant increase in the plots received 100% NPK **(Figure 7.2a & 7.2b)**. The super optimal (150% NPK) treatment recorded significant increase in yield compared to other plots which received 50% P and K along with 100% N that means effect of P and K application was significant.

Table 7.2 Effect of long-term fertilizer application on grain yield of maize and wheat under superimposed treatments in LTFE at PAU Ludhiana

Treatment		Maize (kg ha^{-1})				Wheat (kg ha^{-1})			
		2016	2017	2018	Mean	2016-17	2017-18	2018-19	Mean
T_1S_1	50% NPK (Original)	3340	3180	3010	3180	3980	3710	4010	3900
T_1S_2	100% N 50% PK	5150	4960	4770	4960	4870	4590	4940	4800
T_1S_3	100% N 50% PK+Zn	5220	5050	4870	5050	5170	4720	5170	5020
T_3S_1	150% NPK (Original)	5750	5510	5830	5690	5620	5980	5570	5720
T_3S_2	150% N 50% PK	5820	5370	6020	5740	5550	5430	5180	5390
T_3S_3	150% N 50% PK+Zn	5860	5500	6290	5880	5070	5670	5320	5350
T_4S_1	100% NPK (Original)	5360	5490	5670	5500	5330	5400	5310	5340
T_4S_2	100% NK 50% P	5310	5180	5520	5340	5290	4920	4900	5030
T_4S_3	100% NK 50% P+Zn	5450	5390	5640	5490	5450	5140	5160	5250
T_9S_1	100% NPK-S (Original)	5270	5460	5850	5530	5240	4770	5350	5120
T_9S_2	100% NK	4480	4780	4150	4470	4540	4560	4660	4580
T_9S_3	100% NPK(-S)+Zn	5480	5120	5900	5500	5150	4880	5490	5170

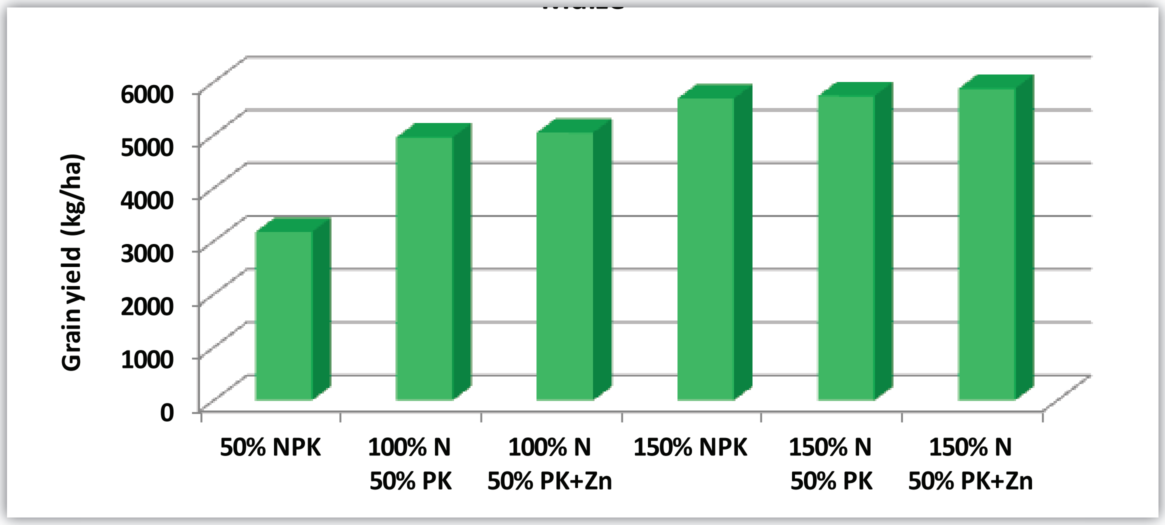


Figure 7.2a Impact on maize yield with reutilization of P in Inceptisols of Ludhiana

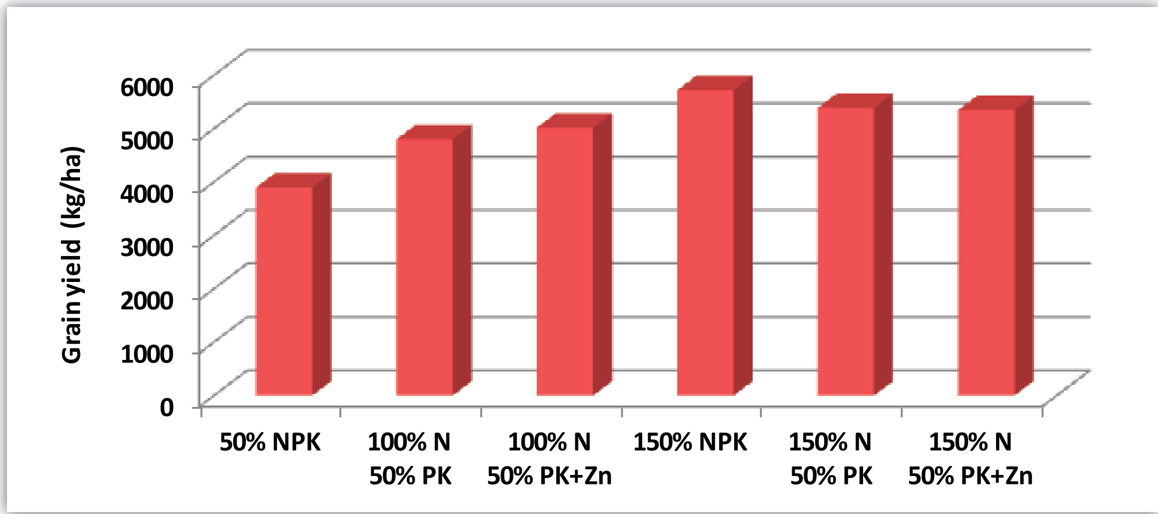


Figure 7.2b Impact on wheat yield with reutilization of P in Inceptisols of Ludhiana

7.2.2 Soil properties

Data pertaining to the long-term effects of fertilizer application through superimposed treatments on important soil chemical properties like pH, EC, organic carbon and available N, P and K status are presented in **Table 7.3**). The soils received prolonged application of fertilizers had pH ranged from 6.85 to 7.41, electrical conductivity from 0.16 to 0.15 dS m^{-1}, soil organic carbon from 0.38 to 0.46%, available N from 108.2 to 130.1 kg ha^{-1}, available P from 22.7 to 84.5 kg ha^{-1} and available K ranged from 94.1 to 145.6 kg ha^{-1}.

Table 7.3 Effect of long-term fertilizer application on soil chemical properties under superimposed treatments at PAU Ludhiana (2017-18)

Treatment		pH	EC (dS m^{-1})	OC (%)	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
T_1S_1	50% NPK (original)	7.18	0.170	0.379	108.2	34.2	94.1
T_1S_2	100% N 50% PK	7.14	0.185	0.379	120.8	38.4	94.1
T_1S_3	100% N 50% PK+Zn	7.15	0.175	0.402	123.9	39.7	96.9
T_3S_1	150% NPK (original)	7.24	0.175	0.432	130.1	84.5	126.6
T_3S_2	150% N 50% PK	7.40	0.175	0.439	127.0	34.4	120.4
T_3S_3	150% N 50% PK+Zn	7.09	0.180	0.451	128.6	35.6	140.6
T_4S_1	100% NPK (original)	7.41	0.170	0.458	122.3	59.7	166.3
T_4S_2	100% NK 50% P	7.28	0.165	0.443	120.8	36.3	143.4
T_4S_3	100% NK 50% P+Zn	7.37	0.160	0.398	123.9	38.1	152.9
T_9S_1	100% NPK-S (original)	6.98	0.170	0.451	117.6	61.9	142.3
T_9S_2	100% NK	6.89	0.170	0.458	120.8	22.7	137.2
T_9S_3	100% NPK(-S)+Zn	6.85	0.170	0.398	122.3	64.1	145.6

Availability of micronutrients improved in superimposed treatments with increase in inorganic fertilizers application and ranged from 10.7 to 14.7 mg kg^{-1} for Fe, from 2.1 to 5.4 mg kg^{-1} for Zn, from 0.94 to 5.4 mg kg^{-1} for Cu and from 7.2 to 10.6 mg kg^{-1} for Mn (**Table 7.4**). The available micronutrients content of all the plots recorded sufficient level of concentration even after growing of crops for 45 years.

Table 7.4 Effect of long-term fertilizer application on micronutrients content in soil under superimposed treatments in maize-wheat cropping sequence

Treatment		Zn	Cu	Fe	Mn
		mg kg^{-1}			
T_1S_1	50% NPK (Original)	2.5	0.8	10.9	7.6
T_1S_2	100% N 50% PK	3.1	0.9	13.6	8.9
T_1S_3	100% N 50% PK+Zn	3.7	1.1	11.2	8.4
T_3S_1	150% NPK (Original)	3.0	2.6	12.1	9.4
T_3S_2	150% N 50% PK	3.0	3.2	12.4	10.6
T_3S_3	150% N 50% PK+Zn	5.4	3.4	13.0	9.7
T_4S_1	100% NPK (Original)	3.2	2.4	11.3	7.3
T_4S_2	100% NK 50% P	2.8	3.0	11.7	8.6
T_4S_3	100% NK 50% P+Zn	3.7	5.4	10.9	7.2
T_9S_1	100% NPK(-S) (Original)	2.5	1.3	14.7	8.7
T_9S_2	100% NK	2.1	0.9	10.7	9.8
T_9S_3	100% NPK(-S)+Zn	5.2	3.0	13.2	10.2

7.3 Ranchi

7.3.1 Crop Productivity

7.3.1.1 Soybean

Data revealed that suboptimal dose of NPK (50% NPK) was inferior to optimal dose of NPK (100% NPK) while, super optimal dose of 150% NPK was unable to impose its superiority over optimal dose of NPK (100% NPK). Continuous application of N in the form of urea resulted in drastic decline in productivity and the yield recorded was even less than that of unmanured or control plots (**Table 7.5**). Application of N and P fertilizers without K (100% NP, i.e. application of urea and DAP only) was inferior to even suboptimal dose of NPK. Application of N through ammonium sulphate and supplementing with P and K through SSP and MOP, respectively, i.e. in 100% N (S) PK the grain yield reduced drastically even less than the suboptimal dose of NPK for few years. Change in the source N fertilizer from ammonium sulphate to urea during 2010 resulted in spectacular increase in grain yield of soybean during the years under report and it was found to be better than 100% NPK. Over the years it was found that application of FYM along with the recommended dose of NPK recorded highest grain yield of soybean followed by lime application with recommended dose of NPK but the treatment difference was not statistically significant. Over the years as well as in the years of report no yield difference was recorded in hand weeded or weedicide applied plots. Application of urea alone recorded around 80% reduction in grain yield of soybean as compared to the recommended dose of fertilizers. Similarly application of urea and DAP recorded 46-53% reduction in grain yield of soybean as compared to the recommended dose of fertilizers and deficiency of K was noticed on soybean leaf under field conditions. Supplementing lime/FYM along with recommended dose of NPK fertilizers improved grain yield of soybean up to 46%.

Table 7.5 Effect of lime/FYM on grain yield in superimposed treatments in LTFE at Ranchi (2016-19).

Treatment	Soybean (kg ha^{-1})				Wheat (kg ha^{-1})			
	2016	2017	2018	Mean	2016-17	2017-18	2018-19	Mean
100% NP	598	547	821	655	291	380	3368	3356
100% NP+lime	1521	1521	1863	1635	366	412	4188	3989
100% NP+FYM	2274	2051	1829	2051	383	470	4581	4370
100% N	564	530	547	547	53	650	650	610
100% N+Lime	923	752	940	872	68	974	821	826
100% N+FYM	2256	1470	1658	1795	250	246	3077	2678
100% N(S)PK	2222	1744	1726	1897	267	407	4068	3601
100% N(S)PK +Lime	2444	2188	2291	2308	361	436	4752	4239
100% N(S)PK +FYM	2821	2530	2154	2501	316	434	5060	4188
150% NPK	1949	1504	1932	1795	231	366	4154	3373
150% NPK+5.0 t FYM	2393	2120	2120	2211	294	444	4291	3892
150% NPK+10.0 t FYM	2615	2325	2256	2399	369	544	4872	4667
CD (0.05)	367	392	291	-	831	850	611	-

In superimposed treatments application of either FYM or lime resulted in increase in grain yield of soybean for in 100% NP, 100% N, 100% N(S)PK,150% NPK. Mean increase was 76-174, 168-460 and 80-85% for 100% NP, 100% N and 100% N(S)PK treatments, respectively, as compared to their respective original treatments. FYM was found to be more effective than lime for 100% NP and 100% N treatments, while lime was better than FYM for the third treatment 100%N (S)PK **(Figure 7.3)**. Application of FYM for the fourth superimposed treatment receiving 150% NPK increased crop productivity by 13-18% as compared to the original treatment mean over the years. More than fifteen years of study on the effect of ameliorants for different treatments have clearly shown the importance of application of lime/FYM for increasing crop productivity in soybean-wheat cropping system. It has clearly shown application of lime along with balanced NPK or FYM along with imbalanced use of fertilizers enhanced the crop yield.

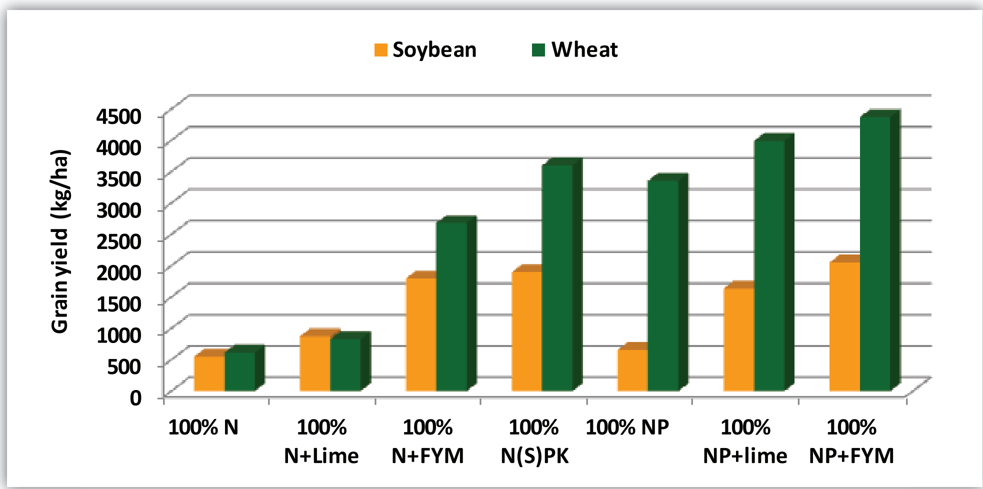


Figure 7.3 Impact of lime and FYM in imbalanced nutrient options in Alfisols of Ranchi

7.3.1.2 Wheat

Application of optimal level of fertilizers produced higher yield than suboptimal dose of fertilizers and the increase was around 28% during 2016-19 (**Table 7.5**). Application of 150% NPK recorded similar grain yield of wheat as compared to the recommended dose of fertilizers. Lowest grain yield of 690 to 740 kg ha^{-1} was recorded under control. Application of N alone through urea recorded at par yield of wheat compared to control. Application of FYM or lime along with 100% NPK to soybean increased grain yield of succeeding wheat by around 30% during 2016-19 **(Figure 7.3)**. When mean grain yield of wheat over the years (1972-18) was compared with optimal level of NPK highest decline of 83% was recorded in control, followed by 73% for 100% N. In superimposed treatments application of either FYM or Lime for the *kharif* crop resulted in increase in grain yield of succeeding wheat crop over the years. The FYM was found to be more effective than lime for 100% NP and 100% N treatments, while lime was better than FYM for 100% N(S)PK. In the fourth superimposed treatment 150% NPK, application of FYM increased crop productivity by 15-27% as compared to the original treatment over the years.

7.3.2 Soil properties

Effect of continuous use of fertilizer either single or in combinations with and without FYM/lime in acid soils on various soil chemical properties of the soil are presented in **Table 7.6**.

7.3.2.1 Soil reaction

Results revealed that maximum reduction in pH by around 1.0 unit was observed in treatment 100% N(S)PK+W, followed by 100% N and 150% NPK (**Table 7.6**). Lime application along with recommended dose of NPK resulted in increase in pH by 0.7 units after harvest of wheat crop. In superimposed treatments application of lime increased the pH of the soil while FYM application lead to stabilization in pH of soil as compared to their initial value. In the fourth superimposed treatment there was no influence of FYM application on the pH of soil after harvest of soybean or wheat.

Table 7.6 Effect of continuous use of lime/FYM on pH, organic carbon, N, P and K in soil after harvest of wheat in superimposed treatments (2018-19)

Treatment	pH	OC (%)	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
100% NP	5.46	0.45	174.2	90.9	73.6
100% NP+Lime	5.95	0.42	185.4	91.3	92.4
100% NP+FYM	5.47	0.44	216.2	90.7	128.8
100% N	4.47	0.54	171.4	110.5	25.2
100% N+Lime	5.87	0.49	189.6	103.2	28.0
100% N+FYM	5.31	0.61	192.4	97.8	26.7
100% N(S)PK	4.83	0.53	217.6	105.0	119.3
100% N(S)PK+Lime	5.97	0.65	198.0	99.7	128.2
100% N(S)PK+FYM	5.72	0.51	199.4	107.9	163.2
150% NPK	5.07	0.44	186.8	124.2	161.0
150% NPK+5 Mg ha^{-1} FYM	5.22	0.48	186.8	114.0	197.8
150% NPK+10 Mg ha^{-1} FYM	5.35	0.55	210.6	104.4	173.5
CD (0.05)	0.37	0.19	32.7	9.9	28.2

7.3.2.2 Soil organic carbon

Post harvest soil sample analysis for soil organic carbon status after 45 years of intensive cropping in general there was a decline in organic carbon content in almost all the treatments except 100% N(S)PK and 100% NPK+FYM. Application of FYM @ 10 Mg ha^{-1} during the *kharif* season along with recommended NPK could maintain initial organic carbon content of soil. There was reduction in organic carbon content of soil in lime treated plots. In superimposed treatments the effect of FYM for increasing organic carbon was also marked.

7.3.2.3 Nutrient status

After more than four decades of intensive cropping, it was observed that in general there was a decline in available N content of soil from the initial value of 295 kg ha^{-1} in all treatments (**Table 7.7**). Similarly, it was observed that in general there was built up of P in these soils and highest P accumulation was observed in super-optimal treatment followed by 100% NPK+FYM and 100% N (S) PK in wheat. However, in general there was a decline in available K content of soil from the initial value of 157.7 kg ha^{-1} in all treatments and the decrease was 25-95 kg ha^{-1} after 46 years of cropping and highest decrease was observed with 100% NP. In superimposed treatments some effect of FYM for increasing available K was also observed.

7.3.2.4 Electrical conductivity

Electrical conductivity of soil, which is an index of total soluble salts in the soil. Continuous use of fertilizers, manure and lime influenced electrical conductivity of soil but the values were observed to be much below 1.0 dSm^{-1}. Application of fertilizers alone or in combination with lime/FYM increased EC of soil as compared to control (**Table 7.7**).

Table 7.7 Effect of continuous use of lime/FYM on various parameters after harvest of wheat in superimposed treatments in LTFE at Ranchi

Treatment	EC (dSm^{-1})	Available S (kg ha^{-1})	Exchangeable Ca (kg ha^{-1})	Exchangeable Mg (kg ha^{-1})
100% NP	0.09	22.1	720	257
100% NP+Lime	0.10	22.4	1313	270
100% NP+FYM	0.13	24.9	912	287
100% N	0.13	21.2	324	176
100% N+Lime	0.17	19.6	1106	287
100% N+FYM	0.12	24.5	563	257
100% N(S)PK	0.16	165.4	301	116
100% N(S)PK +Lime	0.14	172.4	833	146
100% N(S)PK +FYM	0.15	182.9	401	162
150% NPK	0.15	20.0	427	203
150% NPK+5.0 Mg FYM	0.11	21.9	493	256
150% NPK+10.0 Mg FYM	0.11	26.8	745	219
CD (0.05)	0.04	4.38	67.0	22.7

7.3.2.5 Secondary nutrients

Data on secondary nutrients revealed that status for exchangeable Ca and Mg due to intensive cropping decreased considerably and lowest exchangeable Ca and Mg was found for the treatments 100% N and 100% N(S)PK treatment, respectively (**Table 7.7**). In superimposed treatments application of lime or FYM resulted in slight improvement on secondary nutrients status of the soil. Available S content of soil was found highest in 100% N(S) PK treatment which was around 173.2 kg ha^{-1} after harvest of wheat crop. In superimposed treatments effect of lime or FYM on available S was not influenced by ameliorants.

7.4 Bangalore

7.4.1 Crop productivity

7.4.1.1 Finger millet

The improvement in yield of finger millet due to FYM (10 Mg ha^{-1}) superimposition in T_3 (150% NPK) was from 3127 to 3633 kg ha^{-1} (**Table 7.8**). The T_4S_1 (Original) i.e. (100% NPK with hand weeding) recorded a mean yield of 2543 kg ha^{-1} and slight increase in yield to 2888 kg ha^{-1} (T_4S_3) in spite of reducing the P doses to half in presence of FYM and lime. This suggests that grain yield was not affected by reducing the P doses to half the dosage in P-buildup soils. The original treatment T_6 S_1 (100% NP) recorded a mean value of 792 kg ha^{-1} grain yield, substantially increased to 2342 (T_6 S_2) and 2760 kg ha^{-1} (T_6S_3) due to superimposition with K+FYM and K+FYM+lime, respectively. The grain yield was not affected in spite of reducing the P doses to half the doses in both superimposed treatments. The lowest yield of 800 kg ha^{-1} in T_7 S_1 (100% N) was increased to 2095 (T_7 S_2) and 2471 (T_7 S_3) kg ha^{-1} due to superimposition with 100% PK + FYM and 100% PK + FYM + lime, respectively suggesting the benefit of P, K and FYM application **(Figure 7.4a & 7.4b)**.

Table 7.8 Grain yield of finger millet and maize due to superimposition in LTFE at Bangalore (2016-19)

Treatment	Finger millet (kg ha^{-1})				Maize (kg ha^{-1})			
	2016	2017	2018	Mean	2016-17	2017-18	2018-19	Mean
T_3S_1: 150% NPK	2988	2913	3481	3127	7100	5558	4141	5600
T_3S_2: 150% NPK+5 Mg ha^{-1}+FYM	3300	3183	3636	3373	7432	6100	4458	5997
T_3S_3: 150% NPK+10 Mg ha^{-1}+FYM	3605	3429	3866	3633	7948	6259	5041	6416
T_4S_1: 100% NPK (HW)	2299	2456	2875	2543	6554	4911	3549	5005
T_4S_2: 100% NK+50% P+ FYM	2472	2700	2936	2703	7204	5615	3916	5578
T_4S_3: 100% NK+50% P+ FYM+ Lime	2838	2813	3014	2888	8320	5713	3968	6000
T_6S_1: 100% NP	705	980	690	792	3072	2500	1698	2423
T_6S_2: 100% NK+50% P + FYM	2698	2174	2153	2342	7184	5235	4376	5598
T_6S_3: 100% NK+50% P+ FYM+ Lime	3134	2496	2649	2760	8131	5506	4602	6080
T_7S_1: 100% N	880	841	679	800	3476	2065	1452	2331
T_7S_2: 100% NPK+FYM	2039	2176	2069	2095	5830	5106	3838	4925
T_7S_3: 100% NPK+FYM+Lime	2608	2245	2559	2471	7456	5402	4812	5890

7.4.1.1 Maize

The yield of 5600 kg ha^{-1} in original treatment (T_3S_1) was increased to 6416 kg ha^{-1} in T_3S_3 due to FYM application @ 10 Mg ha^{-1} (**Table 7.8**). Reducing the P dosage to half of RDF there was slight improvement in yield from 5005 (T_4S_1) to 6000 kg ha^{-1} (T_4S_3) in presence of FYM and Lime. Maize yield was increased from 2423 (T_6 S_1) to 5598 kg ha^{-1} in (T_6 S_2) and 6080 kg ha^{-1} in case of T_6S_3 suggesting the importance of K fertilization and FYM. The Original treatment (T_7 S_1) recorded the lowest grain yield of 2331 kg ha^{-1} and the same was improved due to super imposition with Phosphorus, Potassium and FYM (49.25 kg ha^{-1} in T_7 S_4 and 5890 kg ha^{-1} in (T_7S_3) **(Figure 7.4a** & **7.4b)**.

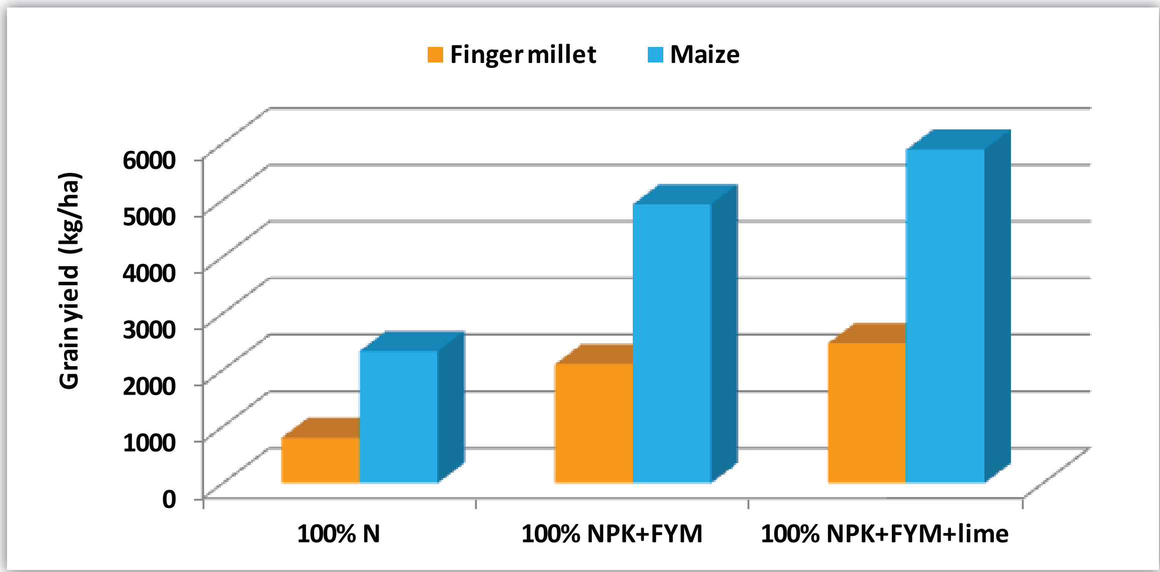


Figure 7.4a Impact of lime and FYM in imbalanced nutrient options (100% N) in Alfisols of Bangalore

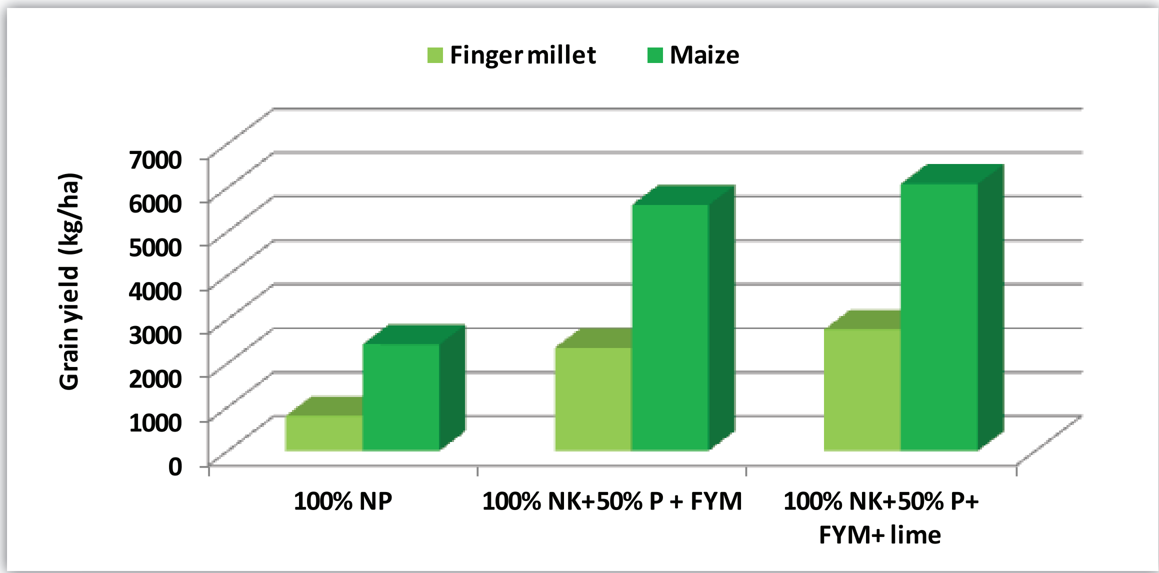


Figure 7.4b Impact of lime and FYM in imbalanced nutrient options (100% NP) in Alfisols of Bangalore

7.4.2 Nutrient uptake

7.4.2.1 Finger millet

Slight variation was observed in total uptake of nitrogen among T_3S_1, T_3S_2 and T_3S_3. Nitrogen uptake was highest in T_4S_3 (91.88 kg ha^{-1}) compared to other two. The total uptake of nitrogen was increased about 3 times in T_6S_3 and T_7S_3 treatments over their corresponding original treatments due to superimposition (**Table 7.9**). The uptake of P both in T_6 and T_7 increased substantially from 5.03 to 16.35 kg ha^{-1} and 3.51 to 18.35 kg ha^{-1}, respectively. The difference in uptake of P was not much in T_3 and T_4 superimposed treatments. However, there was increase in uptake of P there after superimposition. The reduced dose of P does not affect the uptake of P in T_4 and T_6 in presence of FYM and K fertilization. The total uptake of K also increased from 17.27 to 67.36 kg ha^{-1} in T_6 and 13.80 to 64.90 kg ha^{-1} in T_7 due to superimposition. Not much variation in uptake of Ca, Mg and S was observed due to super imposition in T_3 and T_4 treatments (**Table 7.9**). However, effect of superimposition on uptake of Ca, Mg and S was very clear in case of T_6 and T_7. Similarly, micronutrient uptake followed same trend (**Table 7.10**).

Table 7.9 Effect of long term application of fertilizers on major and secondary nutrient uptake by finger millet in superimposed treatments (2016-19)

Treatment	N	P	K	Ca	Mg	S
	(kg ha^{-1})					
T_3S_1: 150% NPK	77	20	73	29	21	11
T_3S_2: 150% NPK+ 5 Mg ha^{-1} +FYM	84	24	89	33	23	13
T_3S_3: 150% NPK+ 10 Mg ha^{-1}+FYM	92	28	99	37	26	14
T_4S_1: 100% NPK (HW)	64	14	64	26	16	8
T_4S_2: 100% NK+ 50% P+FYM	74	16	73	29	20	12
T_4S_3: 100% NK+ 50% P+FYM+ Lime	77	18	74	32	24	12
T_6S_1: 100% NP	19	5	17	7	6	5
T_6S_2: 100% NK + 50% P+FYM	57	12	58	21	16	10
T_6S_3: 100% NK+ 50% P+FYM+ Lime	69	16	67	29	20	13
T_7S_1: 100% N	18	4	14	6	5	4
T_7S_2: 100% NPK+ FYM	58	15	57	23	20	10
T_7S_3: 100% NPK+ FYM+ Lime	70	18	65	29	23	14

Table 7.10 Effect of long term application of fertilizers on micronutrient uptake by finger millet in superimposed treatments (2017-19)

Treatment	Zn	Cu	Fe	Mn
	(g ha^{-1})			
T_3S_1: 150% NPK	201	99	512	745
T_3S_2: 150% NPK+5 Mg ha^{-1} +FYM	212	109	536	889
T_3S_3: 150% NPK+10 Mg ha^{-1} +FYM	248	131	659	939
T_4S_1: 100% NPK (HW)	175	93	516	520

T_4S_2: 100% NK+50% P+ FYM	195	106	587	509
T_4S_3: 100% NK+50% P+ FYM+ Lime	203	114	612	556
T_6S_1: 100% NP	48	22	149	144
T_6S_2: 100% NK+50% P + FYM	126	74	424	446
T_6S_3: 100% NK+50% P+ FYM+ Lime	179	98	558	632
T_7S_1: 100% N	36	21	112	126
T_7S_2: 100% NPK+ FYM	142	77	363	455
T_7S_3: 100% NPK+ FYM+ Lime	166	88	510	590

7.4.2.2 Maize

Similar to finger millet, there was slight increase in the uptake of all the nutrients in superimposed treatments of T_3 (150% NPK) and T_4 (100% NPK)compared to their corresponding original treatments (T_3S_1 and T_4S_1). However, the entire nutrients uptake substantially increased in superimposed treatments of T_6 (100% NP) and T_7 (100% N) over that of respective original treatments (T_6S_1 and T_7 S_1) (**Table 7.11** & **7.12**).

Table 7.11 Effect of long term application of fertilizers on major and secondary nutrient uptake by maize in super imposed treatments (2016-19)

Treatment	N	P	K	Ca	Mg	S
	(kg ha^{-1})					
T_3S_1: 150% NPK	110	25	109	67	34	15
T_3S_2: 150% NPK+ 5 Mg ha^{-1} +FYM	126	28	127	71	41	20
T_3S_3: 150% NPK+ 10 Mg ha^{-1} +FYM	146	32	144	82	45	24
T_4S_1: 100% NPK (HW)	98	18	94	57	32	16
T_4S_2: 100% NK+ 50% P+ FYM	112	23	123	65	40	18
T_4S_3: 100% NK+ 50% P+ FYM+ Lime	120	26	132	80	38	19
T_6S_1: 100% NP	51	7	40	26	14	7
T_6S_2: 100% NK + 50% P + FYM	116	20	103	67	37	16
T_6S_3: 100% NK+ 50% P+ FYM+ Lime	127	23	122	81	41	18
T_7S_1: 100% N	39	6	31	20	11	7
T_7S_2: 100% NPK+ FYM	102	20	102	61	32	16
T_7S_3: 100% NPK+ FYM+ Lime	116	25	121	77	40	18

Table 7.12 Effect of long term application of fertilizers on micronutrient by maize over the years in superimposed treatments (2017-19)

Treatment	Zn	Cu	Fe	Mn
	(g ha^{-1})			
T_3S_1: 150% NPK	229	93	368	365
T_3S_2: 150% NPK+ 5 Mg ha^{-1}+FYM	246	83	377	411
T_3S_3: 150% NPK+ 10 Mg ha^{-1}+FYM	292	96	450	452

T_4S_1: 100% NPK (HW)	198	75	348	372
T_4S_2: 100% NK+ 50% P+ FYM	213	90	382	424
T_4S_3: 100% NK+ 50% P+ FYM+ Lime	234	82	369	421
T_6S_1: 100% NP	103	41	169	180
T_6S_2: 100% NK + 50% P + FYM	250	85	363	384
T_6S_3: 100% NK+ 50% P+ FYM+ Lime	264	81	370	399
T_7S_1: 100% N	86	36	140	152
T_7S_2: 100% NPK+ FYM	205	70	336	360
T_7S_3: 100% NPK+ FYM+ Lime	244	95	370	431

7.4.3 Soil properties

The impact of superimposition on soil properties such as pH, EC, OC and available N, P and K indicated improvement in primary, secondary and micro nutrients over control (**Table 7.13** & **7.14**). Soil pH was significantly higher with application of FYM and lime compared to fertilizer alone treatments in respective superimposed treatments. The increase in pH was maximum when T_7 (100% N) which was superimposed with FYM and lime (6.35). No much variation was observed with respect to salt content. However, slightly higher EC were recorded when main treatments were superimposed with lime. Organic carbon contents gradually increased wherever FYM was superimposed (S_2 and S_3) compared to S_1 in the (**Table 7.13**) respective treatments. The available N content in all treatments found to be lower than initial soil. Significantly higher available N content was observed when treatments were superimposed with FYM compared to original treatments.

Table 7.13 Soil properties in superimposed treatments (2018-19)

Treatment	pH	EC (dSm^{-1})	OC (%)	N	P_2O_5	K_2O
					(kg ha^{-1})	
T_3S_1: 150% NPK	5.4	0.2	0.6	154	260	107
T_3S_2: 150% NPK+ 5 Mg ha^{-1} +FYM	5.6	0.2	0.7	134	160	121
T_3S_3: 150% NPK+ 10 Mg ha^{-1} +FYM	5.4	0.2	0.8	140	185	118
T_4S_1: 100% NPK (HW)	6.0	0.2	0.6	176	177	95
T_4S_2: 100% NK+ 50% P+ FYM	5.9	0.2	0.7	157	122	123
T_4S_3: 100% NK+ 50% P+ FYM+ Lime	5.9	0.2	0.7	157	139	112
T_6S_1: 100% NP	6.0	0.2	0.6	137	173	78
T_6S_2: 100% NK + 50% P + FYM	6.0	0.2	0.4	137	135	106
T_6S_3: 100% NK+ 50% P+ FYM+ Lime	6.1	0.2	0.6	151	132	117
T_7S_1: 100% N	6.1	0.2	0.6	165	66	82
T_7S_2: 100% NPK+ FYM	6.2	0.2	0.6	132	138	126
T_7S3: 100% NPK+ FYM+ Lime	6.4	0.2	0.6	157	137	140
Initial	6.2	0.1	0.5	257	34	123
CD (0.05)	0.2	0.0	0.1	22.7	8.0	20.4

There was build up in available P content in all superimposed treatments except T_7 (100% N) treatment and maximum build up was observed in 150% NPK treatment superimposed with FYM 10 t ha^{-1} (185.15 kg ha^{-1}). The available K content in soil was recorded significantly higher in all superimposed treatments with FYM and lime compared to original treatments and maximum was found in treatment 100% N superimposed with 100% PK, FYM and lime (139.50 kg ha^{-1}). A slight increase in exchangeable Ca and Mg and available sulphur content was found when original treatments are superimposed (**Table 7.14**). The micronutrients content in soil found slightly higher when main treatments were superimposed with FYM and lime compared to original treatments and maximum content was observed in T_3 superimposed with FYM 10 t ha^{-1}. However, differences were non-significant in case of available Fe due to superimposition.

Table 7.14 Soil properties in superimposed treatments (2018-19)

Treatment	Ca	Mg	S	Zn	Cu	Fe	Mn
	cmol kg^{-1}		mg kg^{-1}				
T_3S_1: 150% NPK	4.3	2.2	22.0	5.0	1.1	6.1	16.4
T_3S_2: 150% NPK+ 5 Mg ha^{-1}+FYM	4.3	3.1	22.7	6.9	1.0	5.1	11.9
T_3S_3: 150% NPK+ 10 Mg ha^{-1} +FYM	4.6	3.6	23.4	5.2	1.0	5.2	15.2
T_4S_1: 100% NPK (HW)	4.2	2.6	13.5	4.6	0.8	4.7	15.1
T_4S_2: 100% NK+ 50% P+FYM	6.2	3.7	19.9	4.1	0.7	4.8	12.1
T_4S_3: 100% NK+ 50% P+FYM+ Lime	4.5	3.9	17.0	4.3	0.8	4.6	12.1
T_6S_1: 100% NP	5.5	3.3	9.2	4.5	0.8	5.5	14.6
T_6S_2: 100% NK + 50% P + FYM	6.2	3.6	12.1	3.9	0.7	5.1	14.8
T_6S_3: 100% NK+ 50% P+ FYM+ Lime	8.1	4.1	9.9	4.8	0.7	4.4	12.1
T_7S_1: 100% N	7.5	3.3	7.1	3.3	0.8	5.0	14.6
T_7S_2: 100% NPK+ FYM	7.1	3.6	7.1	4.0	0.8	4.9	12.4
T_7S_3: 100% NPK+ FYM+ Lime	6.9	4.8	8.5	5.9	0.9	4.6	15.5
Initial	3.3	1.6	20.7	2.4	2.3	5.2	55.4
CD (0.05)	0.7	0.4	2.1	1.1	0.1	NS	1.8

Significant differences were observed with respect to major, secondary and micronutrient uptake among superimposed treatments of the long term fertilizer experimental plots. The treatment T_3S_3 (150% NPK +10 tons FYM) recorded highest value followed by T_3S_2 (150% NPK + 5 tons FYM) and T_3S_1 (150% NPK). The lowest value was recorded in treatments T_7S_1 (100% N) followed by T_6S_1 (100% NP).

8. TRIBAL (TSP) AND SCHEDULED CASTE SUB PLAN (SCSP) ACTIVITIES

LONG-TERM EXPERIMENTS generate extensive and valuable information which can be used for studying sustainability of intensive agriculture. Several years may take to appear distinguishable changes in soil fertility because of imbalanced fertilizer use and unscientific management practices. In addition to management practices, the climatic factors also alter the physical, chemical and biological properties and condition of soil. It also provides the best possible means of identifying emerging trends in nutrient imbalances and deficiencies and to formulate future strategies and policies for maintaining soil health. Especially, in the remote places where peoples are quite away from the advance technologies, the front line demonstrations are surely acted as light house for diversified agriculture and maintenance of soil health.

8.1 Tribal Sub Plan (TSP)

8.1.1 Akola

Field demonstrations on 'Evaluation of sustainable nutrient management practices on yield, nutrient uptake and soil fertility status' were conducted on tribal farmer's field at various locations of Akola district (Maharashtra) under the TSP. The soils were characterized at each site to have initial properties like pH, EC, organic carbon and available nutrient status. The fertilizers were applied according to the respective treatments. The entire dose of P and K along with half dose of N was applied at the time of sowing and the remaining dose of N was applied after 21 DAS to sorghum and wheat. The entire dose of N, P and K was applied at the time of sowing in soybean and chickpea .

About 190 frontline demonstrations (FLDs) were conducted in tribal areas at Jambhu, Kotha, Baru Toli, Duni and Ghota villages in Akola district. The crops soybean (cv JS 335), wheat (HD-2189) and chickpea (JAKI 9218) were tested on farmers' fields with following treatments:

Treatment	N : P_2O_5 : K_2O (kg ha^{-1})			
	Sorghum	Soybean	Chickpea	Wheat
100% NPK (RDF)	100:50:40	30:75:30	25:50:30	120:60:60
100% NPK +FYM @ 5 t ha^{-1}	100:50:40	30:75:30	25:50:30	120:60:60
100% NP (-K)	100:50:00	30:75:00	25:50:00	120:60:00
Farmers' Practice	70:30:00	15:35:00	10:25:00	40:25:00

Recommended dose of fertilizer

The recommended doses were followed for soybean (30:75:30), sorghum (100:50:40), wheat (120:60:60) and chickpea (25:50:30 kg N, P_2O_5 and K_2O ha^{-1}). The half dose of N and full dose of P and K of fertilizers was applied at the time of sowing to sorghum and wheat and remaining dose of N after 21 days after sowing. However, full dose of N, P and K at the time of sowing was applied in soybean and chickpea.

Crop productivity

The data pertaining to the effect of various fertilizer treatments on grain yield of various crops during the year 2016-19 (**Table 8.1**). The application of 100% NPK + FYM @ 5 t ha^{-1} recorded significantly higher grain yield of soybean, sorghum, chickpea and wheat crops as compared to recommended dose of fertilizer, imbalanced use of fertilizer and farmers practice during 2018-19. The grain yield of soybean, sorghum, wheat and chickpea crop was significantly higher with 100% NPK application over 100% NP i.e. without application of potassium. Among the various treatments, significantly lower grain and straw yield of soybean, sorghum, wheat and chickpea was recorded under the farmers practice.

Table 8.1 Effect of various treatments on grain yield (kg ha^{-1}) of various crops (2018-19)

Treatment	Sorghum	Soybean	Wheat	Chickpea
100% NPK	33.36	17.60	31.87	18.15
100% NPK + FYM @ 5 Mg ha^{-1}	28.20	13.86	29.47	16.06
100% NP (-K)	28.00	13.21	26.63	14.93
Farmers' Practice	21.67	10.02	20.46	11.28
CD (0.05)	2.81	0.90	1.71	1.79

FLD on soybean at Kota

FLD on wheat at Jambu

Farmers' Practice

100% NPK + FYM @ 5 Mg ha^{-1}

Plate 8.1 Front line demonstrations and impact of INM on crop (Akola, Maharashtra)

Distribution of Inputs at Baru and Toli village

Interaction with farmers' at Baru

FLDs on wheat at Duni

FLDs on chickpea at Duni

Field Day at Ghota

Plate 8.2 Organization of Field Days/Training/Front line demonstration in Tribal Villages (2016-19)

8.1.2 Pattambi

Demonstration trials on various technologies like INM, balanced fertilizer application, varietal performance and crop management were conducted on vegetables, banana, rice, turmeric, ginger, colacasia, elephant foot yam and tapioca crops. About 21 demonstration trials were conducted at on farmers' field at various location of Pattambi, Palakkad district, Kerala under the TSP programme. Soil test based fertilizer application was recommeded for various crops. The demonstration of various technologies on farmers' field resulted in 15 to 29% increase in crop yield. During the year 2016-17, long term income yielding crops like fruit plants, black pepper and coconut were also promoted in the farmers' field. In addition to demonstration trials, farmers' trainings and farm input distribution were also executed under the TSP programme. The Grafted fruit plants of mango (100 nos.), jackfruit (50 nos.), sapota (50 nos.), pickle lime (25 nos.), West India cherry (50 nos.), hybrid coconut seedling (20 nos.), rooted pepper cutting (2500 nos.) were distributed under this programme. Also, vermicompost (2500 kg) and chemical fertilizers (1000 kg) were also distributed to 114 farmers of 23 families.

Plate 8.3 Training Programme on various aspects of INM and soil and water conservation

Demonstration of Technologies

Demonstrations were conducted in vegetables, banana, rice, turmeric, ginger, colacasia, elephant foot yam and tapioca covering 21 farmers. Technologies such as scientific nutrient management (INM, split application and balanced nutrients) new varieties and crop management were demonstrated in these plots. Soil testing was conducted and based on the results nutrients were recommended for various crops. As far as possible we emphasized the use of their own resources. Critical inputs like seeds of upland rice, seed materials of turmeric, ginger, colacasia, elephant foot yam, vermicompost, and chemical fertilizers were supplied under the TSP programme. For other crops, seeds and cow dung available with them were utilized. For comparison, the yields obtained in the previous year were taken if available.

Demonstration plots of scientific crop production were undertaken in 4 categories. The demonstrations benefitted the farmers and enhanced the average yield and income of the tribal farmers. There were several activities namely (i) Introduction of upland variety 'Vaisakh' with economic advantage, (ii) Additional yield was obtained through demonstration was nearly 1200 kg which brings about an additional income of Rs. 48,000/- in banana cultivation, (iii) In case of ginger, total economic advantage due to demonstration was nearly 3500/25 cents (iv) Introduced HYV of turmeric i.e. 'Varada' to the area, (v) Demonstrated the improvement in yield with INM in vegetables and (vi) Intercropping with colocasia and elephant foot yam was demonstrated on farmers' fields.

Yield advantage with intervention

Total beneficiaries under TSP were 180 and average yield obtained in the demonstrations (**Table 8.2**)

Table 8.2 Yield advantage with interventions in tribal villages of Kerala (2018-19)

Crop and variety	Demonstration yield/ acre	Yield increase (%)	Technology intervention
Cowpea Veg. type	1280 kg	21	Addition of Potash and Neem cake and vermicompost
Bitter gourd	2000 kg	18	Fertilizer addition
Banana	9 kg/plant	29	Addition of split application of fertilizer and vermicompost
Upland rice	800 kg/acre	-----	New crop. Low yield due to delay in rainfall
Turmeric	26 q/acre	25	New variety (test yield-kept unharvested for seed purpose)
Ginger	18 q/acre	17	Addition of vermicompost and fertilizers
Colocasia	25 q/acre	20	Addition of vermicompost and fertilizers
Elephant foot yam	30 q/acre	15	Addition of vermicompost and fertilizers
Tapioca	45 q/acre	25	Addition of cowdung and fertilizers

8.1.3 Palampur

The farmers were imparted technical know how about balanced fertilization and integrated nutrient management in different crops through training programmes and demonstration trials at different villages. Training programmes were conducted for Kinnauri, Gaddi tribals of Himachal Pradesh in tribal villages viz., Chhonda (Kinnaur), Garnota & Kakroti (Chamba), Uttarala, Sungal, Mathred & Darati (Kangra) and Lari (Lahaul Spiti) during 2016-19. About 310 FLDs were conducted on maize and wheat on farmers' fields in Gujredha, Nain Uttrala and Dhulara villages in Himachal Pradesh.

Training at Sungal (Kangra-Dist.)

Training at Mathred (Kangra-Dist.)

Training at Lari (Lahaul spiti-Dist.)

Training at Darati (Kangra-Dist.)

Plate 8.4 Training programmes organized at tribal villages in Himachal Pradesh

Plate 8.5 Field demonstrations in tribal villages in Himachal Pradesh

8.1.4 Raipur

The front line demonstration trials were conducted at Hingnadeeh village under Kumahri tribal block of Durg district with seventeen farmers under TSP during kharif and rabi season during -2016-17. The rice and wheat grain yields were higher in optimal and balanced dose of nutrient application as compared to imbalanced (nitrogen alone) nutrient application and farmers' practice. The rice and wheat yield was almost doubled under optimal and balanced nutrient application as compared to farmers' practice. The grain yield trend for wheat and rice was observed in the order of balanced nutrients > imbalanced nutrient > farmers' practice. The highest paddy and wheat yield recorded was 40 and 27 kg/ha, respectively. The front line demonstrations were also conducted in four villages (Tendu, Mahora, Khada and Dakaipara) under Bainkunthapur tribal block of Koria district with seventy farmers under the TSP during kharif and rabi season during-2016-17. The yields of both the crops were found maximum in balanced application of nutrients and minimum in farmers' practice. The highest paddy and wheat yield recorded was 34 and 24 kg/ha, respectively.

From the frontline demonstration trials, it was observed that the application of potassic fertilizers may be skipped or may be applied once in 2-3 years based on soil test results without compromising yield and economic returns under potassium rich Vertisols condition. Application of phosphatic fertilizer is essential under Vertisols to obtain higher yield of succeeding wheat crop after rice cultivation, Application of nitrogenous fertilizer alone (imbalanced fertilizer application) delays the flowering period (10-15 days) in rice and subsequently delayed the sowing of wheat crop resulting in lower productivity. The wheat grain yield loss of 55-65% was recorded in the absence of P and K fertilizer application. The marginal and/or resource constrained farmers who are unable to apply optimal (100% NPK) dose of recommended fertilizer shall apply sub-optimal (half) dose of the recommended balanced fertilizer to harvest almost 12% increase in rice yield over imbalanced fertilizer application (nitrogenous fertilizer alone). The dissemination of results to farmers field under FLD trial programme resulted in bridging the gap between fertilizer usage (NPK ratios) towards more balanced way with 4:2:1 (Jagdalpur), 9:1:1 (Dantewada) and 3:1:1 (Kanker); and rice productivity of 1.1, 0.9 and 1.2 t/ha, respectively.

About 70 FLDs were conducted in tribal villages of Hingnadeeh, Rajnandgaon, Surguja and Gariyaband in Raipur district (Chhattisgarh). The crops grown were rice (cv Rajeshwari) in kharif season and chickpea (cv JAKI -9218) during rabi season during 2017-18. The inputs such as seeds, inorganic fertilizers (Urea, SSP & MOP), and herbicides were distributed to the farmers. The application of potassic fertilizers may skip on soil test basis without compromising yield and return as Vertisols of the region are rich in potassium hence farmer's apply only once in 2-3 years. Getting higher yield of succeeding wheat crop after rice, application of phosphatic fertilizer is essential under Vertisols. Sole application of nitrogenous fertilizer alone delays the flowering (10-15 days) in rice and consequently delayed sowing of wheat, resulting in lower productivity.

Balanced application of fertilizers at optimal level i.e. 100% NPK is quite promising in enhancing wheat productivity upto 20% over farmers practice at Korea and Surajpur district of Chhattisgarh. The grain yield loss in the absence of P and K fertilizer application was around 55-65% in wheat. At village hingnadeeh under Chhattisgarh plains the optimum dose of NPK fertilizer gave around 30% increase in rice yield compared to farmers practice.

Training programme on soil testing by kit was conducted. Analysis of soil samples from farmer's field after kharif crop and harvesting, monitoring of rabi crops were done. The FLDs were conducted on balanced fertilization during Kharif seasons. Monitoring of FLD's regarding plant protection measures and crop monitoring were done. Harvesting and data collection and FLD's was conducted on balanced fertilization during Rabi seasons as well.

Resource poor farmers who are unable to apply full dose of recommended fertilizer shall apply half of the recommended dose of fertilizers in balanced way to harvest 10% increase in wheat yield over recommended dose of nitrogenous fertilizers alone. Frontline demonstration trials (50 nos.) on balanced fertilization has been tested on tribal farmer's fields of Rajnandgaon districts village Malpuri of Chhattisgarh with rice and chickpea crops during 2018-19.

In Malpuri village of Rajnandgaon, rice crop (cv Rajeshwari) gave yield advantage of 15.7- 23.9% while chickpea (cv JAKI-9218) gave 21-25% increase in yield during rabi season.

Rice yield from 25 locations in Farmers' Practice ranged from 37.4 to 42.4 q ha^{-1} with the average yield of 39.44 q ha^{-1}; whereas, under balanced fertilizer applications, the rice yield ranged from 45.1 to 50.3 q ha^{-1} with mean yield of 48.25 q ha^{-1}. The percentage increase in rice yield over farmers practice ranged from 15.7–23.9% with mean value of 19.8% indicating the role of balanced fertilizer application for achieving a higher crop yield.

Chickpea yield from 25 locations in Farmers Practice ranged from 4.1 to 5.1 q ha^{-1} with the average yield of 4.6 q ha^{-1}; whereas, under balanced fertilizer applications, the chickpea yield ranged from 7.1 to 8.1 q ha^{-1} with mean yield of 7.6 q ha^{-1}. The percentage increase in chickpea yield over farmers practice ranged from 31.0 – 45.3% with mean value of 38.15% indicating the role of balanced fertilizer application for achieving a higher crop yield.

Front Line Demonstration (TSP activities) on 'Balanced Fertilization' under AICRP-LTFE, Raipur Centre with Farmers under Agroclimatic zone (I) – Chhattisgarh plains at Village-Malpuri, District- Rajnandgaon.

Plate 8.6 FLDs at Rajnandgaon (Chhattisgarh)

8.1.5 Bangalore

Under tribal sub plan of Govt. of India, agricultural inputs viz., fertilizers and seeds were distributed to 650 beneficiary farmers covering Mysore, Tumkur, Chamarajnagar and Chikkaballapur districts of Karnataka during 2016-17 to 2018-19. The training programme on integrated nutrient management and field demonstration on soil sampling protocol were conducted in respective villages. The soil samples collected from the beneficiaries were analysed for fertility status and soil health cards were distributed to the beneficiaries.

About 650 beneficiaries were benefitted from Hosapodu Doddi (Chamarajanagara (Tq & Dist), Sollepura, H.D.Kote (Tq), Hebbala, Hunusur (Tq), Mysrore Dist., Basmangi Kaval, Madhugiri (tq), Tumkur (dist), Karnataka., Kittagali, Madhugiri (tq), Tumkur (Dist), Karnataka. ; Kaarpalli, Madhugiri (tq), Tumkur (dist), Karnataka.; Makareddypalli, Bagepalli (Tq), Chikkaballapur (Dist), Karnataka; Muddalapalli, Bagepalli (Tq), Chikkaballapur (Dist), Karnataka.; Boodipadaga (Rangasandra), Chamarajanagara (Tq & Dist) during 2016-17 to 2018-19. About 31,350 kg Urea, 12,350 kg DAP, 15,950 kg SSP, 17,800 kg MoP fertilizers and 1010 kg ragi seeds, 520 kg maize seed were distributed to the farmers.

The FLDs on finger millet gave 6.3 q/acre with INM compared to 5.3 q/acre under farmers' practice in Basmangi Kaval, Kittagali and Kaarpalli villages (Tumkur dist, Karnataka). Thus, INM has a yield advantage of 18% over farmers practice. Similarly, in case of maize, 26.6 q/acre with INM compared to 22.7 q/acre under farmers' practice with 17% yield improvement.

8.1.6 Bhubaneswar

Frontline demonstration trials were conducted at different locations of Kandhamal, Deogarh and Keonjhar ditrict, Odisha. Under TSP programme during 2016-17 to 2018-19. The balanced fertiliser application on the basis of soil test results recorded the highest yield in all the districts with a mean increase of 39 to 50.14% yield over farmers' practice under rice-rice cropping system. It has also been observed that farmers' have realized the beneficial effect of soil test based NPK fertilizer and integrated nutrient management (INM) in increasing rice yield. The average increase in crop yield and economic returns in different locations under the influence of INM and farmers' practice (**Table 8.3**).

Table 8.3 Yield advantage due to nutrient management practices (2016-19)

District	Village	No of farmers	Mean grain yield (t/ha)		Additional yield (t/ha)	Return per rupee invested	
			FP	STBR		FP	STBR
			Kharif-2016				
Kandhamal	Katadanga	15	2.7	4.6	1.9	0.81	1.29
Deogarh	Kailash	40	3.6	6.0	2.4	1.08	1.54
Keonjhar	Juanga	18	4.0	6.4	2.4	1.19	1.48
			Rabi-2016-17				
Keonjhar	Kadalibadi	15	3.1	5.7	2.6	0.99	1.61
Kandhamal	Kamberikia	16	2.9	5.4	2.5	0.72	1.19
Deogarh	Kailash	10	3.1	5.0	1.9	1.01	1.41
			Kharif-2017				
Keonjhar	Kundhei	20	3.2	5.5	2.3	0.94	1.29
Kandhamal	Bearpanga	21	2.9	4.8	1.9	1.01	1.29
Kandhamal	Lendrikia	10	4.3	6.0	1.7	1.29	1.48
Kandhamal	Baubinaju	24	4.4	6.0	1.6	1.06	1.23
Keonjhar	Sunaripasi	9	3.6	5.5	1.9	1.14	1.42
	Sagadapata	11	3.3	5.3	2.0	0.95	1.12

Plate 8.7 Visit of QRT Members to FLDs at Bearpanaga village at Kandhamal district (TSP programme)

Plate 8.8 Dr Muneshwar Singh, PC (LTFE) visits farmers' field (Deogarh district)

8.1.7 Ranchi

Long term experiments conducted in the state have amply demonstrated application of organic manure on sustaining high potential productivity and soil health. Organic manure application has beneficial effect on aggregate and structural stability, water holding capacity, supply and retention of plant nutrients, biological nitrogen fixation, detoxifying impact on acidity and other physical, chemical and biological properties of soil. Based on the technology and fertilizer practices generated out of the long term fertilizer experiment, it is estimated that, the current level of food grain production of 45.6 lakh tones can be raised to a level of 54.7 lakh tonnes in the state with application of FYM along with the farmers' practice (**Table 8.4**). Profitability can be increased with the judicious use of chemical fertilizers for food grain crops or with adoption of integrated nutrient management practices (**Table 8.4)**.

Table 8.4 Productivity and profitability of nutrient management practices under farmers' field in different districts of Jharkhand

Particulars	NP	NPK	NPK+ Lime	NPK + FYM	Farmers' Practice
W. Singhbhum	25.00	37.8	46.4	45.1	18.5
Lohardaga	25.80	37.8	35.7	48.5	24.4
Gumla	24.00	36.4	40.6	42.6	21.4
Ranchi	24.80	33.6	48.1	37.0	17.7
Mean (A)	24.90	36.4	42.7	43.3	20.5
Cost (₹)	4991	6222	9422	9222	2862
Yield advantage (kg/ha)	440	1590	2220	2280	-
Addl. Cost (₹)	2129	3360	6560	6360	-
Additional benefit	6710	24251	33855	34770	-
B:C ratio	3.2	7.2	5.2	5.5	-

Soil test values for the field of tribal farmers from Jaria, Bedo, Ranchi, Chatta, Karra and Khunti indicated that the average soils have pH 5.06, soil organic C 0.43%, available status of P was 57.03 kg ha^{-1} and available status of K was 154.2 kg ha^{-1} .

8.2 Scheduled Caste Sub Plan (SCSP)

8.2.1 Ludhiana

8.2.1.1 Soil Properties

Front line demonstration trials were conducted at different locations of Hoshiarpur and Nawanshahr dictrict of Punjab.

Table 8.5 Basic soil properties of selected fields

District	Location	pH	EC (dS m^{-1})	OC (%)	N	P	K	S
					(kg ha^{-1})			
Hoshiarpur	Location 1	7.32	0.583	0.75	161	15.5	135	12.2
	Location 2	7.30	0.243	0.36	117	14.1	119	11.3
	Location 3	7.14	0.668	0.66	156	15.7	138	13.5
	Location 4	6.83	0.256	0.42	143	14.2	110	11.6
	Location 5	7.31	0.26	0.80	160	18.2	201	16.8
	Location 6	7.35	0.206	0.66	155	17.3	156	13.4
Nawanshahr	Location 7	8.41	0.212	0.37	88	30.28	202	9.8
	Location 8	8.45	0.204	0.25	70	28.45	199	9.5

The soils under study was neutral to alkaline in reaction (pH: 6.83-8.45), electric conductivity ranged from (0.204 to 0.668 dS m^{-1}), low to high in SOC (0.27-0.80%), low in available N (70-161 kg ha^{-1}), medium to high in available P (14.1-30.28 kg ha^{-1}), low to medium in available K (110-202 kg ha^{-1}) and low in available S (9.5-16.8 kg ha^{-1}) Table 8.5.

8.2.1.2 Crop yield

The data pertaining to grain yield of maize under different nutrient management practices at different locations are presented in **Table 8.6**. The grain yield of maize ranged from 10.0 to 45.5 and 16.1 to 43.3 q ha^{-1} at different locations of Hoshiarpur and Nawanshahr, respectively. The minimum and the maximum value were observed under control and 100% NPK+FYM, respectively. The effect of organic manure (sole application of FYM) on grain yield was lower than chemical fertilizer (NPK) with an increase in yield of 13.3 q ha^{-} was observed over control. Integrated application of recommended dose of NPK along with FYM resulted in maximum maize yield among the various treatments. The yield under NPK+FYM treatment was higher by 6.2 and 16.9 q ha^{-1} compared to 100% NPK and FYM treatments, respectively.

Table 8.6 Effect of different fertilizer management practices on maize grain yield (q ha^{-1})

District	Location	Maize grain yield (q ha^{-1})			
		Control	100% NPK	FYM @ 10 Mg ha^{-1}	100% NPK + FYM (10 Mg ha^{-1})
Hoshiarpur	Location 1	13.2	39.3	27.5	45.5
	Location 2	10.0	31.5	21.3	39.8
	Location 3	14.1	38.0	26.8	44.5
	Location 4	14.5	40.8	27.6	44.0
	Location 6	11.2	36.2	25.5	43.3
Nawanshahr	Location 7	16.1	37.5	30.0	43.2
	Mean	13.2	37.2	26.5	43.4

8.2.2 Coimbatore

Front line demonstrations (FLD) on maize crop were conducted at 10 locations of Coimbatore district (Anamalai and Karamadai blocks), Tamil Nadu to demonstrate the results of Integrated Nutrient Management practices (100% inorganic fertilizers + FYM @ 10 Mg ha^{-1}) with framers practice. In the above two blocks, 10 scheduled caste farmers (7 farmers at Anamalai block and 3 farmers at Karamadai block) were selected for conducting FLD trials. Inputs such as seeds, fertilizers, organic manures, herbicides, plant protection chemicals, sprayers and spades were distributed to the beneficiary farmers. Maize Hybrid CO HM – 6 was used as test crop in all these 10 locations studied.

Soil samples collected from all the fields were analysed for pH, electrical conductivity and available nutrient status (**Table 8.7**). Based on the analytical data, soil health cards were prepared in local language (Tamil) and distributed to the farmers (10 Nos.). During the entire cropping period farm advisories were given on nutrient management and pest management aspects.

The maize grain yield varied from 3993 kg ha^{-1} (farmers practice) to 6133 kg ha^{-1} (INM practice). Application of fertilizers through Integrated Nutrient Management practice (100% NPK + FYM @ 10 Mg ha^{-1}) recorded the highest grain yield at all the locations. The yield increase in INM over farmers' practice ranged from 14.6 to 27.2%. Through FLD programme, the farmers were exposed with the benefits of INM technology viz., higher productivity and economic returns. The farmers had shown their interest to know more about INM practices during the field demonstration trial carried out by the AICRP LTFE scientists.

Table 8.7 Initial soil properties of farmers' fields under FLD trials

Particulars	pH	EC (dS m^{-1})	Soil Available Nutrients (kg ha^{-1})		
			$KMnO_4$ - N	Olsen - P	NH_4OAC- K
Location 1	7.92	0.14	192.3	21.2	482
Location 2	7.13	0.15	184.6	20.9	503
Location 3	6.98	0.23	201.4	22.4	512
Location 4	8.02	0.21	224.9	19.8	613
Location 5	8.13	0.19	238	18.6	542
Location 6	7.84	1.22	197	21.8	496
Location 7	7.90	0.20	214	17.3	509
Location 8	8.09	0.16	248	18.2	455
Location 9	7.72	0.24	188	15.3	482
Location 10	6.99	0.21	219	18.8	454

Table 8.8 Impact of INM practices on grain yield (kg ha^{-1}) of maize under FLD trials

Particulars	Grain yield (kg ha^{-1})		Yield increase (%) over Farmers' Practice
	Farmers' Practice	INM practice	
Location 1	4398	5272	19.8
Location 2	4732	5423	14.6
Location 3	5098	6133	20.3
Location 4	4551	5429	19.3
Location 5	3993	5081	27.2
Location 6	4803	5511	14.7
Location 7	4632	5730	23.7
Location 8	5052	5831	15.4
Location 9	4573	5440	18.9
Location 10	4800	5681	18.3

9. DEMONSTRATIONS & FIELD TRIALS

IN ORDER TO DEMONSTRATE the technologies emerging from AICRP-LTFE and the benefits due to balanced and INM strategies, field trials and demonstrations on farmers field being done by respective centres of AICRP-LTFE that have been presented here:

9.1 Pattambi

9.1.1 Demonstration of Technologies

Demonstration illustrated an increase in average yield and income of the farmers in tribal areas. For instance, (i) Introduction of upland variety Vaisakh with economic advantage (ii) Total additional yield obtained through demonstration in banana was ~ 1200 kg which brings about an additional income of Rs. 48,000/- (iii) Total economic advantage due to demonstration in ginger was Rs 3500 per 25 cents (iv)Introduced high yielding variety (HYV) Varada for turmeric cultivation to the adjoining areas. (v) Demonstrated the improvement in yield with integrated nutrient management (INM) in vegetables (vi) Inter cropping with colocasia and elephant foot yam.

Plate 9.1 Front line demonstrations on *in situ* green manuring on farmers' field (Pattambi, Kerala)

In situ green manuring identified as a cost effective substitute for farm yard manure application

In situ green manuring with Dhaincha identified and popularized as a cost effective and farmer friendly technology (**Plate 9.1**) indicating growth in average grain yield (average for kharif and rabi) of paddy over the years. Technology demonstrations were conducted in farmers' fields during 2016-19 in rice 4 treatments viz., 100% NPK (90:45:45), *In situ* green manuring with dhaincha + 100% NPK (90:45:45), *in situ* green manuring with dhaincha + 50% NPK (90:45:45) and FYM 5 Mg + 100% NPK. The demonstration was done in a total area of 45 acres with 20 participant farmers in kharif season. *In situ* green manuring with Dhaincha produces on an average 35 metric tonnes green matter per hectare and it is a widely accepted as soil health management practice with respect to addition of organic matter.

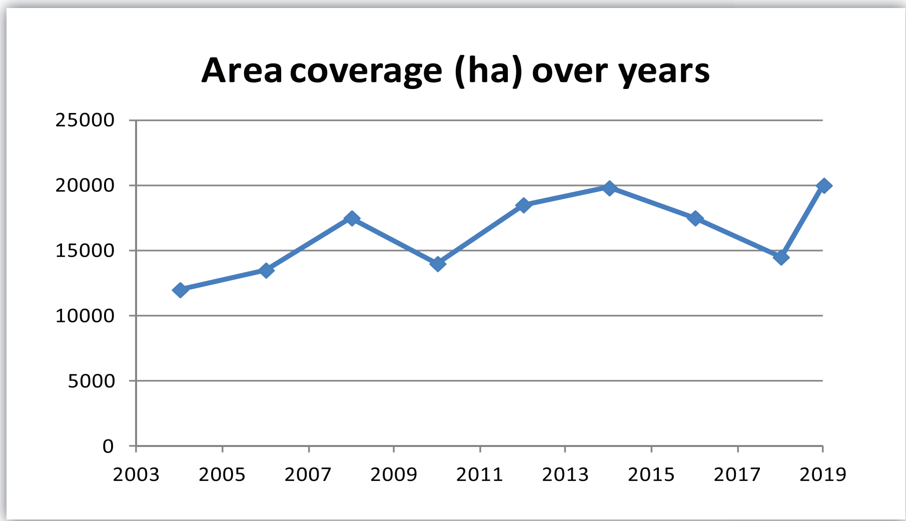


Figure 9.1 Status of area under green manuring in Kerala State

Nutrient Composition of Dhaincha

It was recorded in dhaincha that there was an increase in biomass partitioning to the roots. The fresh weight by shoot 1.25 (26.32%) and root 3.50 kg m^2 (73.68%) with a dry weight 0.301 and root 0.385 kg m^2, which was 43.82 and 56.12%, respectively. The N, P and K content in biomass of dhaincha was 2.4, 0.4 and 0.9%, respectively that contributing in terms of nutrients to the tune of 150, 27 and 61 kg ha^{-1}.

Green Manuring as Effective as FYM addition in rice

100% NPK + *in situ* green manuring using dhaincha seeds @ 12.5 kg ha^{-1} to substitute FYM addition in rice.

Table 9.1 Net profit (Rs) per hectare over the years on integration of in-situ green manuring over balanced and INM.

Year	100% NPK	100% NPK + 5 Mg FYM	100% NPK + *in situ* green manuring
2016-17	64080	94320	107825
2017-18	53260	72625	79595
2018-19	88750	130000	142250
Average	206090	296945	329670

Economic advantage (in situ GM over FYM) = Rs. 10,931/- per ha

Table 9.2: The economics of growing green manuring crops under rice-rice cropping system of Pattambi, Kerala

Particulars	100% NPK	100% NPK+5 Mg FYM	50% NPK+ 5 Mg FYM	100% NPK+ in situ green manuring	50% NPK+ in situ green manuring
			2016-17		
Kharif	4040	5150	4640	5200	4230
Rabi	3600	4660	4230	4500	3840
Total	7640	9810	8870	9700	8070
Cost of cultivation (Rs)	104000	121500	117231	105575	101306
Return (Rs)	168080	215820	195140	213400	177540
Net profit (Rs)	64080	94320	77907	107825	76234
B:C ratio	1.62	1.78	1.66	2.02	1.75
			2017-18		
Kharif	3350	4100	3640	3910	3740
Rabi	3810	4650	4230	4360	4120
Total	7160	8750	7870	8270	7860
Cost of cultivation	115000	133000	130996	116750	114746
Return	168260	205625	184945	196345	184710
Net profit	53260	72625	53949	79595	69964
B:C ratio	1.46	1.54	1.41	1.66	1.6
			2018-19		
Kharif	4550	5850	4850	5900	4980
Rabi	4400	5550	4750	5350	4800
Total	8950	11400	9600	11250	9780
Cost of cultivation	135000	155000	152815	139000	136815
Return	223750	285000	240000	281250	244500
Net profit	88750	130000	87185	142250	107685
B:C ratio	1.66	1.84	1.57	2.02	1.79

(Fertilizer cost for 100% NPK @ Rs 4269/- (Urea- Rs. 1209/-, Rajphos Rs 1800/-, MOP Rs 1260/-) in 2017; Rs 4008/- (Urea- Rs. 5.6/kg, Rajphos Rs 9 per kg, MOP Rs 11.88 per kg) in 2018; Rs 4008/- (Urea- Rs. 5.07 per kg, Rajphos Rs 9 per kg, MOP Rs 18.09 per kg) in 2019. FYM 5 t per ha @ Rs 17500/- in 2017; Rs 18000/- in 2018; Rs. 20000/- in 2019. Dhaincha seeds 12.5 kg/ha @ Rs 66 per kg + application cost Rs 700/- = Rs. 1525/- in 2017; @ Rs 60 per kg + application cost Rs 1000/- = Rs. 1750/- in 2018; @ Rs 80 per kg + application cost Rs 1000/- = Rs 2000/- in 2019. General cost of cultivation including labour, seeds, plant protection chemicals and application excluding manures and fertilizers @ Rs. 49866/- per hectare in 2017; Rs. 110992/- per ha in 2018; Rs. 130631/- per ha in 2019. Price of paddy @ Rs 22.00 per kg in 2017; Rs 23.50 per kg in 2018; Rs 25.00 per kg)

Non availability of farmyard manure is the most important soil health restoration constraint in Kerala and become the costlier input in rice next only to labour charges. *In situ* green manuring with dhaincha is the most appropriate technology for substituting FYM addition in soils of Kerala. The technology is being adopted in 20000 ha in Kerala. As per the results of demonstration trial of 2016-19 an average amount of Rs 10909 has been saved per hectare and total economic advantage of this technology is 21.82 crore/year.

Due to over consciousness on chemicals in production system, some farmers are reducing fertilizer application but not able to provide enough organic manures. In such a situation reducing the fertilizer doze to 50% provided in situ green manuring is practiced can give yield and economic return more than applying 100% NPK as proved in demonstrations conducted in farmers' fields.

Coverage in the state	: 20000 ha (20% area coverage)
Coverage in the district	: 5000 ha
Cost of organic manure saving in the state	: 20000 ha * 5 ton * Rs 4/- =400,000,000 per year
Quantity of dhaincha seeds distributed	: 3200 kg (3 years)

9.1.2 Development of multi-nutrient mixtures for foliar application

The over dominance of iron in Kerala soils result in the physiological deficiency of other cations such as zinc, copper and even potassium. Moreover, now-a-days multi-nutrient deficiencies are occurring very commonly in almost all the crops. In this context, considering the extent of deficiencies and impaired availability of essential nutrients, multi-nutrient mixtures were developed at RARS Pattambi using nutrient carriers for foliar application in rice, banana and vegetable crops. Initially, the mixing compatibility and storage properties were analyzed during the preparation of the mixtures. The mixture was developed through a number of trials with varied number of sources of nutrients such as zinc, copper, boron, molybdenum, iron and manganese. Nutrient carriers were selected as the fillers for the mixture so that unnecessary cost for inert materials can be avoided. A nine compound formula was developed and later crop specific nutrient mixtures were prepared considering crop uptake and deficiency- sufficiency ranges for the selected crop while fixing the proportion of the compatible chemicals in the mixture. The multi-nutrient mixtures suitable for foliar application were developed for rice and banana which contain K, Mg, S, Zn, Cu, B and Mo along with traces of iron, manganese and nitrogen. Pot culture and field experiments were conducted at RARS Pattambi and in the farmers' fields of Palakkad district, and the foliar application of the mixtures could improve crop productivity in both the crops. The technology is being demonstrated in large areas in different parts of the state.

Plate 9.2 Multi-nutrient mixtures for foliar application (Pattambi, Kerala)

Paddy mixture

The total cropped area under rice comes below 2 lakh hectares in Kerala. If 25% of the area can be brought under multi-nutrient mixture application, 600 tonnes of the mixture can be produced annually (@ 12 kg/ha). The approximate cost of production of 600 tonnes of paddy mixture is 6 crores which can amount to a value of 12 crores. The net profit for the entrepreneurs practicing the technology will come to 6 crores per annum if the rate will be fixed at Rs 200 per kg.

Carpet seeding in rice

It is a labour saving technique in rice production. By this technique transplanting and weeding can be completely avoided. Paddy seeds fixed required spacing in rolling sheets made up of organic material is unrolled in puddle soil. As holes are provided for rice seeds emergence no weed growth up to 50 days in the field. About 25% yield increase in rice by adopting this technology. The commercial productions of pre-seeded rolling sheet are in pipeline.



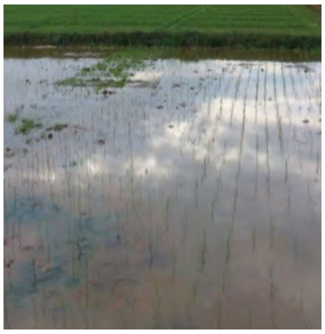



Plate 9.3 Carpet seeding in rice (Pattambi, Kerala)

Plant sap based liquid manure for foliar nutrition

Plant sap based liquid manure prepared from phyto accumulator *Mirabilis jalapa* suitable for foliar nutrition especially for organically grown vegetable cultivation is developed under Kerala State Govt. Funded project.

Technology Transferred

- *In situ* green manuring using dhaincha seeds @ 12.5 kg ha^{-1} can substitute FYM addition in rice: green manuring has become popular throughout the state of Kerala. Recently, due to non availability of farm yard manure, it is the most important soil health restoration technique in Kerala covering 20% of the cropped area under rice.
- The INM recommendation for reduced load of chemical fertilizers (50% NPK+ FYM/*in situ* green manuring is equivalent to 100% NPK): Higher load of chemical fertilizers to the soil and to the crop, As the state is moving towards organic policy, this technology has been accepted with appreciation in the transition stage, throughout the state of Kerala

Technology developed

- Multi nutrient mixtures for foliar application in rice, banana and vegetables
- Carpet seeding technique in rice
- Plant sap based liquid manure for foliar nutrition

9.2 Akola

Field trials on farmer's field in intensive crop growing area on Vertisols were conducted. The crops selected were soybean and wheat. Each farmer considered as one replication. The soils were characterized at each site in detail for present status of different forms of soil potassium i.e. exchangeable K, Non exchangeable K, Water soluble K as well as for major properties like pH, EC, $CaCO_3$, organic carbon and available nutrient status.

Table 9.3 Effect of various treatments on grain and straw yield of soybean and wheat (2016-17)

Tr. No	Treatments N: P_2O_5: K_2O kg ha^{-1}	Yield of Soybean (kg ha^{-1})		Treatments N: P_2O_5: K_2O (kg ha^{-1})	Yield of Wheat (kg ha^{-1})	
		Grain	Straw		Grain	Straw
T_1	30:75:00	1437	1700	120:60:00	2705	4773
T_2	30:75:30	1565	1933	120:60:30	3168	5614
T_3	30:75:60	1787	2327	120:60:60	3449	6110
T_4	30:75:90	1838	2403	120:60:90	3594	6315
	CD (0.05)	106	68		173	418

Soil fertility status

The soil nutrient status as influenced by various levels of K is presented **Table 44**. The application of various levels of potassium did not have significant influence on various soil properties (viz; pH, electrical conductivity, organic carbon, available N and available P) except that, available K (**Table 9.4**). The various levels of potassium significantly increased the status of available K in soil. However, application of 90 kg K_2O ha^{-1} along with common dose of N and P significantly improved the status of available K.

Table 9.4 Soil chemical properties as influenced by various treatments of K under soybean (kharif 2017-18)

Tr No.	Treatments N: P_2O_5: K_2O kg ha^{-1}	pH	EC (dSm^{-1})	OC (g kg^{-1})	Available Nutrients (kg ha^{-1})		
					N	P	K
T_1	30:75:00	7.71	0.27	5.39	199.33	14.57	394.17
T_2	30:75:30	7.72	0.30	5.43	203.00	14.61	399.17
T_3	30:75:60	7.74	0.27	5.46	206.83	14.66	403.67
T_4	30:75:90	7.73	0.29	5.47	210.17	14.70	407.17
	CD (0.05)	NS	NS	0.011	NS	NS	1.51

The highest grain yield (1838 kg ha^{-1}) was obtained with the application of 30:75:90 kg NPK ha^{-1} (T_4) followed by 30:75:60 kg NPK ha^{-1} (1787 kg ha^{-1}) (T_3) which was found to be on par with each other. The soil pH and electrical conductivity was found to be non-significant due to the effect of potassium application after harvest of soybean 2017-18. The effect of application of graded levels of potassium was found to be significant on organic carbon of soil after harvest of soybean while the increasing level of potassium slightly increased the OC of soil under wheat crop. The application of potassium from 0 kg ha^{-1} to 30, 60 and 90 kg ha^{-1} showed linear increase in N and P status of soil & available K status increased significantly under both the crop (soybean and wheat). The highest grain (3594 kg ha^{-1}) and straw yield (6315 kg ha^{-1}) of wheat was recorded with the application of 120:60:90 kg NPK ha^{-1}.

Plate 9.4. FLD's on application of potassium in soybean and wheat at Rahit (Taluka Barshitakli) and at Rajanda and Katkheda (Taluka Barshitakli) Dist Akola.

9.3 Jabalpur

Farmer field trial on response of phosphorus (P) in Vertisols were laid out on the basis of inherent high available soil P status with soybean-wheat cropping sequence with soybean and wheat cropping system. The recommended dose of fertilizer for soybean was 20:80:20 ($N:P_2O_5:K_2O$ kg ha^{-1}) and Wheat : 120:80:40 ($N:P_2O_5:K_2O$ kg ha^{-1}) and farmers' practice (FP). The nutrient application in FP were 13 kg N and 34 kg P_2O_5 ha^{-1} (30 kg DAP per acre); for soybean and wheat: 70 kg N and 34 kg P_2O_5 ha^{-1} (30 kg DAP per acre) and two split dose of Urea @ 50 kg per acre were made.

Application of 100% NPK+FYM gave the highest average yield of soybean (**Table 9.5**). The lowest with farmer's practice. The highest increase in yield (33%) was observed with 100% NPK + FYM over farmer's practice, followed by 22% increase in yield (100% NPK) of soybean over farmer practice. The 50% P application with 100% NK was found to increase the yield by about 9% over farmer's practice.

A similar trend was also recorded with wheat yield. The lowest yield was recorded in farmers' practice. Maximum increase in yield (24%) was observed with 100% NPK + FYM over farmers' practice, followed by 18% increase in yield (100% NPK) of wheat over farmer's practice. The data further showed that even the 50% P application with 100% NK was found to be increased the yield by about 10% in wheat over farmers' practice.

Table 9.5 Average grain yield (kg ha^{-1}) of soybean and wheat on high P containing soils (2016-19)

Treatment	Soybean	Wheat
100% NPK+FYM	1259	4523
100% NPK	1153	4327
100% NK+50% P	1026	4027
100% NPK-S	1079	3875
Farmers Practice	945	3660

9.4 Palampur

The demonstrations of balanced and integrated nutrient management (INM) practices were conducted on farmers' field at Palampur. The farmers were showcased the crop performance and other benefits of adopting beneficial combinations of inorganic and organic fertilizers.

100% NPK + FYM   Farmers' Practice   100% NPK + FYM   Farmers' Practice

Plate 9.5 FLD's at Palampur (Himachal Pradesh)

9.5 Udaipur

Evaluation of efficiency of most sustainable fertilizer use practices for enhancing productivity on continuous maize-wheat cropping at farmer's field.

Table 9.6 Effect of fertilizer use practices on grain yield (kg ha^{-1}) of maize and wheat at farmers' field (pooled 2016-19)

Treatment	No. of OFT										
	Maize										
	1	2	3	4	5	6	7	8	9	10	Average
$NP_{1/2}K_0$	3450	3270	3400	3200	3050	3260	3350	3520	3200	3050	3275
NPK_0	3540	3300	3520	3360	3200	3520	3520	3720	3460	3160	3430
NPK	3670	3560	3600	3520	3260	3660	3580	3890	3580	3290	3561
NPK+FYM	3728	3658	3658	3718	3448	3698	3658	3838	3538	3338	3628
	Wheat										
$NP_{1/2}K_0$	4430	4330	4400	4240	4050	4260	4350	4520	4220	4070	4287
NPK_0	4580	4420	4560	4360	4280	4580	4560	4780	4460	4160	4474
NPK	4690	4580	4640	4620	4360	4680	4620	4890	4540	4260	4588
NPK+FYM	4840	4610	4670	4630	4410	4770	4630	4850	4650	4310	4637

Field experiments based on LTFE technology were taken to farmers' fields at 100 (at two-three villages) locations in maize-wheat cropping system. The experiments consisted of four treatments, viz., $NP_{1/2}K_0$, NPK_0, NPK, NPK+FYM. The increase in yield by application of NPK_0 over $NP_{1/2} K_0$ was 155 kg ha^{-1} indicating that full dose of phosphorus is needed (**Table 9.6**). The yield further increased with application of potassium along with NP. The highest average yield of maize was recorded in 100% NPK + FYM followed by NPK, NPK_0. This integrated use of fertilizer and manure gave highest yield of maize and increase in yield was 10.77% higher than the treatment $NP_{1/2} K_o$. In case of wheat, the increase in NPK and NPK + FYM yield on application of NPKo, over $NP_{1/2}$Ko were 4.36, 7.02 and 8.16% respectively. Likewise in maize, the highest grain yield of wheat was recorded in NPK + FYM treatment followed by NPK.

9.6 Bangalore

The AICRP-LTFE Bangalore centre had distributed several agricultural inputs to farmer, (Plate 9.6 a & b) conducted trainings and soil samples were collected from their fields, which were used for soil fertility assessment and then soil health cards were distributed to them. Field level demonstrations were also performed to explain them about the benefits of INM over farmers' practice.

(a) Makareddyapalli, Bagepalli (Tq), Chikkaballpur

(b) Boodipadaga (Rangasandra), Chamarajangara

Plate 9.6 Input Distribution in different tribal villages in various districts under TSP at Bagalore (Karnataka)

10. AWARD, RECOGNITION & VISIT

10.1 Award & Recognition

10.1.1 PC Unit LTFE

- Drs MC Manna, RH Wanjari, Muneshwar Singh, AK Patra and SK Chaudhari (2018) received IPNI-FAI Award for Best Research on 'Management and Balanced Use of Inputs in Achieving the Maximum Yield'.

Dr MC Manna receiving an Award

10.1.2 AICRP LTFE Centres

ICAR-IARI New Delhi

- Dr BS Dwivedi (2016) received Dhiru Morarji Memorial Award for the Best article in Agricultural Sciences published in Indian Journal of Fertilisers for the article entitled "Integrated nutrient management for enhancing nitrogen use efficiency".
- Dr BS Dwivedi (2016) received XVII Hari Krishna Shastri Memorial Award of ICAR-IARI.
- Dr BS Dwivedi (2017) received ICAR Rafi Ahmed Kidwai Award for "Outstanding Research Contributions in Natural Resource Management".

Dr BS Dwivedi receiving an Award

- Dr BS Dwivedi (2017) received SN Ranade Memorial Lifetime Achievement Award for "Excellence in Micronutrient Research", IMT Technologies, Pune.
- Dr BS Dwivedi (2018) received ISSS-Platinum Jubilee Commemoration Award for "Lifetime Outstanding Research and Teaching Contributions in the Area of Improving Soil Health and Nutrient Use Efficiency".

- Dr BS Dwivedi (2018) received FAI Golden Jubilee Award for "Excellence in Nitrogen Management for Sustainable Crop Production".

- Dr MC Meena (2017) received SN Ranade Memorial Award, IMT Technologies, Pune.

Dr MC Meena receiving an Award

- Dr MC Meena (2017) received Young Scientist Award by the Society for Rapeseed-Mustard Research, Bharatpur.

- Dr MC Meena (2019) received B Laxminarayana Memorial Award, ICAR-IARI, New Delhi.

Dr MC Meena receiving an Award

- Dr Abir Dey (2017) received FAI-Golden Jubilee Award for Outstanding Doctoral Research in Fertilizer Usage.

- Dr Abir Dey (2017) received Indian Society of Soil Science (ISSS)-Commendation Certificate for Outstanding Doctoral Research Work in Soil Science.

UAS GKVK Bangalore

- Dr GG Kadalli (2017) received ICAR Best Teacher Award from University of Agricultural Sciences, Bengalure on October 4, 2017

Dr GG Kadalli receiving an Award

- Ms Jayanthi T (2018) received Women Scientist Award in 14th Kannada Vignana Sammelana-2018 during 15 - 16th September 2018 at Kolar, Karnataka.

- Dr GG Kadalli (2018) received Best Oral Presentation Award in the DST sponsored National Seminar on 'Technological Interventions to Enhance Nutrient Use Efficiency to Meet Food Security and Environmental Sustainability', at Annamalai University, Annamalai Nagar (Tamil Nadu) on 26-27th October 2018.

Dr GG Kadalli receiving an Award.

TNAU Coimbatore

- Dr M Malarkodi (2016) received Tamil Nadu Young Scientist Award for the year 2016
- Dr D Jayanthi (2019) received Recognition Certificate for getting Externally funded scheme in 2019
- Dr G Sridevi (2016) received Best Researcher Award in 2016

CSK HPKV Palampur

- Drs Gourav, Neha Chauhan, NK Sankhyan and RP Sharma (2019) received Best Paper Award for the research paper entitled “Assessment of the quality of wheat as affected by continuous application of fertilizers and amendments in an acid Alfisol” *In*: 4th International Group Meeting at CSK HPKV Palampur, organized by Society for Advancement of Wheat and Barley Research (SAWBAR), CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur (HP) and ICAR-Indian Institute of Wheat and Barley Research, Karnal during 14-18 February, 2019.

KAU Pattambi

- Dr Thulasi V (2016) received V-Haritham Kshoni Jwala Award organized by Haritham Trust, Kerala.

Dr Thulasi V receiving an Award

- Dr Thulasi V (2019) received Best Trainees Award among the participants of the Short Course on “Recent advances in soil carbon sequestration and stabilization for soil health improvement and climate change mitigation” held at ICAR-Indian Institute of Soil Science, Bhopal during 10-19th December, 2019.
- Drs Moosa PP and Thulasi V (2019) received Best Team Research Award- participating scientists of the Foundation day Awards of KAU, 2019.

MPUA&T Udaipur

- Dr SC Meena (2017) received ‘Scientist of the Year Award’ in International Conference on Global Research Initiative for Sustainable Agriculture and Allied Sciences (GRISAAS)-2017 (2-4 December, 2017).

JNKVV Jabalpur

- Dr BS Dwivedi (2016) received ‘Excellence in Teaching Award-2016’ in International Conference at NBI, Lucknow (UP).

Dr BS Dwivedi receiving an Award

- Dr BS Dwivedi (2016) received Best Scientist Award-2016 in International Seminar at IISR, Lucknow (U.P.).

Dr BS Dwivedi receiving an Award

- Dr BS Dwivedi (2018) received 'Best Scientist Award-2018' in International Conference at CSUA&T, Kanpur (U.P.).

- Dr BS Dwivedi (2019) received 'Young Scientist Award-2019' in International Conference at Kathmandu, Nepal.

Dr BS Dwivedi receiving an Award

- Risikesh Thakur, BS Dwivedi, NK Khampariya and SD Sawarkar (2019) received 'Best Paper Award' for the paper entitled "Effect of inorganic fertilizers and farm yard manure on profile distribution of different sulphur fractions in Vertisols" presented in International Conference on 'Food Security through Agriculture and Allied Science' at Tribhuvan University, Kathmandu (Nepal) (27–29 May, 2019).

- Dr BS Dwivedi (2019) Elected as Councillor- Members in the Council of the Indian Society of Soil Science, New Delhi.

Dr PDKV Akola

- Dr SD Jadhao (2016) received Best Poster presentation Award in the State Level Seminar on "Development in Soil Science: Climate Change and its influence in Natural Resource Management" organized by Dapoli Chapter of ISSS (September 22-23, 2016).

- Dr SD Jadhao (2016) received Best Poster presentation Award in the International Conference on

'Integrated Land Use Planning for Smart Agriculture-An Agenda for Sustainable Land Management' organized by ISSLUP (November 10-13, 2016).

- Dr SD Jadhao (2018) received Best Poster presentation Award in National Seminar on 'Potential, Prospects and Strategies for Doubling Farmers Income' organized by Vasantrao Naik Smruti Pratisthan, Pusad and Dr PDKV, Akola (December 15-16, 2018).
- Dr SD Jadhao (2019) received Best Poster presentation Award in International Seminar on "Entrepreneurship in Agriculture and Renewable Energy Sector" organized by Unconventional Energy Sources and Electrical Engineering, College of Agril. Engineering, Dr PDKV, Akola (March 15-16, 2019).

ICAR-IASRI New Delhi

- Dr (Mrs) Anindita Datta (2017) received Jawaharlal Nehru Award for P.G. Outstanding Doctoral Thesis Research in Agricultural and Allied Sciences 2017 awarded by ICAR.

Dr (Mrs) Anindita Datta receiving an Award

10.1.3 Students working under AICRP-LTFE

JNKVV Jabalpur, ICAR-IARI New Delhi, BAU Ranchi, UAS GKVK Bangalore

- Mr Jarupula Suman, PG Student received All India Best Research Award 2016 (Jagar Nath Raina Memorial) guided by Dr BS Dwivedi.
- Avijit Ghosh (2017) received IARI Merit Medal for MSc Research Work.
- Avijit Ghosh (2017) received ISSS Zonal Award (North Zone) for Best Presentation of M.Sc. dissertation.
- Debarup Das received (2019) IARI Merit Medal for PhD Research Work.
- Debarup Das (2019) received Fertiliser Association of India Golden Jubilee Award for Outstanding Doctoral Research in Fertilizer Usage.
- Debarup Das (2019) received SP Roychoudhury (ISSS-Delhi Chapter) Gold Medal for Ph.D. Research Work.
- Lavanya KR (2018-19) received University of Agricultural Sciences, Bangalore, STCR Gold Medal for her MSc Research work on 'Fractionation studies of Calcium, Magnesium and Sulphur in soils of Long Term Fertilizer Experiments under finger millet- maize cropping sequence' .

10.2 Visits

10.2.1 Dr PDKV, Akola

Visit of Dr. Muneshwar Singh, PC (LTFE), ICAR-IISS, Bhopal (5 September 2018)

Visit of Dr. Subba Rao, Former Director, ICAR-IISS, Bhopal (19 January 2017)

Visit of KVK Staff (8 March 2017)

Visit of Hon'ble VC, Dr PDKV, Akola (1 October 2018)

Visit of Dr. Muralidharuddu, PC (STCR), ICAR-IISS, Bhopal (11 January 2017)

Visit of Dr. V. K. Kharche, Director of Research, Dr PDKV, Akola (22 November 2017)

10.2.2 OUAT, Bhubaneswar

Dr Muneshwar Singh PC LTFE, ICAR-IISS, Bhopal visitsTribal villages in Deogarh district
(21 August 2016)

Visit of QRT Members at farmer's trial at Bearpanaga village at Kandhamal district under TSP programme
(17 October 2017)

10.2.3 TNAU, Coimbatore

Arulmozhiselvan, K., M. Malarkodi and B. Gokila. 2016. Visit by Trainees to long term experiments: lessons learnt from Long Term Fertilizer Experiments (LTFE). Model training course on Good Agricultural Practices for alleviating Multinutrient deficiencies in soils and plants held on 21-18 Nov, 2016 at Dept. of Soil Science and Agricultural Chemistry, Directorate of Natural Resource Management, Tamil Nadu Agricultural University.

10.2.4 VNMKV, Parbhani

- Dr Muneshwar Singh PC-LTFE, ICAR-IISS, Bhopal visited experimental site of AICRP on LTFE, VNMKV, Parbhani on 1-2 August, 2018.
- Farmers visited LTFE on 17 September, 2018.
- Dr SR Mohanty, Network Coordinator, AINP on Soil Biodiversity and Biofertilizer, ICAR-IISS, Bhopal visited AICRP on LTFE, VNMKV, Parbhani on 6 February, 2019.

Hon'ble VC Dr AS Dhawan, Director of Research Dr DP Waskar and Head Dept. Soil Science Dr Syed Ismail visit LTFE VNMKV Parbhani (9 October 2019)

Visit of Dr Muneshwar Singh, PC LTFE, ICAR-IISS Bhopal to LTFE Laboratory at VNMKV, Parbhani (4 September 2018)

Visit of Dr SR Mohanty Network Co-ordinator, AINP BNF, Bhopal, Head Dept. Soil Science Dr. Syed Ismail to LTFE, at VNMKV, Parbhani (6 February 2019)

Farmers visit to LTFE experiment at VNMKV Parbhani (17 September 2018)

11. PUBLICATIONS

11.1 Research Paper

11.1.1 PC Unit LTFE (ICAR-IISS, Bhopal)

International

Joshi SK, RK Bajpai, Prahalad Kumar, Alok Tiwari, Vinay Bachkaiya, MC Manna, Asha Sahu, S Bhattacharjya, Mohammad Mahmudur Rahman, RH Wanjari, Muneshwar Singh, Vassanda Coumar, Ashok K Patra and SK Chaudhari (2017) Soil organic carbon dynamics in a Chhattisgarh Vertisol after use of a rice–wheat system for 16 years. *Agronomy Journal* 109(6): 2556-2569.

Jha P, S Neenu, I Rashmi, BP Meena, RC Jatav, BL Lakaria, AK Biswas, M Singh and AK Patra (2016) Ameliorating effects of leucaena biochar on soil acidity and exchangeable ions. *Communications in Soil Science Plant Analysis* 47(10): 1252-1262. DOI dx.doi.org/10.1080/00103624.2016.1166380.

Majhi P, KK Rout, G Nanda and Singh M (2019) Soil quality for rice productivity and yield sustainability under long term fertilizer and manure application. *Communications in Soil Science and Plant Analysis* 50 (11): 1330-1343.

Manna MC, Mohammad Mahmudur Rahman, Ravi Naidu, Asha Sahu, Sudeshna Bhattacharjya, RH Wanjari, Ashok Kumar Patra, SK Chaudhari, Kaushik Majumdar and SS Khanna (2018) Bio-Waste Management in Subtropical Soils of India: Future Challenges and Opportunities in Agriculture. *Advances in Agronomy* 152: 87-148.

Manna MC, Muneshwar Singh, RH Wanjari, Asit Mandal and AK Patra (2016) Soil Nutrient Management for Carbon Sequestration. *Encyclopedia of Soil Science*, Third Edition DOI: 10.1081/E-ESS3-120052914. pp. 1-6.

Padhan Kshitipati, Sudeshna Bhattacharjya, Asha Sahu, MC Manna, MP Sharma, Muneshwar Singh, RH Wanjari, RP Sharma, GK Sharma and AK Patra (2019) Soil N transformation as modulated by soil microbes in a 44 years long term fertilizer experiment in a sub-humid to humid Alfisol. *Applied Soil Ecology* 145: 103355.

Purohit D, M Mandal, A Dash, KK Rout, N Panda and M Singh (2019) Influence of long term fertilization on soil microbial biomass and dehydrogenase activity in relation to crop productivity in an acid Inceptisols. *Oryza* 56(3): 305-311.

Singh M, RH Wanjari, Brij Lal Lakaria, AO Shirale, U Kumar and S Jamra (2019) Wheat and rice response to potassium in Vertisols; Results from 120 plot pairs across Bhopal, Jagtial, Jabalpur, and Raipur Districts, India. e-ifc (An International Newsletter by International Potash Institute. No. 57

Singh MV, V Goswami and RH Wanjari (2019) Evaluation of right source of boron and sulphur for enhancing yield and quality of crops. *Better Crops South Asia* 11(1): 27-30.

National

Dash A, KK Rout, M Mandal and M Singh (2018) Effect of 11 years long term manorial practices on nematode population and diversity in rice agroecosystem. *Journal of Pharmacognosy and Phytochemistry* 7(5): 286-288.

Dash A, M Mandal, KK Rout and M Singh (2018) Influence of long term fertiliser experiments on soil organic carbon, available nutrients and microbial population in an acid Inceptisols of tropical India. *International Journal of Chemical Studies* 6(5): 255-258.

Jadhao SD, Dipali Arjun, DV Mali, Muneshwar Singh, VK Kharche, RH Wanjari, PR Kadu, BA Sonune and PN Magare (2018) Effect of long-term manuring and fertilization on depth wise distribution of potassium fractions under sorghum-wheat cropping sequence in Vertisol. *Journal of the Indian Society of Soil Science* 66 (2):172-181.

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Mule Pooja, SD Jadhao, RJ Patil and BA Sonune (2019) Soil nutrient status and yield of wheat by INM under continuous sorghum-wheat cropping sequence in Vertisols. *International Journal of Chemical Studies* 7(4): 829-832.

Patil RJ, SD Jadhao, BA Sonune and DV Mali (2019) Effect of long term manuring and fertilization on yield and micronutrient status under wheat grown in Vertisols. *Journal of Phamacognosy and Phytochemistry* 8(4): 1680-1684.

11.1.2.12 IGKV Raipur

International

Joshi SK, RK Bajpai, Prahlad Kumar, Alok Tiwari, Vinay Bachkaiya, MC Manna, Asha Sahu, S.Battacharya, MM Rahman, RH Wanjari, M Singh, Vassada Coumar, AK Patra and RS Choudhary (2017) Soil organic carbon dynamics in a Chhattisgarh Vertisol after use of rice wheat system for 16 years. *Agronomy Journal* 109(6): 1-14.

National

Jadhao SD, RK Bajpai, Alok Tiwari, Vinay Bachkaiya, K Tedia and Rahul Kumar (2016) Potassium dynamics as influenced by long term manuring and fertilization under rice-wheat cropping sequence in Vertisols. *Annals of Plant Physiology* 29(2): 29-35.

Nayak Tripti and Alok Tiwari (2016) Long term effect on organic and inorganic fertilization influence on soil quality under rice-wheat cropping system in Vertisol. *The Ecoscan* issn: 0974-0376, (Special Issue, 669-674).

Nayak Tripti, Alok Tiwari, RK Bajpai and Vinay Bachkaiya (2016) Effect of organic and inorganic fertilization on microbial biomass carbon and CO_2 evolution on wheat crop under Vertisol. *Advances in Life Sciences* 5(14): 5574-5579.

Singh AK, RN Singh, Alok Tiwari, RG Goswami and T Kumar (2018) Effect of long term rice establishment methods on physical properties in Vertisol. *International Journal of Chemical Studies* 6(6): 2403-2407.

11.1.2.13 ICAR-IARI, New Delhi

International

Das D, BS Dwivedi, SP Datta, SC Meena, BK Agarwal, DK Shahi, M Singh, D Chakraborty and S Jaggi (2019) Potassium supplying capacity of a red soil from eastern India after forty-two years of continuous cropping and fertilization. *Geoderma* 341: 76–92.

Ghosh A, R Bhattacharyya, Abir Dey, BS Dwivedi, MC Meena, MC Manna and R Agnihotri (2019) Long-term fertilisation impact on temperature sensitivity of aggregate associated soil organic carbon in a sub-tropical Inceptisol. *Soil and Tillage Research* 195: 104369.

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National

Das D, BS Dwivedi, SP Datta, SC Meena, AK Dwivedi, M Singh, VK Singh, D Chakraborty and S Jaggi (2019) Long-term fertilization effects on soil potassium and crop yields in a Vertisol. *Indian Journal of Agricultural Sciences* 89: 1086–90.

Dey Abir, BS Dwivedi, MC Meena, SP Datta, KB Polara, HK Sobhana and M Singh (2017) Boron fractions of a Vertic Ustochrept as influenced by thirteen years of continuous fertilization and manuring. *Journal of the Indian Society of Soil Science* 65: 326-333.

Dwivedi BS, VK Singh, K Shekhawat, MC Meena and Abir Dey (2017) Enhancing use efficiency of phosphorus and potassium under different cropping systems of India. *Indian Journal of Fertilisers* 13(8): 20-41.

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11.1.2.14 JAU Junagadh

Bodar KH, KB Polara, PB Bunsa and BB Barad (2018) Fractions of zinc in calcareous *Vertic Haplustepts* as influenced by sixteen years of fertilization and manuring in LTFE soils. *Journal of Pharmacognosy and Phytochemistry* 7(2): 2760-2764.

Gediya SP and AV Rajani (2018) Long term effect of balance nutrient management on dynamics of important physical properties of a calcareous under AICRP-LTFE soils. *International Journal of Chemical Studies* 6(5): 288-291.

Rajani AV, SP Gediya, AS Jadeja and DV Hirpara (2019) Long term effect of balance nutrients management on dynamics of important chemical properties of calcareous soils. *Journal of Pharmacognosy and Phytochemistry* 8(5): 238-241.

Sumara MS, AV Rajani and AS Jadeja (2019) Effect of long-term nutrient management on potassium dynamics in calcareous (*Vertic Haplustepts*) soil. *International Journal of Chemical Studies* 7(4): 1053-1058.

Tripura Pradip, KB Polara and Mayur Shitab (2018) Influence of long term fertilization on yield and active pools of soil organic carbon in an *Typic Haplustepts* under groundnut-wheat cropping sequence. *International Journal of Current Microbiology Applied Science* 7(9): 781-794.

Tripura Pradip, KB Polara, KB Parmar and KH Bodar (2018) Effect of integrated nutrient management on nitrogen dynamics under groundnut-wheat system of *Typic Haplustepts* in long term fertilizer experiment. *International Journal of Chemical Studies* 6(4): 3234-3239.

Vekaria LC, HL Sakarvadia, PB Bunsa, KB Polara, DV Parkhia and HP Ponkia (2016) Dynamics of copper fractions in calcareous *Vertic Ustochrepts* under AICRP-LTFE Soils. *The Ecoscan* 10(1&2): 181-184.

11.1.2.15 JNKVV Jabalpur

International

Dubey Lokesh, BS Dwivedi, AK Dwivedi and RK Thakur (2016) Effect of long term application of fertilizers and manure on profile distribution of various phosphorus fractions in Vertisol. *Green Farming* 7(2): 365-370.

Dwivedi BS, Abhishek Sharma, AK Dwivedi and RK Thakur (2019) Response of phosphorus application on productivity of wheat at farmer field. *Universal Journal of Agricultural Research* 7(1): 20-24.

Gupta Anshita, AK Dwivedi, Anil Nagwanshi and BS Dwivedi (2018) Effect of long term application of chemical fertilizers and organic manure application on crop quality parameters in soybean crop. *International Journal of Current Microbiology and Applied Sciences* Special Issue 7: 1403-1407.

Nagwanshi Anil, AK Dwivedi, BS Dwivedi and K Anupama (2018) Effect of long term application of fertilizer and manure on soil properties of a Vertisol in soybean-wheat cropping sequence. *International Journal of Chemical Studies* 6(3): 2946-2949.

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5(6): 1931-1934.

Suman J, BS Dwivedi, AK Dwivedi and SK Pandey (2017) Impact of continuous addition of fertilizers and manure on soil nutrient status, uptake, yield, protein and oil content of soybean in a Vertisol. *Research Journal of Agricultural Sciences* 8(1): 159-163.

Suman J, BS Dwivedi, AK Dwivedi and SK Pandey (2018) Forms of Sulphur and their relationship with soil physical properties in Vertisol. *International Journal of Chemical Studies* 6(1): 975-980.

National

Gupta Anshita, AK Dwivedi, Anil Nagwanshi, BS Dwivedi and AK Vishwakarma (2019) Impact of long term application of inorganic fertilizer and farm yard manure on productivity of soybean in Vertisol. *Bulletin of Environment Pharmacology and Life Sciences* 8(4): 116-132.

Nagwanshi Anil, AK Dwivedi, BS Dwivedi and SK Dwivedi (2018) Effect of long term application of fertilizers and manure on leaf area index, nodulation and yield of soybean in Vertisol. *Journal of Pharmacognosy and Phytochemistry* 7(4): 1962-1965.

Patel Gajendra, BS Dwivedi, AK Dwivedi, Risikesh Thakur and Muneshwar Singh (2018) Long-term effect of nutrient management on soil biochemical properties in a Vertisol under soybean–wheat cropping sequence. *Journal of the Indian Society of Soil Science* 66(2): 215-221.

Raghuwanshi Chanchlesh, NK Khamparia, RK Thakur, SK Sahare, Vaishali Sharma and BS Dwivedi (2016) Impact of long-term application of fertilizers and organic manure on yield attributes characters, yield of soybean and soil fertility in a Vertisol. *Ecology, Environment and Conservation* 22(2): 745-753.

Suman J, BS Dwivedi, AK Dwivedi and SK Pandey (2018) Effect of long term application of nitrogen and Sulphur nutrition on nitrogen assimilation in soybean. *Journal of Pharmacognosy and Phytochemistry* 7(1): 2000-2004.

11.2 Other Publications

11.2.1 PC Unit LTFE (ICAR-IISS, Bhopal)

Technical Bulletin

Shri Ram, Muneshwar Singh, RH Wanjari, Pradeep Sirari, Pawan Kumar Pant and Ashok K Patra (2016) Impact of long term fertilizer application on crop productivity, grain and soil quality under rice-wheat system on Mollisols in Northern India. p. 1-47.

Book Chapter

Singh Muneshwar and RH Wanjari (2017) Balanced nutrition a key for improving nutrient use efficiency. *In* Advances in Nutrient Dynamics in Soil-Plant System for Improving Nutrient Use Efficiency (Eds: R Elanchezhian, AK Biswas, K Ramesh and AK Patra). pp. 27-35.

Singh Muneshwar and RH Wanjari (2017) Nutrient management for enhancing productivity and nutrient use efficiencies in long term fertilizer experiments. *In* Enhancing Nutrient Use Efficiency- Concepts, Methods and Management Interventions (Eds: Kulasekaran Ramesh, Ashis Kumar Biswas, Brij Lal Lakaria, Sanjay Srivastava and Ashok Kumar Patra). New India Publishing Agency, New Delhi, India. pp. 93-106.

Wanjari RH and Muneshwar Singh (2017) Assessment of soil quality and sustainability under intensive cropping systems in Long Term Fertilizer Experiments in India. *In* Sustainable Farming and Soil Health Management (Eds: Sanjay Arora and Suraj Bhan), Soil Conservation Society of India, NASC Complex, Pusa, New Delhi, pp. 87-95.

Wanjari RH (2017) Cereal Based Cropping Systems. *In* Enhancing Nutrient Use Efficiency-Concepts, Methods and Management Interventions (Eds: Kulasekaran Ramesh, Ashis Kumar Biswas, Brij Lal Lakaria, Sanjay Srivastava and Ashok Kumar Patra). New India Publishing Agency, New Delhi, India. pp. 263-278.

Muneshwar Singh, RH Wanjari, Roopchand Jatav and Shweta Jamra (2017) दीर्घकालीन उर्वरक प्रयोग का मृदा स्वास्थ्य एवं फसलो पर प्रभाव. *In* वार्षिक हिन्दी पत्रिका–मृदा स्वास्थ्य आलोक – प्रवेशांक–2017' ; संपादक डॉ. ए.के. त्रिपाठी, डॉ. ए.बी. सिंह, एस. रमण,, डॉ. एम. सी. मन्ना एवं डॉ. अशोक कुमार पात्र). pp. 60-68.

Success Story

Singh Muneshwar, RH Wanjari and BS Brar (2018) A Success Story on 'Reutilization of accumulated soil phosphorus: Lessons learnt from AICRP-LTFE. ICAR-Indian Institute of Soil Science, Bhopal. P 1-4.

11.2.2 VNMKV Parbhani

Leaflet

Shirale ST, Syed Ismail, VD Patil and Muneshwar Singh (2017) Lessons Learnt and Experiences from Long Term Fertilizer Experiment in Soybean-Safflower Cropping Sequence on Vertisol.

11.2.3 KAU Pattambi

Leaflets

Thulasi V, PP Moossa and MC Narayanankutty (2016) Nutrient deficiencies and correction. RARS Pattambi, KAU.

Moossa, PP, Thulasi V, MC Narayanankutty and P Raji (2016) Phytoaccumulators for nutrient management in organic farming. RARS Pattambi, KAU.

Thulasi V, PP Moossa and MC Narayanankutty (2016) Biofertilizers. RARS Pattambi, KAU.

MSc Thesis

Vineetha MV (2016) Influence of different nutrient management options on available nutrients in soil layers. MSc Chemistry, MPMMSN Trust College Shornur.

Divya M (2016) Distribution of organic carbon and available nutrients in different size fractions of soil. MSc Chemistry, MPMMSN Trust College Shornur.

Varna P (2016) Effect of long term application of manures and fertilizers on acidity in soil. MSc Chemistry, MPMMSN Trust College Shornur.

Sumayya Sulaiman (2017) Sequestration of carbon as influenced by nutrient management practices under long term fertilizer experiments. MSc in Soil Science & Agricultural Chemistry, College of Horticulture, Vellanikkara, KAU.

Sudhamani (2018) Carbon sequestration and crop weather relations in long term fertilizer experiments. MSc Climate Change, Academy of Climate Change Education and Research, KAU.

Jasma VA (2019) Optimization techniques in long term fertilizer trials- Rice-rice system. MSc Agricultural Statistics, College of Horticulture, Vellanikkara, KAU.

11.2.4 TNAU, Coimbatore

Book Chapter

Jayanthi D and M Malarkodi (2019) Long term fertilizer experiment and permanent manurial experiment. *In* Training Manual on Natural Resource Management to Agricultural Field Officers (Maldives). TNAU Offset Press (Training Division, Directorate of Extension Education, TNAU, Coimbatore).

Jayanthi D, M Malarkodi and B Gokila (2019) Niraivana payir mahasulukku samacheer ura nirvaga uthigal. *In* Technical Training Manual on National Sustainable Agriculture Project – Soil Health Card, published by JDA, Coimbatore, pp .29-31.

Malarkodi M, D Jayanthi and B Gokila (2019) Integrated nutrient management for sustaining soil health and crop productivity for long run: Lessons learnt from permanent manurial experiment. *In* Proceedings of National Conference on 'Climate Smart Agriculture for Livelihood Security: Challenges and Opportunities' at ADAC&RI, Tiruchirappalli (13-14 September 2019). pp 220-221.

11.2.5 PAU Ludhiana

Book Chapter

Dheri GS, BS Brar and Debankur Sanyal (2016) Salt-affected Soils: Nitrous Oxide Emissions. *Encyclopedia of Soil Science*, Third Edition. pp 1969-71. (DOI: 10.1081/E-ESS3-120053998).

Dheri GS, BS Brar and Debankur Sanyal (2016) Soil Degradation by Brick Making. *Encyclopedia of Soil Science*, Third Edition. pp 255-57. (DOI: 10.1081/E-ESS3-120052925).

Practical Manual

BS Brar, SS Dhaliwal, GS Dheri, BS Sekhon, MS Mavi, RS Gill and RK Gupta (2016) *Manures and Fertilizers* (Soils 204). pp.76.

Training Manual

Dheri GS, Soumen Pal, Varinderpal Singh, Sudeep Marwaha and OP Choudhary (2019) Compendium of Hands on Training on Statistical Tools and Database Management in Agriculture Compiled by Department of Soil Science, PAU, Ludhiana. pp.1-186.

Post Graduate Student

MSc Thesis

Anmol Singh (2018) Soil aggregate associated organic carbon and its impact on greenhouse gases emissions in different cropping system.

Gagandeep Dhawan (2019) Effect of long-term application of chemical fertilizers and organic manures on nitrogen budgeting in maize-wheat and rice-wheat cropping systems.

Maninder Singh (2019) Effect of long-term fertilizer application on potassium mineralogy and nutrition under maize-wheat cropping system.

Sarveen Kaur (2019) Carbon footprints of rice and maize production under long-term fertilizer scenarios.

PhD Thesis

Harshneet Singh (2017) Dynamics of micronutrient cations in soil plant system as influenced by long term application of farmyard manure and inorganic fertilizers in maize-wheat cropping system.

11.2.6 Dr PDKV Akola

MSc Thesis

Pooja Anil Muley (2018) Potassium release dynamics under long term sorghum-wheat sequence in Vertisols.

Rahul Patil (2019) Effect of long term nutrient management on rooting behavior and root chemical properties of wheat under sorghum-wheat cropping.

11.2.7 ICAR-IARI New Delhi

MSc Thesis

Ghosh Avijit (2016) Long-term effects on soil aggregation and carbon pools under wheat based cropping systems in two soils.

Das Anit (2019) Effect of long-term fertilization and manuring on zinc dynamics under maize-wheat cropping system.

PhD Thesis

Das Debarup (2018) Effect of long-term fertilization and manuring on soil-K forms in Alfisol, Inceptisol and Vertisol.

11.2.8 JAU Junagadh

MSc Thesis

Gediya Sanjaybhai Prakashbhai (2018) Long term effect of balance nutrient management on dynamics of important physico-chemical properties of a calcareous *Vertic Haplustept* under AICRP-LTFE soils.

Sumara Mohammadirshad Salimbhai (2019) Impact of long-term balance nutrient management on soil potassium dynamics under groundnut-wheat cropping sequence in a calcareous *Vertic haplustepts* under AICRP-LTFE soils.

PhD Thesis

Pradip Tripura (2018) Dynamics of major nutrients and soil organic carbon fractions in medium black calcareous (*Typic haplustepts*) under LTFE soils

11.2.9 JNKVV Jabalpur

MSc Thesis

Anshita Gupta (2016) Soil phosphorus dynamics as affected by long term application of fertilizers and manure in a Vertisol.

Priyanka Pathariya (2017) Effect of continuous application of fertilizers and manure on distribution of potassium pools in a Vertisol.

Sunil Panwar (2017) Influence of long term application of fertilizer and manure on distribution of zinc fraction in a Vertisol.

Abhishek Khandagale (2017) Distribution of nitrogen fractions as influenced by continuous application of fertilizers and manure in a Vertisol.

Rohit Verma (2017) Effect of long term application of fertilizer and manure on physiological biochemical attributes, yield and quality of soybean grown on Vertisol.

Anjali Chandrol (2017) Effect of long term fertilizer and manure application on physiological character of soybean and nutrient status of soil.

Pankaj Muchala (2018) Influence of long term application of fertilizer and manure on distribution of soil phosphorus fraction in Vertisol.

Chandrabhan Basaliya (2018) Impact of long term application of fertilizer and FYM on productivity and quality of soybean.

Bhagyashri Oshale (2018) Impact of long term application of fertilizer and FYM on productivity and quality of Wheat grown in black soil.

Purushottam Suman (2018) Long-term effect of fertilizer and manure application on distribution of S fractions in a Vertisol.

Jalendra Bairwa (2019) Changes in soil microbial environment under long term application of fertilizer and manure.

Gourav Chimaniya (2019) Nutrient uptake and quality of soybean as influenced by long term application of fertilizer and FYM.

Nilesh Patidar (2019) Effect of long term nutrient management on status of humus fractionations in Vertisols.

Sushma Kulesh (2019) Effects of continuous application of fertilizers and FYM on changes in soil fertility and yield of soybean in Vertisols.

PhD Thesis

Anil Nagwansi (2018) Impact of long term fertilizer and FYM application on sustainability of soil fertility, crop productivity under soybean-wheat sequence in a Vertisol.

Rishikesh Tiwari (2019) Soil chemical and biochemical properties as influenced by continuous application of fertilizer and manure in black soil.

12. STAFF POSITION

THE HEADQUARTER of the ***All India Coordinated Research Project*** on ***Long Term Fertilizer Experiments (AICRP-LTFE) to Study Changes in Soil Quality, Crop Productivity and Sustainability*** was shifted from ICAR-Indian Agricultural Research Institute (IARI) New Delhi to ICAR-Indian Institute of Soil Science (IISS), Bhopal during June 1997 and since then functioning from Bhopal. The staff position of PC Unit AICRP-LTFE ICAR-IISS, Bhopal (M.P) and Cooperating Centres at the end of 31st March, 2019 is given below:

Name	Designation	From	To (*indicates continuation)
PC Unit AICRP-LTFE ICAR-IISS, Bhopal (M.P)			
Dr Muneshwar Singh	Project Coordinator	18.08.2005	31.03.2019*
Dr RH Wanjari	Principal Scientist	07.01.1999	31.03.2019*
Mr Sunny Kumar	Personal Secretary	21.12.2011	31.03.2019*
Mr Roopchand Jatav	Research Associate	19.05.2016	30.09.2017
Mr Uttam Kumar	Research Associate	28.08.2018	31.03.2019*
Mr AK Mishra	Lab Attendant	10.06.1999	25.03.2017
Mr Jagannath Gour	Skilled Supporting Staff	27.03.2017	31.03.2019*
ICAR-IARI New Delhi			
Dr BS Dwivedi	Principal Scientist	13.03.2003	31.03.2019*
Dr Mahesh C Meena	Scientist	05.12.2007	31.03.2019*
Dr Abir Dey	Scientist	01.11.2015	31.03.2019*
Dr Narender	Research Associate	01.04.2016	31.08.2018
ICAR-CRIJAF Barrackpore (West Bengal)			
Dr DK Kundu	Principal Scientist	07.07.2013	31.03.2019*
Dr AR Saha	Principal Scientist	20.08.2008	31.03.2019*
Dr Swapnanjali Sasmal	Research Associate	21.04.2016	31.08.2018
CSKHPKV Palampur (Himachal Pradesh)			
Dr Raj Paul Sharma	Principal Scientist	22.02.2007	31.03.2019*
Dr Narender K Sankhyan	Principal Scientist	26.11.2010	31.03.2019*
Dr Swapana Sepehya	Research Associate	16.05.2013	05.11.2018
Mr Satish Kumar	Beldar	22.12.1995	31.05.2017
UAS GKVK Bangalore (Karnataka)			
Dr RC Gowda	Professor	07.06.2009	31.01.2018
Dr GG Kadalli	Professor	15.02.2018	31.03.2019*
Dr DC Hanumanthappa	Assistant Professor	02.08.2010	14.06.2017
Mrs Jayanthi T	Assistant Professor	15.02.2018	31.03.2019*
Dr Chennakeshava S	Assistant Professor	02.02.2018	15.02.2018
Dr Veeranagappa	Research Associate	01.04.2016	03.02.2018

Dr Sidharam Patil	Research Associate	11.11.2017	01.02.2018
Dr Sidharam Patil	Research Associate	14.02.2018	31.03.2019*
Mr Nagaraj CH	Messenger	06.06.2016	31.03.2019*
Mr A Jagannatha	Lab Attendant	01.04.2016	25.05.2016
BAU Ranchi (Jharkhand)			
Dr Prabhakar Mahapatra	Jr. Scientist-cum Assistant Professor	21.07.2004	31.03.2019*
Mr Ashok Kumar	Laboratory Attendant	01.07.2017	31.03.2019*
PAU Ludhiana (Punjab)			
Dr BS Brar	Sr. Soil Scientist	01.12.1995	31.05.2017
Dr Gurmeet Singh Dheri	Sr. Soil Chemist	13.01.2010	31.03.2019*
Mr Harminder Uppal	Research Fellow	27.05.2016	31.03.2019*
Mr Shamsher Singh	Lab Attendant	17.12.2009	31.03.2019*
PJTSAU Jagtial (Hyderabad) (Telangana)			
Dr G Kiran Reddy	Scientist	21.02.2014	31.07.2017
Dr P Ravi	Scientist	19.02.2018	31.03.2019*
Mr A Umarajshekar	Research Associate	01.04.2016	18.02.2018
Mr CH Venureddy	Research Associate	24.05.2018	31.03.2019*
GBPUA&T Pantnagar (Uttarakhand)			
Dr Shri Ram	Professor	16.06.1998	31.03.2019*
Mr Gopal Jaiswal	Lab/Field Attendant	22.11.2014	31.03.2019*
Dr Pradeep Kumar Sirari	Senior Research Fellow	04.09.2017	31.03.2019*
TNAU Coimbatore (Tamil Nadu)			
Dr K Arulmozhiselvan	Professor	01.01.2010	15.5.2018
Dr R Shanmugasundaram	Professor	16.05.2018	21.01.2019
Dr D Jayanthi	Associate Professor	22.01.2019	31.03.2019*
Dr M Malarkodi	Assistant Professor	10.04.2015	31.03.2019*
Dr B Gokila	Research Associate	02.03.2016	31.03.2019*
Mrs K Tamilselvi	Lab Technician	01.07.2011	31.03.2019*
OUAT Bhubaneswar (Odisha)			
Dr KK Rout	Senior Scientist (Professor)	01.04.2016	31.03.2019*
Dr (Mrs) Mitali Mandal	Junior Scientist (Asst. Professor)	01.04.2016	31.03.2019*
Dr Debasis Purohit	Research Associate	17.09.2017	19.03.2018
Mr Avisek Dash	Research Associate	24.09.2017	31.03.2019*
Mr Dasarathi Pradhan	Laboratory Attendant	01.04.2016	31.03.2019*
JNKVV Jabalpur (Madhya Pradesh)			
Dr AK Dwivedi	Principal Scientist	31.07.2013	31.03.2019*
Dr BS Dwivedi	Scientist	10.05.2013	31.03.2019*
Mr Abhishek Sharma	Research Associate	26.09.2015	31.03.2019*

IGKV Raipur (Chhattisgarh)			
Dr Alok Kumar Tiwari	Principal Scientist	06.07.2013	31.03.2019*
Mr Vinay Bachkaiya	Scientist	06.11.2012	31.03.2019*
MPAU&T Udaipur (Rajasthan)			
Dr SK Sharma	Professor	01.07.2014	30.04.2017
Dr SC Meena	Associate Professor	01.07.2013	31.03.2019*
KAU Pattambi (Kerala)			
Dr PP Moosa	Associate Professor	29.07.2008	31.03.2019*
Dr V Thulasi	Assistant Professor	28.06.2010	31.03.2019*
Mr A Unnikrishnan	Attendant	15.05.1996	31.03.2019*
VNMKV Parbhani (Maharashtra)			
Dr Syed Ismail	Associate Professor	26.10.2015	19.07.2017
Dr ST Shirale	Assistant Professor	19.03.2008	21.01.2018
Dr RN Khandare	Associate Professor	22.01.2018	31.03.2019*
Mr Syed Gouse Syed Husen	Lab Attendant	01.11.2018	31.03.2019*
Dr PDKV Akola (Maharashtra)			
Dr SD Jadhao	Associate Professor	10.03.2008	31.03.2019*
Dr DV Mali	Assistant Professor	01.04.2012	16.03.2017
Dr BA Sonune	Assistant Professor	17.03.2017	31.03.2019*
JAU Junagadh (Gujarat)			
Dr MS Solanki	Professor	01.04.2016	31.03.2019*
ICAR-IASRI New Delhi			
Dr BN Mandal	Senior Scientist	01.04.2016	31.03.2019*
Mr Sunil Kumar Yadav	Scientist	01.04.2017	31.03.2019*
Dr Anindita Datta	Scientist	01.04.2017	31.03.2019*

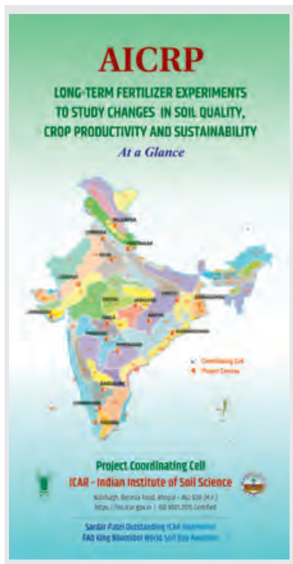
RETIREMENT

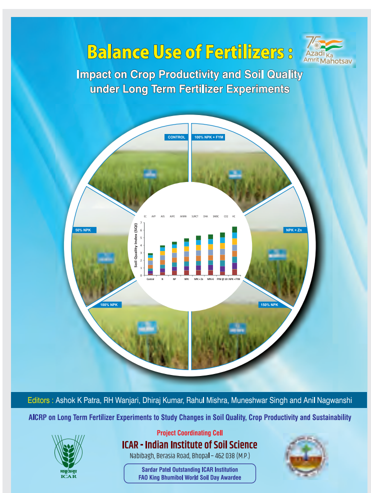
Dr BS Brar received his professional education in Soil Science from PAU, Ludhiana and recipient of university merit scholarship during BSc and MSc and BARC Fellowship during PhD. He began his professional carrier in PAU as Assistant Soil Chemist in December 1984 and elevated to the post of Soil Scientist in October 1990, Senior Soil Scientist (Professor) in October 1998, Head, Department of Soil Science in March 2016 and got superannuated on 31st May 2017.

He was the Principal Investigator (PI) of AICRP on LTFE for 22 years. Dr Brar completed 8 Adhoc research project as PI and one as CoPI. He published 95 research papers; 1 book; 12 book chapters; 12 extended summaries, 9 manuals, 41 project reports and 57 extension articles. He taught UG and PG courses, guided 2 PhD and 14 MSc students. Students guided as major advisor for doctorate research secured prestigious Golden Jubilee FAI Gold Medal for Outstanding Doctoral Thesis Award 2007. M.Sc student Zonal Award for North Zone of Indian Society Soil Science on the basis of her Master's research.

Dr Brar is the Fellow of Indian Society Soil Science. He presented research papers during international conferences/symposia in USA, New Zealand, Japan and India. He has also worked as 'Visiting Professor' with Dr Ratan Lal at Ohio State University, Columbus, USA. The LTFE centre at PAU Ludhiana was one of the contributors in the Chaudhary Devi Lal Outstanding AICRP 2004 Award received to AICRP LTFE during his tenure. Shiksha Rattan Puraskar 2007 by the India International Friendship Society, New Delhi, for his meritorious services in Soil Science of Agricultural Education. Imphos- FAI Award 2007 by World Phosphorus Institute of Casablanca, Morocco and Fertilizer Association of India.

New Arrival (Publication)





Indian Council of Agricultural Research

Chaudhary Devi Lal Outstanding All-India Co-ordinated Research Project (AICRP) Award 2004

The Chaudhary Devi Lal Outstanding All-India Co-ordinated Research Project (AICRP) Award for the year 2004 is presented to

Long Term Fertilizer Experiment (LTFE)

for outstanding contribution in the field of

Natural Resource Management

New Delhi
16 July 2005

Mangala Rai
Director-General

Sharad Pawar
Union Minister for Agriculture

ICAR

CHAUDHARY DEVI LAL OUTSTANDING AICRP AWARD, 2004

TO

LONG TERM FERTILIZER EXPERIMENT (LTFE), INDIAN INSTITUTE OF SOIL SCIENCE (IISS), BHOPAL

CITATION

The AICRP Long Term Fertilizer Experiments is operating at 17 SAUs/ICAR centres since 1970 to conduct long term fertilizer experiments to study the changes in soil quality, crop productivity and sustainability. Long term experiments initiated under this project are assets to the nation which have generated valuable database and are very helpful in planning strategies on production and consumption of fertilizer and formulation of efficient fertilizer use pratices for enhancing and sustaining higher productivity and maintaining soil quality and environment.

Research contributions from the project have led to the development of integrated plant nutrient supply and management strategies for improving soil fertility and enhancing and sustaining productivity of intensive cropping systems (rice-wheat, rice-rice, maize-wheat, fingermillet-maize, soybean-wheat and groundnut-wheat) in major soil groups of India (Inceptisols, Alfisols, Vertisols and Mollisols). Results have established that application of fertilizer N alone had a deleterious effect on soil productivity. The magnitude of crop responses to P and K application was much higher in Alfisols and Vertisols than in Inceptisols and Mollisols. Balanced and optimum use of NPK maintained soil organic carbon (SOC) irrespective of cropping system and soil type. The decline in factor productivity over the years was associated with deficiencies of sulphur and zinc. Balanced and integrated use of NPK and organic (farmyard) manure is absolutely essential for the sustainability of intensive cropping systems.

Thus, LTFE project has made significant contribution in promoting judicious use of fertilizer in diversified agroecological situations which are helpful in maintaining soil quality, increasing food production, generating more employment and improving environment.

स्वस्थ मृदा

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