IMPACT OF LONG TERM INTEGRATED NUTRIENT MANAGEMENT SYSTEM ON SOIL HEALTH AND RICE PRODUCTIVITY

by

RAKHI R.
(2015-11-038)

THESIS

Submitted in partial fulfilment of the requirement for the degree of

MASTER OF SCIENCE IN AGRICULTURE

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
COLLEGE OF AGRICULTURE, VELLAYANI,
THIRUVANANTHAPURAM-695 522
KERALA, INDIA

2017

DECLARATION

I, hereby declare that this thesis entitled **"Impact of long term Integrated Nutrient Management system on soil health and rice productivity"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Vellayani
19.08.2017

Rakhi R.
(2015-11-038)

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CERTIFICATE

Certified that this thesis entitled **"Impact of long term Integrated Nutrient Management system on soil health and rice productivity"** is a record of research work done independently by Ms. Rakhi R. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

Vellayani
19.08.2017

Dr. Rani B.
(Major Advisor, Advisory Committee)
Professor
Dept. of Soil Science and Agricultural Chemistry
College of Agriculture, Vellayani

CERTIFICATE

We, the undersigned members of the advisory committee of Ms. Rakhi R., a candidate for the degree of **Master of Science in Agriculture** with major in Soil Science and Agricultural Chemistry, agree that the thesis entitled **"Impact of long term Integrated Nutrient Management system on soil health and rice productivity"** may be submitted by Ms. Rakhi R., in partial fulfilment of the requirement for the degree.

19-8-2017

Dr. Rani B.
Professor
Department of Soil Science and
Agricultural Chemistry
College of Agriculture, Vellayani,
Thiruvananthapuram-695 522

19-8-2017

Dr. Sam T. Kurumthottical
Professor and Head
Department of Soil Science and
Agricultural Chemistry
College of Agriculture, Vellayani,
Thiruvananthapuram-695 522

19/8/2017

Dr. K. Ushakumari
Professor
Department of Soil Science and
Agricultural Chemistry
College of Agriculture, Vellayani
Thiruvananthapuram-695 522

19/8/2017

Dr. K. C. Manorama Thampatti
Professor
Department of Soil Science and
Agricultural Chemistry
College of Agriculture, Vellayani
Thiruvananthapuram-695 522

19/8/17

Dr. Jacob John
Professor and Head
Integrated Farming Systems
Research Station, Karamana
Thiruvananthapuram-695 002

19/8/17

External Examiner
Dr. G. Byju
Principal Scientist
Central Tuber Crops Research Institute
Sreekariyam, Thiruvananthapuram-695 017

Acknowledgement

First and foremost, praises and thanks to the Almighty, for everything that happens to me...

*With immense pleasure, I would like to express my sincere gratitude to **Dr. Rani B.** Professor, Department of Soil Science and Agricultural Chemistry for the constructive guidance, constant inspiration, critical scrutiny of the manuscript and valuable suggestions which rendered me to accomplish the research work successfully. I extend my sincere gratitude for providing a stress free situation by the open minded approach and for the care and affection bestowed on me throughout the study period.*

*I convey my heartfelt thanks to **Dr. Sam T. Kurumthottical.** Professor & Head, Department of Soil Science and Agricultural Chemistry for the unceasing encouragement, valuable advices and whole hearted approach right from the beginning of the thesis work.*

*I extend my sincere gratefulness to **Dr. Ushakumari, K,** Professor, Department of Soil Science and Agricultural Chemistry for the valuable suggestions, technical advice and incessant motivation throughout the research work.*

*I am extremely thankful to **Dr. K, C. Manorama Thampatti,** Asst. Professor, Soil Science and Agricultural Chemistry for the unstinting support, suggestions and passionate approach rendered during the period of research work.*

*I gratefully acknowledge with thanks **Dr. Jacob John.** Professor & Head, Farming System Research Station, Karamana for his constructive comments, creative suggestions and, affectionate approach at all the stages of research work.*

*I express my sincere thanks to **Dr. Sumam Susan Varghese** and **Dr, Sumam George** , Retd. Professors and Heads, Department of Soil Science and Agricultural Chemistry for the valuable advice, unstinted motivation and for the valuable support in providing lab facilities.*

*I extend my gratefulness to my teachers **Dr. P. B. Usha, Dr. Sudharmai Devi, Dr. Usha Mathew, Dr. B. Aparna, Dr. Gladis, Dr. Biju Joseph, Dr. Komala Amma, Dr. Thomas George and Dr. Naveen,** Department of Soil Science and Agricultural Chemistry for their support and advice at all stages of research work. I also remember the help and support from **Biju chettan, Aneesh chettan, Maya chechi and Soumya chechi.***

I express my heartfelt thanks to ***Dr. A. Sajeena*** *(Assistant Professor, IFSRS, Karamana),* ***Dr. B. Sudha*** *(Assistant Professor, IFSRS, Karamana),* ***Mr. Tomy Abraham*** *(Farm officer, IFSRS, Karamana) and* ***Mr. Hirosh Kumar K. S.*** *(Technical officer, IFSRS, Karamana) for their valuable suggestions and support provided during my hardship days. I also express my heartfelt thanks to the non-teaching staffs of IFSRS, Karamana-* ***Saji chettan, Arun chettan, Aneesha chechi, Arya chechi, Antu chettan*** *and* ***Sreekkutty*** *for their kind support and help during the work.*

I am also thankful to ***Dr. Suresh Kumar****, Professor , RTL, for giving permission to use the Atomic Absorption Spectrophotometer during the course of my research work..*

I would like to thank ***Dr. N. Anith*** *and* ***Dr. Meenakumari****, Professor, Department of Microbiology for giving permission to conduct microbial studies during the course of my rese4arch work.*

I express my thanks and whole hearted cheers to my batch mates ***Dhanesh, Dhanya, Aswathy, Anjana*** *and* ***Usha*** *for their help, love, encouragement and support which made my days more colourful. It's my pleasure to express my special thanks to my seniors and juniors* ***Sai chettan, Sreya chechi, Priya chechi, Visweswaran Sir, Shamsi, Sree, Geethu and Sooraj*** *for their help and support throughout the study period. I express my heartfelt thanks to* ***Dathan Sir*** *and* ***Nibin chettan*** *for their love, care, suggestions and support.*

Words are inadequate to express my thanks to my beloved friends ***Reshma, Lizu, Gaayu, Asu, Rakhi, Greeshma, Thouseem*** *and* ***Harishma*** *for their constant support, love, care and for the happiest moments we cherished together.*

I am beholden beyond words to express my indebtedness to my ***Achan, Amma and Ammu*** *for their unconditional love, sacrifices and support bestowed on me during my hard periods.*

Rakhi R.

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LIST OF ABBREVIATIONS AND SYMBOLS USED

%	:	Per cent
@	:	At the rate of
^0C	:	Degree Celsius
µg	:	Microgram
AICRP	:	All India Coordinated Research Project
B	:	Boron
B:C	:	Benefit : Cost
Ca	:	Calcium
CD	:	Critical Difference
CEC	:	Cation Exchange Capacity
cfu	:	Colony forming units
cm	:	Centimeter
cm^3	:	Cubic centimeter
c mol (p+) kg^{-1}	:	Centi mol (p+) per kilogram
Cu	:	Copper
DAT	:	Days after transplanting
dS m^{-1}	:	deci Siemens per meter
DTPA	:	Diethylene triamine penta acetic acid
EC	:	Electrical conductivity

et al.	:	Co-workers/ co authors
FYM	:	Farmyard manure
Fe	:	Iron
Fig.	:	Figure
g	:	Gram
GM	:	Green manure
h^{-1}	:	Per hour
i.e.	:	That is
IFS	:	Integrated Farming System
INM	:	Integrated Nutrient Management
K	:	Potassium
KAU	:	Kerala Agricultural University
kg ha^{-1}	:	Kilogram per hectare
m^{-2}	:	Per square metre
Mg	:	Magnesium
mg g^{-1}	:	Milli gram per gram
mg kg^{-1}	:	Milli gram per kilogram
Mg m^{-3}	:	Mega gram per meter cube
mm	:	Millimetre
Mn	:	Manganese
Mo	:	Molybdenum

mt	:	Million tonnes
N	:	Nitrogen
NS	:	Non significant
P	:	Phosphorus
pH	:	Negative logarithm of hydrogen ions
RDF	:	Recommended dose of fertilizers
RDN	:	Recommended dose of nutrients
S	:	Sulphur
SAR	:	Sodium Adsorption Ratio
t ha^{-1}	:	Tonnes per hectare
TPF	:	Triphenyl formazan
viz.	:	Namely
WHC	:	Water holding capacity
Zn	:	Zinc

Introduction

1. INTRODUCTION

Rice and rice based cropping systems play a major role in the Indian food security system. It is one of the staple food crops of the people of India and occupies the foremost position in area and production. The burgeoning Indian population, estimated to reach around 1.6 billion by 2050, demands an annual food grain requirement of 450 mt (Yadav *et al.*, 2010). Such an exponential rise in population coupled with rapid urbanisation has left agriculture with the crucial role of nourishing the population with the limited arable land. Scope for extending the cultivable land being meagre, the only alternative is to enhance the productivity of crops.

Evolution of high yielding varieties of rice and improved management strategies especially by using chemical fertilizers resulted in a dramatic increase in production and productivity during the eighties. But imbalanced and prolonged use of chemical fertilizers with no or inadequate organic addition has led to deterioration of soil physicochemical properties and a steady decline in fertilizer use efficiency with simultaneous reduction in crop response to added fertilizers.

Productivity of rice and rice based cropping system is showing signs of fatigue and has started declining due to heavy dependence on inorganic fertilizers combined with inefficient management of other inputs. Decline in soil fertility and depletion of soil organic carbon has ultimately affected the sustainability of agricultural production.

With no scope for increasing the net cultivable area, increased production can be achieved only by productivity enhancement through different management practices, the most important being improvement of soil organic matter with rational use of organic inputs. However, since organic inputs cannot meet the total nutrient requirement of the system, assured food security through sustained agricultural productivity can be attained only by a wise use of Integrated Nutrient Management (INM) techniques.

Integrated nutrient management aims at maintenance of plant nutrient supply at an optimum level for sustaining crop productivity through maximum utilization of all possible sources of plant nutrients, in an integrated manner. Soil productivity enhancement and maintenance is achieved through balanced use of inorganic fertilizers combined with organics and biological sources of plant nutrients, resulting in improved stock of nutrients in the soil and their sustained and phased availability to the plant thus minimising losses, improving efficiency and crop productivity.

Use of organic inputs including green manures hold great promise in rice based cropping system by preventing the emergence of multiple nutrient deficiencies and soil health deterioration. Reverting to the use of farmyard manure (FYM), crop residue, green manure etc. in conjunction with chemical fertilizers helps to revitalize the soil ecosystem and bring sustainability to agriculture. Hence INM approach was introduced in rice based cropping system since it involves judicious combination of organics and inorganics by effective recycling techniques without any detrimental effects.

Long term addition of organics to soil along with chemical fertilizers increases microbial population (Gupta *et al.*, 1983) organic carbon content and the contents of nitrogen, phosphorus and potassium in soil in addition to improving soil structure, reducing bulk density and increasing porosity and infiltration rate (Pandey *et al.*, 1985). Combined application of organic manures with inorganic fertilizers also enhances the productivity of rice based cropping system (Bharambe and Tomar, 2004).

Continuous addition of organic manures in combination with inorganic fertilizers stimulates mineralization of plant nutrients, thereby improving their availability to plants (Jagtap *et al.*, 2007). In soils where INM has been adopted for several years, the availability of micronutrients has increased significantly (Singh *et al.*, 2006). The availability of nutrients and influence on soil properties is also decided by the type of organic input used in INM due to differences in mineralisation pattern.

Hence this project entitled 'Impact of long term Integrated Nutrient Management system on soil health and rice productivity' was formulated to assess the impact of long term integrated nutrient management practices on soil physical, chemical and biological properties, soil organic carbon content, and to study their impact on rice productivity. The study was conducted as part of a long term experiment initiated during *kharif* 1985-'86 at Integrated Farming System Research Station, Karamana under the AICRP on IFS, Indian Institute of Farming Systems Research, Modipuram.

Review of Literature

2. REVIEW OF LITERATURE

Management of soil nutrient status through judicious integration of organic inputs viz. farmyard manure, crop residue, green manure etc. with inorganic fertilizers, is of utmost importance in designing a sustainable rice-rice cropping system. Soil fertility maintenance with integrated use of organics and inorganics is the objective underlying nutrient management for long term sustenance of crop productivity. Organic additions through FYM, crop residues, compost, green manures, etc. have been practiced in rice-rice cropping system by farmers in Kerala.

This chapter attempts to review the available literature on different organic manures used, the possible substitution of organics for inorganics, their nutrient contribution and effect on soil fertility in a cereal based cropping system.

2.1 EFFECT OF INTEGRATED NUTRIENT MANAGEMENT PRACTICES ON YIELD ATTRIBUTES AND YIELD OF RICE

Yadav *et al.* (2000) reported that 50 per cent of the nitrogen recommendation substituted through organic manures in rice and application of full dose of nutrients as fertilizers alone to succeeding wheat may enhance the sustainability of crop yields under a long term rice-wheat cropping system.

Application of N: P_2O_5: K_2O at the rate of 120: 60: 45 kg ha^{-1} in combination with FYM resulted in improved yield attributes of rice viz. tiller number, number of filled grains per panicle, test weight and grain productivity, compared to purely inorganic source of NPK and the absolute control (Satyanarayana *et al.*, 2002).

Sujathamma and Reddy (2004) found that in rice, the highest number of grains per panicle was attained with the application of 100 per cent nitrogen through inorganic fertilizers which was comparable with 25 per cent nitrogen substituted by green manure + 75 per cent fertilizer nitrogen on sandy clay soils of S.V. Agricultural College Farm, Tirupati.

In a field experiment conducted on clay loam soils of West Bengal, significant increase in the number of effective tillers per plant was recorded with the integrated application of nutrients viz. 50 per cent recommended dose of nitrogen through inorganic fertilisers and 50 per cent N supplied through FYM (Subhendu and Adhikary, 2005).

Yadav *et al.* (2005) observed that yield and yield attributes of rice in a rice-wheat cropping system were favourably influenced by the integration of inorganic fertilizers and organic manures. The maximum yield was obtained in the treatment receiving 25 per cent substitution of RDN through green leaf manure on nitrogen equivalent basis. In a rice-wheat cropping system in an Inceptisol, 50 per cent nitrogen substitution through green manuring during *kharif* and recommended dose of nutrients as fertilizers during *rabi* resulted in the highest grain yield (Bajpai *et al.*, 2006). They also reported significant residual effect due to green manure application on the following crop of wheat over other organic sources.

From a study on the different nutrient management options for rice, Khan *et al*. (2007) noted that combined application of NPK : GM : Zn at a rate of 120 : 90 : 60 kg ha^{-1} : 10 t ha^{-1}: 10 kg ha^{-1} gave significantly higher plant height, number of tillers per m^2, number of panicles per m^2, number of spikelets per panicle, 1000 grain weight, grain yield and straw yield of rice as compared to NPK as inorganic fertilizer alone and the control.

Jana *et al.* (2008) from a field experiment at the Regional Research Substation, Sekhampur, West Bengal reported that conjoint use of 75 per cent recommended dose of nitrogen (RDN) through inorganic fertilizer and 2 tonnes poultry manure recorded the maximum effective tillers per m^2 and grains per panicle, followed by application of 75 per cent RDN along with 4 tonnes green leaf manure, and 75 per cent RDN along with 5 tonnes FYM.

Different combinations of organic manures with chemical fertilizers increased the grain yield significantly over application of organic manures alone in a rice-wheat system (Sarwar *et al.,* 2008). Among the different treatments, addition of compost in combination with chemical fertilizer was found to be significantly superior (3.94 t ha^{-1} for rice and 5.73 t ha^{-1} for wheat) followed by FYM (3.36 t ha^{-1} for rice and 4.38 t ha^{-1} for wheat) and *Sesbania* as green manure (2.86 t ha^{-1} for rice and 3.50 t ha^{-1} for wheat).

Mehdi *et al.* (2011) reported that *Sesbania* at 20 t ha^{-1} along with 75 per cent recommended dose of chemical fertilizers proved to be the best treatment combination to get reasonable grain yield (4.16 t ha^{-1}) and straw yield (15.18 t ha^{-1}) in a recently reclaimed alkali soil at Soil Salinity Research Farm, Pindi Bhattian.

In a study on the impact of combined application of organic manures and fertilizers on crop yield, soil fertility parameters and nutrient uptake pattern in a rice-maize cropping system, the highest rice grain yield observed during *kharif* season was for the treatment receiving 25 per cent N from paddy straw and 75 per cent NPK from inorganic fertilizers and the lowest was for the unfertilized control (Sathish *et al.*, 2011).

Increased tiller number per m^2 in rice was observed with the substitution of 25 per cent nitrogen through FYM along with 75 per cent fertiliser nitrogen but it was on par with 100 per cent nitrogen application through fertiliser alone (Aruna *et al.*, 2012).

Application of complete dose of recommended N and P as fertilizers along with green manures recorded significantly higher number of effective tillers, plant height, 1000 grain weight and grain yield of rice than the recommended dose of N and P as fertilizers alone or the absolute control (Kumar *et al.*, 2012). The maximum yield of rice was obtained for the 100 per cent NP (fertilizers) + GM (6.42 t ha^{-1}) treatment compared to 100 per cent NP (5.31 t ha^{-1}) and 100 per cent NP + wheat residue (6.02 t ha^{-1}) treatment.

Singh *et al.* (2012) recorded that application of 50 per cent RDN as inorganic fertilizers and 50 per cent RDN as FYM resulted in grain yield (1.46 t ha^{-1}) and straw yield (2.23 t ha^{-1}) which was significantly superior over the rest of the fertility treatments but it was on par with the application of 100 per cent RDN through inorganic fertilizers.

Sharma *et al.* (2013) indicated that the growth, development and yield attributes of rice would be the best when 50 per cent N requirement was met through farmyard manure and 50 per cent NPK as inorganics was applied in a rice-wheat cropping system.

Integrated use of organic manures and inorganic fertilizers in sandy clay loam soils of Jorhat, increased the growth parameters of rice-wheat cropping system (Ahmed *et al.*, 2014). Maximum tillers per plot, grain yield and straw yield were recorded for rice where green manure @ 20 ton ha^{-1} was applied along with 150 : 100 : 100 kg ha^{-1} NPK. The residual effect of applied organic manures on the succeeding wheat crop showed that maximum number of tillers per plot and the highest grain and straw yields were obtained for the FYM (20 ton ha^{-1}) plus NPK (300 : 200 : 100 kg ha^{-1}) treatment.

Continuous substitution of 50 per cent N through green manure in rice resulted in maximum grain (7.37 t ha^{-1}) and straw (6.21 t ha^{-1}) yields which was 16.8 and 14.8 per cent respectively higher over 100 per cent NPK applied through chemical fertilizers (Sharma and Subehia, 2014).

Integrated use of FYM or poultry litter with NPK resulted in 28.7 and 25.9 per cent increase in grain yield and 50.3 and 49.4 per cent increase in straw yield respectively as compared to NPK fertilizers alone (Dutta and Longcher, 2015).

Kumara *et al.* (2015) studied the impact of long term integrated nutrient management practices on yield, soil fertility status and nutrient uptake pattern in rice-maize cropping system. Highest rice grain yield was observed during *kharif* for T_9 which received 25 per cent RDN from paddy straw and 75 per cent RDN from chemical fertilizers whereas highest maize yield during *rabi* was observed in T_6 which received 50 per cent RDN through FYM and 50 per cent RDN through chemical fertilizers during *kharif* and 75 per cent RDN through chemical fertilizers alone during *rabi*.

2.2 EFFECT OF INTEGRATED NUTRIENT MANAGEMENT PRACTICES ON ROOT PARAMETERS

Sidiras *et al.* (2001) reported that soil incorporation of organic manure along with fertilizers produced beneficial effects on rice root growth due to an improvement in the physical and chemical environment of rhizosphere soil.

Root characters like length of root, root volume, root penetration, root density, and root dry weight were the highest with conjoint use of inorganic fertilizers and farmyard manure or green manure (Rakesh *et al.*, 2001 and Mandal *et al.*, 2003).

Yang *et al.* (2004) recorded better root morphology and root activity of rice which was manifested as an increase in root density and active root absorptive area due to addition of organic manures into wetland rice soil.

2.3 EFFECT OF INTEGRATED NUTRIENT MANAGEMENT PRACTICES ON SOIL PHYSICAL PROPERTIES

Improvement in physical, chemical and biological properties of soil due to integrated nutrient management has been observed by many scientists. Bharambe and Tomar (2004) concluded that integrated use of FYM and mineral fertilizers was better compared to the application of inorganics alone in improving soil fertility status and enhancing rice productivity. Conjoint application of FYM and inorganic N P fertilizers enhanced the soil physico-chemical and biological properties, leading to improved and sustained productivity of rice (Tilahun *et al.*, 2013).

2.3.1 Bulk Density

Combined application of organic manures and inorganic sources of N decreased the bulk density of soil (Mandal *et al.*, 2003 and Premi, 2003). Chaudhary and Thakur (2007) also reported that FYM along with inorganic fertilizers had a positive effect on reducing the bulk density.

Bajpai *et al.* (2006) reported marked decrease in soil bulk density due to the incorporation of organic nutrient sources like green manure, FYM or crop residue. The lowest bulk density was noted for the treatment receiving 50 per cent NPK through inorganic fertilizer and 50 per cent RDN through green manure (1.43 Mg m^{-3}), while the highest was observed for the control treatment (1.56 Mg m^{-3}). The bulk density was found to be increased over the initial value in plots where organics were not incorporated.

A favourable influence on bulk density with the conjunctive use of organic manures and inorganic feertrilizers in a rice - wheat cropping system was reported by Dhaliwal and Walia (2008) with the lowest value (1.32 g cm^{-3}) observed in the treatment where 50 per cent N was substituted through FYM.

Tadesse *et al.* (2013) showed that addition of FYM, N and P_2O_5 at the rate of 15 t ha^{-1}: 120 kg ha^{-1}: 100 kg ha^{-1} in combination significantly improved the organic matter content and water holding capacity of soil but decreased the bulk density of soil, creating a conducive environment for better growth and development of rice.

After ten years of nutrient management and continuous cropping on a terraced land, the bulk density in the NPK + FYM and NPK + forest litter treated plots showed a significant decrease over NPK application alone (Dutta and Sangtam, 2014).

2.3.2 Water Holding Capacity

Sharma *et al.* (2001) revealed that water holding capacity of soil showed significant improvement with the integration of organic manures with inorganic fertilizers in a rice-wheat cropping system.

From a field experiment envisaged to assess the impact of incorporation of organic manures with chemical fertilizers over three seasons of rice on an Ultisol of Mizoram, it was concluded that FYM application along with fertilizers progressively improved the WHC of soil over inorganic application alone (Laxminarayana, 2006). Findings of Singh *et al.* (2006) also proved that the addition of organic manures either alone or in conjunction with mineral fertilizers improved the water holding capacity of the soil.

Sepehya (2011) reported that significant improvement in water holding capacity of soil was observed under the treatment where 50 per cent RDN (inorganic fertilizers) + 50 per cent RDN as FYM was applied during *kharif* followed by 100 per cent NPK as fertilizers during *rabi.*

2.4 EFFECT OF INTEGRATED NUTRIENT MANAGEMENT PRACTICES ON SOIL CHEMICAL PROPERTIES

2.4.1 Soil pH and EC

Hati *et al.* (2006) noticed an enhancement in EC of soil with 100 per cent NPK (fertilizer) + FYM compared to absolute control and the fertilizer treatments over a 28 year period soybean-wheat-maize rotation. Pothare *et al.* (2007) reported that EC of soil was favourably influenced by the combined application of organics and inorganics in a sorghum-wheat system. Highest values were observed in the treatment receiving 100 per cent NPK as fertilizer along with 10 t FYM ha^{-1}.

Urkurkar *et al.* (2010) also reported that integrated use of fertilizers and organic manures did not bring any significant variation in soil pH among the treatments in rice-wheat sequence.

Integrated use of organic manures and inorganic fertilizers remained superior in favourably decreasing the values of soil characteristics *viz.* pH, EC and SAR in a rice-wheat rotation Mehdi *et al.* (2011). The maximum value after rice harvest was noted where only fertilizers were applied while minimum values were observed where 75 per cent recommended dose of nutrients + FYM at 10 ton ha^{-1} was applied. The residual effect of integrated treatments after wheat, reflected as a maximum reduction in EC, pH and SAR of soil was obtained for the treatment where 75 per cent recommended dose of nutrients + sesbania at 10 ton ha^{-1} was applied.

Application of organic manures (FYM, wheat crop residue and green manure) in combination with chemical fertilizers significantly decreased the soil pH over the no nutrient control and the inorganic fertilizer alone treatment in rice in an experiment conducted at Banaras Hindu University, Varanasi. However, the EC value increased slightly in comparison with fertilizers alone and the control treatment (Kumar *et al.*, 2012).

No significant influence on soil pH was observed in vertisols under sorghum - wheat cropping by the combined use of organics and inorganics. The long term use of either inorganic fertilizers alone or integrated with organics slightly lowered the pH in vertisols under sorghum-wheat cropping (Rao *et al.*, 2013).

Walia *et al.* (2014) found that the treatments where 25 per cent and 50 per cent of the RDN was substituted through FYM, green manure or wheat cut straw and 75 per cent RDN applied as inorganic fertilizers, registered lower pH values after 23 years of rice–wheat cropping system.

No significant differences were noticed among the nutrient treatments for EC values after long-term application of inorganic fertilizers either alone or in conjunction with FYM after 36 cycles of rice-wheat system at Punjab Agricultural University, Ludhiana (Brar *et al.,* 2015).

2.4.2 Cation Exchange Capacity (CEC)

Selvi *et al.* (2003) reported that addition of NPK fertilizers along with FYM or organic residues caused significant increase in CEC of soil over the unfertilized control in a rice- wheat cropping system of an Inceptisol.

CEC of soils was reduced in almost all the treatments applied to an upland rice due to long term application of chemical fertilizers and organic manures (Dutta, 2009). Highest decrease in CEC was obtained in the 100 per cent fertilizer nitrogen applied plot whereas 100 per cent NPK as inorganics + FYM treatment almost maintained the initial status of 12.10 c mol (p+) kg^{-1}.

Verma *et al.* (2010) obtained significant improvement in CEC in all the integrated and inorganic treatments over control under continuous maize-wheat cropping system. However, larger increase in CEC was observed in soils which received nutrients in balanced and integrated form.

Continuous use of fertilizers either alone or in conjunction with organics increased the CEC of soil significantly over control. The integrated treatments registered significantly higher CEC than control but were statistically on par with that observed under 50 and 100 per cent NPK alone. Among the organic sources, FYM substitution recorded higher CEC followed by wheat crop residue and green manure (Sepehya, 2011).

Dutta and Sangtam (2014) studied the effect of integrated nutrient management practices on some important soil properties on terraced land under continuous cultivation of rice for ten years. The results showed an increase in CEC upto 20.4, 17.3, 15.2 and 13.1 per cent respectively for NPK+ FYM+ Zn, NPK+ poultry litter, NPK+ forest litter and NPK+ FYM over NPK application alone.

Gill and Walia (2014) registered a significant increase in CEC of soil with the conjunctive use of FYM with inorganic fertilizers over control and the 100 per cent inorganic treatments, whereas, Brar *et al*. (2015) observed 14 per cent higher CEC in the plots where 150 per cent NPK fertilizers were applied compared to 100 per cent NPK + FYM under 36 years of maize–wheat rotation at Punjab Agricultural University, Ludhiana.

2.4.3 Organic Carbon

Significant improvement in organic carbon status of lowland paddy soils occurred due to the addition of different organic sources along with mineral fertilizers, with the per cent increase more in rice straw treated plots (19.2 - 21.2 per cent) followed by FYM (15.4 - 17.3 per cent) and the lowest (9.6 - 11.5 per cent) for *Sesbania* green manure application (Zia *et al*., 1992).

Bajpai *et al.* (2006) assessed the long term effect of organic sources of nitrogen integrated with inorganic sources on rice and their residual effect on succeeding wheat in a rice-wheat cropping system in an Inceptisol of Raipur. They reported an organic carbon content increase of 22.9 and 27.4 per cent over the initial level and 27.5 and 31.2 per cent over control for rice and wheat respectively after continuous application of FYM for twelve crop cycles.

Maximum increase in organic carbon as well as nitrogen contents were obtained due to substitution of 50 per cent RDN with green manures continuously for fifteen years under rice-wheat system in a neutral soil of Jabalpur (Madhya Pradesh) (Gupta *et al.*, 2006).

Singh *et al.* (2007) concluded that application of inorganic fertilizers along with FYM, green manure or crop residue had created a conducive environment for plant growth by improving the organic carbon content and microbial activities. An increase of 28.6 per cent organic carbon over the initial level and 35.7 per cent over control was observed due to continuous application of fertilizers substituted with FYM.

Dhaliwal and Walia (2008) investigated the effects of conjunctive use of farmyard manure (FYM), green manures (GM) and crop residue incorporation (CRI) along with inorganic fertilizers on the sustainability and productivity of rice- wheat system in a long term fertilizer experiment conducted at Ludhiana. They observed that organic carbon content was improved in all the integrated treatments over their initial values and the highest (0.534 per cent) was obtained where 50 per cent RDN was applied through FYM and 50 per cent RDF as inorganics, followed by 50 per cent N through green manuring along with 50 per cent NPK fertilizers (0.388 per cent).

An increment of organic carbon, available P and K content in soil was observed compared to the initial values in all integrated nutrient treatments contrary to the low values obtained for the treatment receiving only recommended dose of fertilizers (Virdia and Mehta, 2009).

Kumar and Singh (2010) studied the effect of long term application of green manures and farmyard manure on soil fertility in a rice-wheat cropping system. The organic carbon ststus was significantly increased by the incorporation of green manures with and without FYM along with 100 per cent NPK as fertilizers after six cycles of rice-wheat cropping. On the other hand, 100 per cent NPK through mineral fertilizers alone could not maintain the initial status.

Walia *et al.* (2014) studied the impact of long-term integrated nutrient management (INM) on the physical, chemical and microbiological properties of Typic Ustochrept soil of Ludhiana after 23 years of rice–wheat cropping system.

INM technique resulted in an improvement in soil fertility by enhancing the organic carbon content (0.390 to 0.543 per cent), available nitrogen (171.7 to 219.3 kg ha^{-1}), phosphorus (20.5 to 43.3 kg ha^{-1}) and potassium (124.6 to 148.9 kg ha^{-1}) status of soil. The organic carbon build up was maximum with the application of FYM followed by wheat crop residue and green manure.

2.4.4 Available Macronutrients

Zia *et al.* (1992) noted an appreciable build up of nitrogen content in soil due to the application of *Sesbania* green manure, rice straw and FYM along with urea to the extent of 16.4, 10.9, and 12.7 per cent respectively. The available phosphorus content in soil also increased with the incorporation of FYM (6.2 per cent) and rice straw (3.0 per cent).

From a field experiment on a sandy loam soil at the Wheat Research Centre, Nashipur, to study the direct and residual effect of organic manures in conjunction with chemical fertilizers on soil fertility, Bodruzzaman *et al.* (2002) reported that available P content increased dramatically in poultry manure applied plots whereas available N, K and S remained unchanged irrespective of the treatments.

Significant increase of soil organic carbon, P and K status occurred due to addition of different sources of organic inputs. The values were observed to be the highest in FYM treated plots during the rainy season, from a study on a highly permeable foot-hill sandy clay-loam soil (Typic Hapludalf) of Meghalaya, India (Mishra *et al.*, 2003). Application of FYM, cut rice straw as well as green manuring in rice and wheat significantly improved the soil available N, P and K (Vinay, 2006).

Field experiments conducted during 2004-‘05 and 2005-‘06 at the Regional Research Substation, Sekhampur, revealed that soil organic carbon content increased substantially in all organic manure incorporated plots compared to their initial levels, with the highest among them reported for the rice straw incorporated plots. The available P build up was maximum with FYM, followed by sesbania green-leaf manure. They also reported a decline in available K in all the treatments except rice-straw incorporation (Jana *et al.*, 2008).

From a field experiment on rice-wheat cropping system in an Inceptisol for eight consecutive crop seasons (1999-2003), the highest available phosphorus was reported with the application of vermicompost followed by FYM, green manuring and rice residue incorporation (Singh *et al.*, 2008).

Ghosh *et al.* (2010) observed a significant improvement in nutrient availability due to the substitution of inorganic fertilizers either with farmyard manure @ 7.5 t ha^{-1}, paddy straw @ 10 t ha^{-1} or green manure @ 8 t ha^{-1} in a rice-wheat cropping system in the Indo-Gangetic plains of eastern India.

Urkurkar *et al.* (2010) revealed that significant improvement in available N in surface soil (255 kg ha^{-1}) occurred with the substitution of 50 per cent of recommended dose of nutrients through green manure. The soil available P content increased significantly with farmyard manure, composted rice straw and green manure application in combination with 50 per cent recommended dose of nutrients over the initial value and the no nutrient control.

Integrated application of inorganic fertilizers along with organic manures resulted in improving the availability of nutrients as well as major physico-chemical characteristics of soil and in sustaining and restoring the soil fertility (Singh *et al.*, 2011).

Ahmed *et al.* (2014) reported that the combined application of 120 kg N + 39.3 kg P + 100 kg K ha^{-1} along with 10 t FYM ha^{-1} resulted in the build up of organic carbon, available N and P in an inceptisol of Assam.

Pooled data on integrated nutrient management system in the dry sub-humid red and lateritic zone of West Bengal over three years showed that combined use of chemical fertilizers and FYM significantly increased the soil organic carbon (17.07 per cent), and available N (12.9 per cent), P (10.3 per cent) and K (8.89 per cent), over the application of inorganic fertilizers alone (Chatterjee *et al*., 2014).

From a field experiment on an Entic Haplustert in maize, Sanjivkumar (2014) revealed that the treatment receiving vermicompost @ 5 t ha^{-1} along with 75 percent RDF recorded the highest exchangeable calcium content (0.139 per cent) and magnesium content (0.281 per cent), which were proved to be superior over other treatments involving integrated and sole application of organic sources and was on par with the treatment receiving 75 per cent RDF along with green leaf manure @ 12.5t ha^{-1} (0.131 per cent calcium and 0.271 per cent magnesium).

Gogoi *et al.* (2015) reported an increase in the availability of secondary nutrients in soil with the integrated nutrient treatments in rice. Substitution of 50 per cent recommended dose of fertilizers with FYM on N equivalent basis (T_4) enhanced the exchangeable Ca content of soil after *kharif* rice compared to unfertilized control (37.50 per cent) and 100 per cent RDF as fertilizers (22.22 per cent) respectively. Maximum exchangeable Mg (0.52 cmol (p+) kg^{-1}) and available S (14.35 kg ha^{-1}) in soil was also recorded for the treatment T_4.

2.4.5 Available Micronutrients

The beneficial effect of organic manure application on available micronutrient status of soils was ascribed to the addition of micronutrients due to FYM application and to the action of chelating compounds produced from organic matter decomposition, which might have prevented micronutrients from precipitation, oxidation and leaching (Sharma *et al.,* 2001).

Dhaliwal and Walia (2008) studied the effect of conjunctive use of farmyard manure, green manures, crop residue incorporation and inorganic fertilizers on the sustainability and productivity of a rice-wheat system. Significantly higher available Zn, Cu, Fe and Mn status were noticed in the treatment receiving 50 per cent N substituted through FYM and it was followed by the treatment where 50 per cent N was substituted through green manure.

Tetarwal *et al.* (2011) obtained significant improvement in the availability of micronutrients *viz.,* Zn, Fe, Mn and Cu with the addition of 100 per cent NPK along with 10 t ha^{-1} FYM.

The DTPA-extractable Zn, Fe, Mn and Cu in soil improved with the conjunctive use of organics along with 75 per cent or 100 per cent NP fertilizers. The DTPA–extractable Fe significantly increased with the application of 100 per cent NP along with organics as compared to 100 per cent NP alone. DTPA-extractable Mn in soil showed higher value with green manure addition when compared to 100 per cent NP application. Incorporation of crop residues did not significantly increase the DTPA extractable Zn, Mn and Cu in soil (Kumar *et al.*, 2012).

Walia *et al.* (2014) concluded that availability of Zn, Cu, Fe, and Mn in soil gave significant increase due to integrated use of FYM, wheat cut straw and green manure with inorganic fertilizers. Highest available Fe (23.01 mg kg^{-1}) and Mn (13.74 mg kg^{-1}) status was recorded in the treatments which received 50 per cent nitrogen through green manuring and 50 per cent RDN as fertilizers during *kharif* and 100 per cent RDN as fertilizers during *rabi.* Available Zn (2.65 mg kg^{-1}) and Cu (1.66 mg kg^{-1}) were found to be maximum where 25 per cent N was substituted through green manuring and 50 per cent N through wheat cut straw respectively.

The maximum available micronutrient content in soil (Cu, Zn, Mn and Fe) at flowering and harvest stages were observed in treatments receiving 150 kg N ha^{-1} + FYM + biofertilizers, though the treatment influence was significantly related to Fe only. Iron availability increased significantly with increasing dose of nitrogen up to 120 kg ha^{-1} in combination with biofertilizers or FYM or their combination (Goutami *et al.*, 2015).

The maximum available Fe, Mn, Cu and Zn status in soil (28.33, 59.13, 1.33 and 3.24 mg kg^{-1} respectively) was noted with substitution of 50 per cent N through FYM in *kharif* and 100 per cent RDF as fertilizers in *rabi* in a rice-wheat cropping system (Kumara *et al.,* 2015).

2.5 EFFECT OF INTEGRATED NUTRIENT MANAGEMENT PRACTICES ON NUTRIENT UPTAKE BY GRAIN AND STRAW

2.5.1 Uptake of Macronutrients

Baskar (2003) showed that integrated use of FYM and green leaf manuring along with inorganic fertilizers increased the N uptake in rice. The highest percentage increase in N uptake among the organic manure treated plots was recorded for 100 per cent NPK + FYM (14.8 per cent) followed by 100 per cent NPK + green leaf manuring (13.5 percent), compared to the 100 per cent NPK alone treated plots in an inceptisol in the southern districts of Tamil Nadu.

The total uptake of N, P and K by rice crop improved significantly with the application of mineral fertilizers alone or in combination with organic manures like green manure, FYM and cut rice straw in a rice-wheat cropping sequence (Vinay, 2006).

Jana *et al*. (2008) reported that the highest N content and uptake by rice grain and straw was observed under 75 per cent recommended dose of nitrogen (RDN) along with poultry manure @ 2 t ha^{-1} compared to the other treatments but was on par with 75 per cent RDN + *Sesbania* green leaf manuring @ 4 t ha^{-1} and 75 per cent RDN + FYM @ 5 t ha^{-1}.

Gopakkali and Sharanappa (2014) reported that conjoint use of recommended dose of fertilizers with FYM at 10 t ha^{-1} resulted in significantly higher uptake of nitrogen (122.9 kg ha^{-1}), phosphorus (31.3 kg ha^{-1}) and potassium (94.0 kg ha^{-1}) as compared to the purely inorganic treatments on sandy clay loam soils of Karnataka.

Chesti *et al.* (2013) recorded a significant rise in grain yield (4.92 t ha^{-1}) and nitrogen, phosphorus and potassium uptake 116, 20.4 and 125 kg ha^{-1}, respectively by wheat due to the application of 100 per cent NPK as fertilizers and 10 t FYM ha^{-1} as compared to the grain yield of 4.41 t ha^{-1} and total NPK uptake of 95.7, 18.1 and 111 kg ha^{-1}, respectively with 100 per cent NPK alone.

Rani and Sukumari (2013) also observed higher total N, P, K, Fe, Mn and Zn uptake by medicinal rice (Njavara) under integrated nutrient management system than the individual application of organic and inorganic sources. Singh *et al.* (2013) stated that significantly higher N uptake by grain and straw was reported due to integrated nutrient management and recommended doses of fertilizers. The protein content and grain N uptake were positively influenced by integrated nutrient management practices.

Chatterjee *et al.* (2014) showed that inclusion of FYM with inorganic fertilizers increased the uptake of nitrogen, phosphorus and potassium in rice (114, 19 and 67.5 kg ha^{-1} respectively) in the dry sub-humid red and lateritic zone of West Bengal.

2.5.2 Uptake of Micronutrients

Prasad *et al.* (2010) noted that the incorporation of organic manures along with inorganic fertilizers resulted in enhanced micronutrient uptake in a maize-wheat cropping system in an Alfisol of Jharkhand. The maximum uptake was recorded when 50 per cent N was substituted with FYM in maize which was on par with 25 per cent N substituted with FYM and 100 per cent RDF as fertilizers in both the crops.

Ramalakshmi (2014) revealed that conjoint use of 75 per cent chemical fertilizers along with vegetable waste vermicompost @ 2.5 t ha^{-1} significantly increased the zinc and copper uptake in rice. Significant increase in total uptake of Zn, Cu, Mn and Fe with the combined application of organics and recommended fertilizers was also reported by Kumar *et al.* (2012).

Kandeshwari and Thavaprakaash (2016) concluded that incorporation of 75 per cent inorganic N + 12.5 per cent N through FYM along with 12.5 per cent N through well decomposed poultry manure gave higher productivity and increased NPK uptake of rice under the System of Rice Intensification.

2.6 EFFECT OF NUTRIENT MANAGEMENT PRACTICES ON BIOLOGICAL PROPERTIES OF SOIL

2.6.1 Enzyme Activity

Srinivas *et al.* (2004) evaluated the impact of application of different organic manures on soil urease activity using rice as a test crop in a pot culture experiment. They reported that FYM at 10 t ha^{-1} recorded significantly higher soil urease activity followed by green leaf manure and paddy straw.

Dehydrogenase (μg TPF g^{-1} soil 24 h^{-1}) and phosphatase (μg p-nitro phenol g^{-1} soil h^{-1}) activity respectively were significantly decreased under 100 per cent N (50.8 and 120) and 100 per cent NP (70.8 and 144) application (Manna *et al.*, 2005) and increased with balanced fertilizer application *i.e.,* 100 per cent NPK (86 and 199) and integrated application of 100 per cent NPK +FYM (118 and 223) under continuous rice-rice cropping system at Barrackpore.

Nayak *et al.* (2007) recorded an improvement in dehydrogenase and urease activities due to various treatments could be ranked as compost + mineral fertiliser > compost > mineral fertiliser > absolute control. The combined application of fertilizers along with organic manures resulted in increased microbial activity and consequently the enzyme production.

Saha *et al.* (2008 a) explored the long-term effect of organic and inorganic fertilizers on enzyme activities in soils under maize-wheat rotation. Application of FYM improved the soil dehydrogenase activity from 9.7 μg TPF produced g^{-1} h^{-1} in control to 34.4 μg TPF produced g^{-1} h^{-1} after maize and 11.4 μg TPF produced g^{-1} h^{-1} in control to 40.4 μg TPF produced g^{-1} h^{-1} in FYM treatment after wheat.

Highest acid and alkaline phosphatase activity was found in half dose of recommended NPK + FYM treatment and was significantly more than full dose of recommended NPK+ FYM. Unlike other enzyme activities, the highest urease activity was recorded in soils applied with chemical fertilizer viz. NK (259 mg urea hydrolysed g^{-1} h^{-1}) followed by NP (237 mg urea hydrolysed g^{-1} h^{-1}) and NPK (227 mg urea hydrolysed g^{-1} h^{-1}).

Significant improvement in the activities of enzymes viz. urease, phosphatase and dehydrogenase were reported for the treatment receiving combined application of organic manures and chemical fertilizers in a permanent manurial experiment on rice at Kayamkulam in the coastal sandy tract of Onattukara region (Aparna, 2010).

Dehydrogenase activity in soils showed an increasing trend from vegetative to flowering stage in rice and thereafter the activity decreased up to harvest (Chaitanya *et al.*, 2011).

Rai and Yadav (2011) found that the integrated use of inorganic and organic sources of nutrients in wheat gave increased urease activity with 100 per cent N through FYM treatment recorded the highest value (262 μg urea hydrolysed g^{-1} soil h^{-1}).

Acid and alkaline phosphatase and dehydrogenase activities showed an increasing trend with age of the rice crop and exhibited highest activity at flowering stage and thereafter the activity decreased at maturity (Ramalakshmi *et al.*, 2012). The acid and alkaline phosphatase activity respectively were 39.5 and 50.0 at vegetative, 153.0 and 196.0 at flowering and 68.5 and 77.0 μg PNP released g^{-1} soil h^{-1} at harvest stages.

Srilatha *et al.* (2013) noted that the highest acid and alkaline phosphatase activities were recorded in 150 per cent NPK treated plots. These were on par with the application of 100per cent NPK along with FYM (85.1 and 110.5 μg PNP released g^{-1} soil h^{-1} respectively) but higher than the application of either inorganics or organics alone and the unfertilized control in a rice-rice cropping system.

Long term incorporation of FYM along with 100 per cent NPK enhanced the dehydrogenase, urease, acid and alkaline phosphatase activities over 100 per cent NPK as fertilizer alone under rice-wheat cropping system in Mollisols. The application of 100 per cent NPK + 15 t FYM ha^{-1} resulted in significantly higher dehydrogenase activity of 346.9 and 360.9 μg TPF g^{-1} 24 h^{-1} for rice and wheat respectively. The activities of acid and alkaline phosphatase after rice (6.21 and 27.21 μg PNP g^{-1} h^{-1} respectively) and after wheat (3.31 and 23.49 μg PNP g^{-1} h^{-1} respectively) and urease activity of 7.46 and 7.52 mg urea g^{-1} 24 h^{-1} after rice and wheat were also significantly higher for the 100 per cent NPK + 15 t FYM ha^{-1} treatment (Bhatt *et al.*, 2015).

2.6.2 Microbial Count

Long-term studies on the effect of mineral fertilizers and amendments on microbial dynamics in an alfisol of Western Himalayas revealed a decrease in bacterial population and increase in fungal population with graded doses of fertilizers from 50 per cent NPK to 150 per cent NPK. The application of FYM along with 100 per cent NPK showed maximum counts of bacteria, fungus and Azotobacter while highest actinomycetes population was noticed in mineral fertilizer and lime (100 per cent NPK+ Lime) treated plots (Mahajan *et al.*, 2007).

Mujiyati and Supriyadi (2009) recorded higher population of Azospirillum in soils owing to manure application (22.16 x 10^4 cfu g^{-1} soil) compared to the NPK fertilizer treatment and control. They also reported that population of Azospirillum increased with NPK fertilizer application (5.28 x 10^4 cfu g^{-1} soil) over the unfertilized control plots (5.26 x 10^4 cfu g^{-1} soil).

While comparing the organic and conventional systems of rice farming on a clayey Vertisol, Surekha *et al.* (2010) reported significantly higher Azospirillum population for organic farming alone (4.66 log cfu g^{-1} soil) followed by INM treatment (4.58 log cfu g^{-1} soil) over purely inorganic fertilizer application (4.43 log cfu g^{-1} soil).

Babar and Dongale (2011) reported significant increase in microbial population due to INM treatments in mustard – cowpea - rice cropping sequence in the lateritic soils of Konkan. The 50: 50 per cent INM treatment contributed to the highest bacterial, fungal and actinomycetes count in soil throughout the cropping system and its effect was significantly superior to the application of either chemical fertilizer or organic manure applied alone.

Walia *et al*. (2014) studied the impact of integrated nutrient management (INM) system on soil microbiological properties after 23 cycles of a rice-wheat cropping system in Typic Ustochrept soils of Ludhiana. Substitution of 50 per cent of the recommended N through FYM and wheat cut straw gave the maximum population of bacteria, fungi and actinomycetes ranging from (56.4 to 58.5) × 10^6, (26.3 to 28.1) × 10^3 and (41.9 to 44.3) × 10^4 cfu g^{-1} soil, respectively. Inorganic fertilizer application, irrespective of their dose, invariably resulted in low microbial population in soil compared to organic amended treatments.

Alagappan and Venkitaswamy (2015) observed that INM treatments performed better in building up the soil microbial load (bacterial, fungal and actinobacterial population) after the harvest of rice and green gram in the entire cropping system than RDF application alone in both the years of experimentation.

Bhatt *et al*. (2015) monitored the effects of integrated use of chemical fertilizers and FYM in rice-wheat cropping system for two consecutive years on soil biological properties of Mollisols. Treatment receiving 100 per cent NPK + 15 t FYM ha^{-1} registered the highest viable count of bacteria (24.8 and 29.8 cfu × 10^6 g^{-1}), fungi (25.4 and 25.9 cfu × 10^4 g^{-1}) and actinomycetes (40.1 and 41.9 cfu × 10^5 g^{-1}) after rice and wheat crops respectively.

Materials and Methods

3. MATERIALS AND METHODS

The present investigation entitled '*Impact of long term Integrated Nutrient Management system on soil health and rice productivity*' was conducted as part of a permanent manurial trial under AICRP on Integrated Farming System viz. "Permanent plot experiment on integrated nutrient supply system for a cereal based crop sequence" at Integrated Farming System Research Station, Karamana which was started during *kharif* 1985-'86. The study was envisaged to determine the effect of long term integrated nutrient management on the productivity, soil physico-chemical and biological properties in a rice-rice cropping system, after 30 years of continuous application of treatments.

The experiment was undertaken during two cropping seasons *viz. kharif* and *rabi* of 2016-'17. Plant and soil analysis was carried out in the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani. The materials used and methods adopted for the study are presented in this chapter.

3.1 EXPERIMENTAL SITE

The experimental site is geographically located at 8° 28' 25'' N latitude and 76° 57' 32'' E longitudes at an altitude of 5 m above mean sea level.

3.1.1 Climate

A warm humid tropical climate prevailed over the experimental area. The data on various weather parameters *viz.* maximum and minimum temperature, relative humidity (RH) and rainfall during the cropping period were collected from the Agro Meteorology Observatory, IFSRS, Karamana.

The maximum and minimum temperatures recorded during *kharif* ranged from 29.79 to 31.71 °C and 23.49 to 25.29 °C respectively with a total rainfall of 572.97

mm. The data on weather parameters during *kharif* is graphically represented in Fig.1a.

During *rabi*, the maximum and minimum temperatures ranged from 29.91 to 31.97 °C and 21.27 to 24.62 °C respectively with a total rainfall of 115.82 mm. The weather data during *rabi* is illustrated in Fig. 1b.

3.1.2 Cropping Season

The experiment was conducted during two seasons, the first during *kharif* i.e. May - October 2016 followed by *rabi* i.e. October 2016 - February 2017.

3.1.3 Cropping History of the Field

The study was a part of an ongoing experiment under AICRP on Integrated Farming System being conducted at IFSRS, Karamana and started during *kharif* 1985-'86. The treatment combination had been tested during both *kharif* and *rabi* seasons in all the years.

Analysis of soil samples before *kharif* 1985-'86 showed that the soil was acidic, sandy clay in texture, medium in organic carbon (0.86%), low in available N (246.6 kg ha^{-1}), medium in available P (11.2 kg ha^{-1}) and available K (121.6 kg ha^{-1}).

3.2 MATERIALS

3.2.1 Crop and Variety

The variety used for the present study was Uma (Mo-16), which was of medium duration (115-120 days), dwarf, medium tillering, non-lodging and resistant to brown plant hopper. The seeds used for the study were procured from Integrated Farming System Research Station, Karamana.

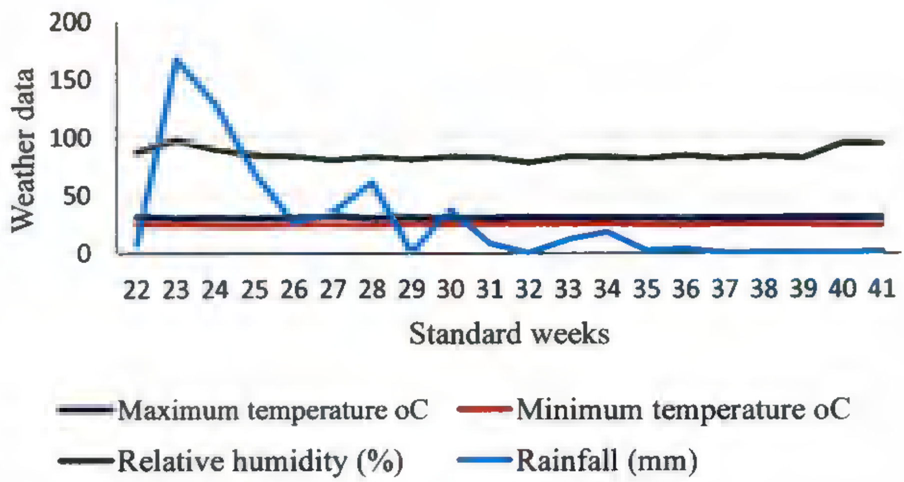

Fig. 1a. Weather data during *kharif* : May - October 2016

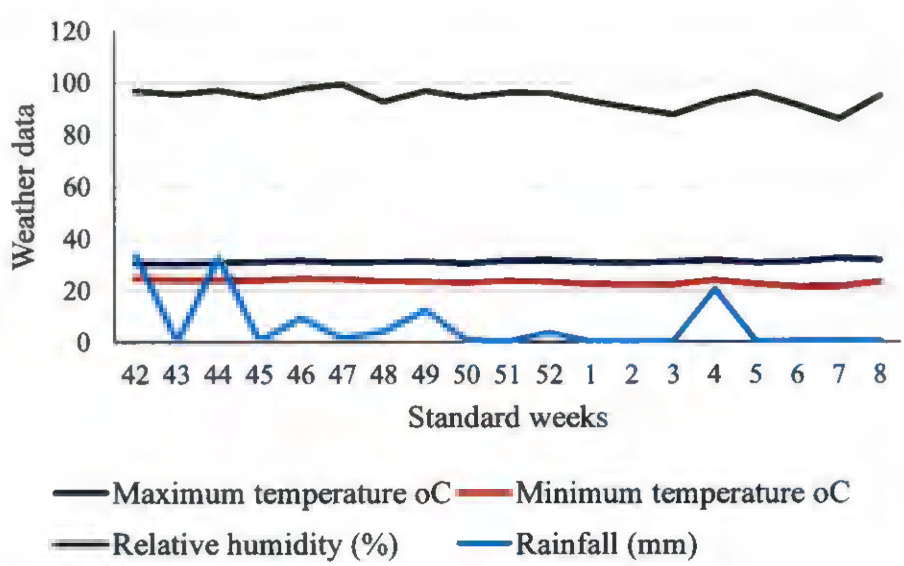

Fig. 1b. Weather data during *rabi*: October 2016 - February 2017

3.2.2 Manures and Fertilizers

Inorganic nutrient sources such as urea (46% N), Rajphos (20% P_2O_5) and muriate of potash (60% K_2O), and organic sources viz. farmyard manure (FYM) (0.8 % N), crop residues (1.2 % N) and green manures (*Gliricidia* 2.3 % N) were used for the study.

3.3 METHODS

3.3.1 Design and Layout

The experiment was laid out in Randomized Block Design comprising of 12 sets of treatment combinations replicated thrice, distributed over *kharif* and *rabi* seasons. The details of the experiment are given below:

Design	:	Randomised Block Design
Treatments	:	12
Replication	:	3
Plot size	:	16 m x 6.3 m
Spacing	:	*Kharif* 20 cm x 15 cm
		Rabi 20 cm x 10 cm
Season	:	*Kharif* 2016-'17
		Rabi 2016-'17

The layout of the experiment site is given in Fig. 2.

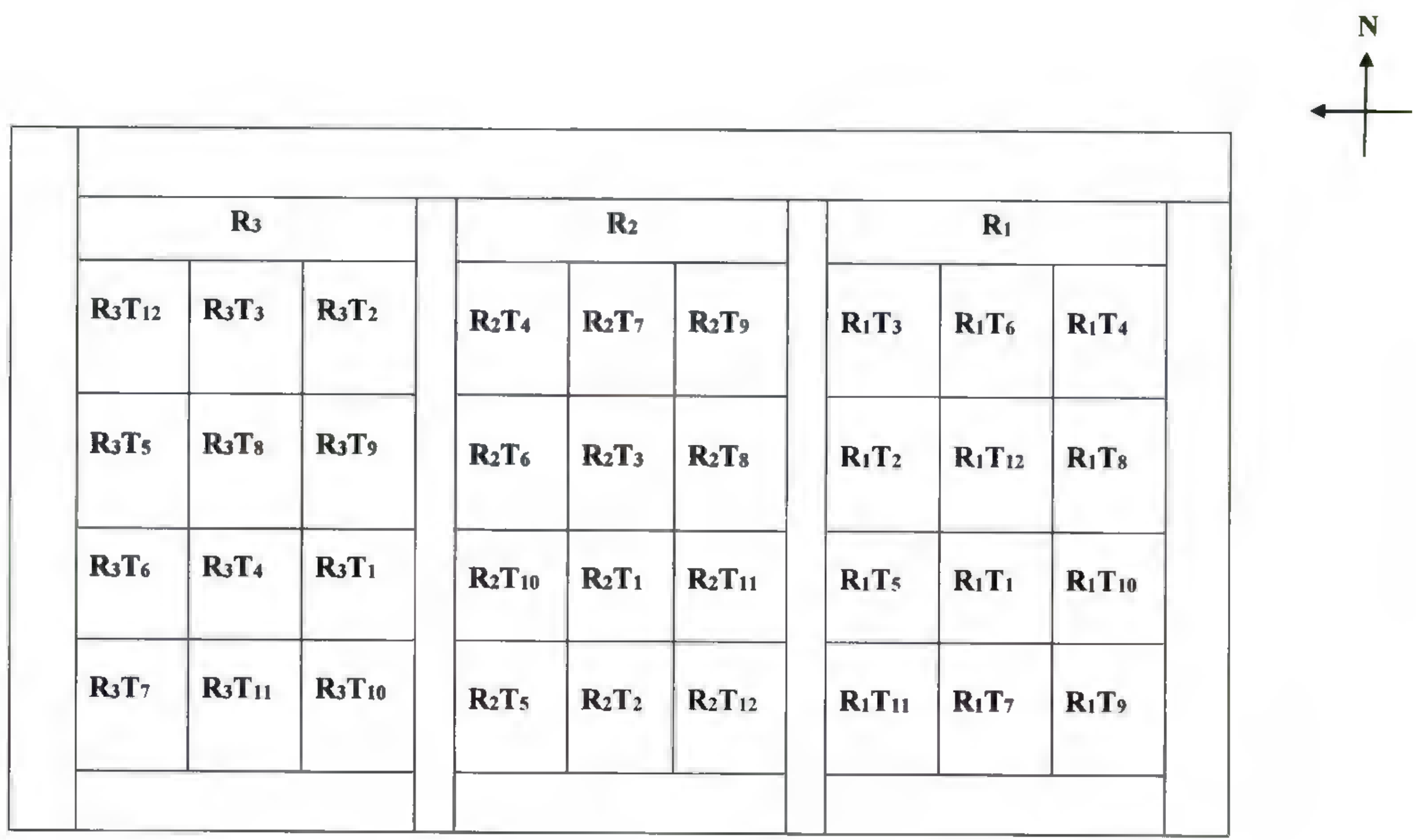

Fig. 2. Layout of the experimental field

Treatment	*Kharif*	*Rabi*
T_1	No nutrient (control)	No nutrient (control)
T_2	50% RDN* as fertilizers	50% RDN as fertilizers
T_3	50% RDN as fertilizers	100% RDN as fertilizers
T_4	75% RDN as fertilizers	75% RDN as fertilizers
T_5	100% RDN as fertilizers	100% RDN as fertilizers
T_6	50% RDN as fert. + 50% RDN as FYM	100% RDN as fertilizers
T_7	75% RDN as fert. + 25% RDN as FYM	75% RDN as fertilizers
T_8	50% RDN as fert. + 50% RDN as crop residues	100% RDN as fertilizers
T_9	75% RDN as fert.+ 25% RDN as crop residues	75% RDN as fertilizers
T_{10}	50% RDN as fert.+ 50% RDN as green manuring	100% RDN as fertilizers
T_{11}	75% RDN as fert.+ 25% RDN as green manuring	75% RDN as fertilizers
T_{12}	Farmers practice (3t FYM, 90: 22.5: 22.5 kg NPK/ha)	Farmers practice (90: 22.5: 22.5 kg NPK/ha)

*RDN : Recommended dose of nutrients - 90:45:45 kg NPK ha^{-1}

3.3.2 Cultural Practices

3.3.2.1 Nursery

Wet nursery method was adopted for raising seedlings. The nursery area was ploughed, levelled and beds of 15 cm height, 1.5 m width and 10 m length were prepared with drainage channels between the beds. Seeds were soaked in water, drained and incubated under warm moist conditions for sprouting. Pre germinated seeds were sown on the third day in the nursery.

Plate 1. General view of the experimental field

3.3.2.2 Main Field Preparation

Each experimental plot was ploughed separately after the application of organic manures wherever necessary, and the bunds were strengthened after removing weeds. Channels were cleared of weeds and depth adjusted to facilitate proper irrigation and drainage to maintain the required water level.

3.3.2.3 Application of Manures and Fertilizers

Organic manures were applied and incorporated in the field as per treatments three weeks before transplanting, during the first ploughing. Fertilizers were applied according to schedule, half the dose of N and K and full dose of P as basal and remaining dose of N and K at panicle initiation stage (KAU, 2016).

3.3.2.4 Transplanting

Twenty one day old seedlings were transplanted @ 2-3 seedlings per hill, at 3 - 4 cm depth and at a spacing of 20 cm x 15 cm during *kharif* and 20 cm x 10 cm during *rabi* season (KAU, 2016).

3.3.2.5 Water Management

The water level was adjusted to 1.5 cm during transplanting and it was subsequently increased to 5 cm which was maintained throughout the growth period with occasional drainage. The experimental area was drained 10 days prior to harvest.

3.3.2.6 Weeding

Two hand weedings were given at 20 and 45 DAT to allow a favourable weed free environment.

3.3.2.7 Harvest

The crop was harvested individually from the net plot area of each plot, leaving two border rows from all sides. After threshing and winnowing, the grain and straw yields were recorded separately.

3.4 OBSERVATIONS

The details of observations taken at the harvest stage of the experiment are described below.

3.4.1 Yield Attributes

Five hills were uprooted from each net plot area randomly and used as sample plants for the study of yield attributes.

3.4.1.1 Number of Total and Productive Tillers

Total number of tillers per hill was calculated at the harvest stage from the five hills selected randomly from the net area of each plot. The number of tillers per hill was counted from these sample plants and the average was calculated.

The average number of productive tillers per hill was counted from the five selected sample hills in each plot at harvest stage and recorded.

3.4.1.2 Number of Spikelets per Panicle

The number of spikelets per panicle was counted from ten randomly selected panicles of the selected hills and the average was recorded.

3.4.1.3 Per cent Filled Grains

The number of filled and unfilled grains were counted from the ten randomly selected panicles of the selected hills, average worked out and per cent filled grains was computed using the equation given below :

$$\text{Per cent filled grains} = \frac{\text{Number of filled grains per panicle}}{\text{Total number of grains per panicle}} \times 100$$

3.4.1.4 Thousand Grain weight

One thousand grains were selected randomly from the filled grains collected from the sample hills of each plot and expressed in grams.

3.4.1.5 Grain and Straw Yield

The mature crop was harvested and threshed separately from the net plot area of each plot and the weight of grain and straw obtained from the plots were expressed in kg ha^{-1}.

3.4.1.6 System Productivity

System productivity was calculated by adding the grain yield and straw yield obtained for *kharif* and *rabi* seasons of the agricultural year and expressed in kg ha^{-1}.

3.4.2 Root Studies

3.4.2.1 Root Dry Weight

The five sample hills from each plot were uprooted at harvest stage and the cleaned root portion was separated for recording root dry weight. Fresh weight of root was first recorded. Subsequently it was oven dried at 70 °C until constant weights were obtained, and average worked out and expressed in grams.

3.4.2.2 Root length

Root length was taken after harvest from the five sample hills of each plot using a meter scale, the average worked out and expressed in cm.

3.4.2.3 Root Volume

After harvest, the five sample hills were uprooted and the root volume was measured by water displacement method using a graduated cylinder and the average worked out. The volume was expressed in cm^3 per hill.

3.4.3 Observations on Pest and Disease Incidence

The incidence of pest and disease attack was monitored throughout the crop period. Timely spraying of pesticides was done to avoid crop damage.

3.5 CHEMICAL ANALYSIS

3.5.1 Soil Analysis

Soil samples were collected before and after *kharif* and *rabi* crop for ascertaining various physico-chemical properties. For determination of bulk density and water holding capacity (WHC), undisturbed core samples were taken. The soil samples for chemical analysis were collected from 0-15 cm depth from five different spots in each plot and composite samples were prepared by quartering method. The samples were shade dried, ground, and passed through 2 mm sieve and stored in air tight containers. The processed samples were analyzed for pH, EC, CEC, organic carbon and soil available nutrients (N, P, K, Ca, Mg, S, Fe, Mn, Cu, Zn and B).

The standard procedures followed are detailed in Table 1.

Table 1. Analytical methods followed in soil analysis

Sl. No.	Parameter	Method	Reference
1	Bulk density	Undisturbed core sample	Black *et al.* (1965)
2	Water holding capacity	Core method	Gupta and Dakshinamurthy (1980)
3	Textural analysis	International pipette method	Robinson (1922)
4	pH	pH meter	Jackson (1973)
5	EC	Conductivity meter	Jackson (1973)
6	Cation exchange capacity	Neutral normal ammonium acetate method	Jackson (1973)
7	Organic carbon	Walkley and Black rapid titration method	Walkley and Black (1934)
8	Available N	Alkaline permanganate method	Subbiah and Asija (1956)
9	Available P	Bray No. 1 extraction and estimation using spectrophotometer	Bray and Kurtz (1945)
10	Available K	Neutral normal ammonium acetate extraction and estimation using flame photometer	Jackson (1973)
11	Exchangeable Ca and Mg	Versanate titration method	Hesse (1971)
12	Available Sulphur	Calcium chloride extraction and estimation by turbidimetry	Chesnin and Yien (1950)
13	Available Fe, Mn, Cu and Zn	0.1 N HCl extraction and estimation using atomic absorption spectrophotometer	Sims and Johnson (1991)
14	Available B	Hot water extraction and estimation by Azomethine-H colorimetry using spectrophotometer	Gupta (1967)

3.5.2 Soil Enzymes

For the determination of soil enzyme activities and microbial count soil samples of each treatment were collected at panicle initiation stage and was immediately stored in polythene bags. The standard procedures followed for soil enzyme analysis are detailed in Table 2.

Table 2. Analytical methods followed in enzyme analysis

Sl. No.	Parameter	Method	Reference
1	Dehydrogenase activity	Colorimetric determination of 2,3,5- triphenyl formazan (TPF)	Casida *et al.* (1964)
2	Urease activity	Colorimetric determination of NH_4^+ released by p-dimethyl aminobenzaldehyde	Porter (1965)
3	Acid phosphatase activity	Colorimetric estimation of p-nitrophenol released	Tabatabai and Bremner (1969)
4	Alkaline phosphatase activity	Colorimetric estimation of p-nitrophenol released	Tabatabai and Bremner (1969)

3.5.3 Soil Microbial Count

The microbial population isolated from the soil sample was enumerated using Serial Dilution Agar Plating method (Timonin, 1940). The population of Azospirillum in soil was enumerated using Most Probable Number (MPN) technique (Alexander, 1965). The media used for the enumeration of microorganisms are given in Table 3.

Table 3. Media used for enumeration of microorganisms

Sl. No.	Microorganism	Media used	Reference
1	Bacteria	Nutrient agar	Atlas and Parks (1993)
2	Fungi	Martin's Rose Bengal agar	Martin (1950)
3	Actinomycetes	Ken Knight's agar	Cappuccino and Sheman (1996)
4	Azospirillum	Nitrogen free Bromothymol blue (NFB) agar	Cochran (1950)

3.5.4 Plant Analysis

Plant samples were collected at harvest stage during both seasons for analysis. All the plant samples were dried in a hot air oven at 70° C until constant weight was obtained, ground and used for analysis. Single acid digestion method using H_2SO_4 was adopted for nitrogen estimation and diacid digestion (HNO_3: $HClO_4$ in 9:4 ratio) was employed for all other nutrients. Chemical analysis of grain and straw was carried out as outlined in Table 4.

Table 4. Analytical methods followed in plant analysis

Sl. No.	Element	Method	Reference
1	Total N	Kjeldahl method	Jackson (1973)
2	Total P	Vanado molybdate yellow colour method	Piper (1966)
3	Total K	Flame photometry	Jackson (1973)
4	Total Ca, Mg	Versanate titration method	Hesse (1971)
5	Total Fe, Mn, Cu and Zn	Atomic absorption spectroscopy	Lindsay and Norvel (1978)
6	Total B	Azomethine – H colorimetric method	Wolf (1971)

3.5.5 Nutrient Uptake

Straw and grain samples were dried in a hot air oven at 70° C and dry weights were taken for calculating the nutrient uptake using the following formula.

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \frac{\text{Concentration of nutrient (\%) x Dry matter production (kg ha}^{-1}\text{)}}{100}$$

3.6 ECONOMICS OF CULTIVATION

Based on the cost of cultivation and prevailing price of grain and straw, the economics of cultivation was determined and expressed in terms of benefit: cost ratio.

$$\text{B: C ratio} = \frac{\text{Gross income}}{\text{Cost of cultivation}}$$

3.7 STATISTICAL ANALYSIS

The data generated from the experiment were statistically analyzed using the technique of Analysis of Variance for Randomised Block Design (Cochran and Cox, 1965) and the significance was tested using F test. Wherever the F values were found significant, critical difference was calculated at five per cent and one percent probability levels.

Results

4. RESULTS

The results obtained from the field experiment conducted at Integrated Farming System Research Station, Karamana during the *kharif* and *rabi* seasons of 2016 –'17 to determine the long term effect of substitution of inorganic fertilizers with different forms of organic manures on soil physico-chemical and biological properties and to study the impact of applied treatments on rice productivity are presented in this chapter.

4.1 EFFECT OF INTEGRATED NUTRIENT MANAGEMENT PRACTICES ON YIELD ATTRIBUTES OF RICE

Table 5 presents the influence of long term nutrient management practices on yield attributes of wetland rice viz. number of total and productive tillers, number of grains per panicle, per cent filled grains and thousand grain weight.

There is significant difference among the treatments in total number of tillers per hill at harvest during *kharif* and *rabi* seasons. All the organic substituted treatments gave total number of tillers statistically on par with the 100 per cent inorganic treatment, with treatment T_{11} (15.13) and T_9 (13.87) showing the highest values during *kharif* and *rabi* respectively and the values were significantly higher compared to the treatments receiving inadequate nutrients (T_2 to T_4) and the farmer's practice.

The treatment effects were found to be significant with respect to the number of productive tillers per hill during *kharif* and *rabi*. Highest number of productive tillers per hill was registered under the treatment T_7 (13.93) and T_9 (13.13) during *kharif* and *rabi* respectively and was on par with all other INM treatments and the 100 per cent inorganic treatment (T_5). Treatments T_7 and T_9 resulted in significantly higher number of productive tillers compared to treatments receiving inadequate nutrients (T_2 to T_4) and the farmer's practice.

Table 5. Effect of integrated nutrient management practices on yield attributes of rice

Treatment			Total tillers per hill		Productive tillers per hill		No. of grains per panicle		Per cent filled grains		Thousand grain weight (g)	
	Kharif	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*
T_1	No fertilizers	No fert.	8.67	7.67	8.00	7.27	94.91	79.75	78.99	77.12	22.97	22.77
T_2	50% fertilizers	50% fert.	10.53	10.00	10.00	9.73	101.96	86.44	79.31	78.14	23.43	23.40
T_3	75% fertilizers	100% fert.	11.40	11.10	11.30	10.60	104.03	87.77	79.41	78.51	23.83	23.27
T_4	75% fertilizers	75% fert.	10.87	10.73	10.07	10.47	103.73	89.56	80.34	79.15	23.93	23.43
T_5	100% fertilizers	100% fert.	15.07	13.27	13.13	12.33	109.36	92.55	84.81	83.03	25.07	24.20
T_6	50% fert.+ 50% FYM	100% fert.	14.07	13.53	12.73	12.47	111.88	98.88	89.30	87.12	25.77	24.80
T_7	75% fert.+ 25% FYM	75% fert.	14.60	13.07	13.93	12.27	115.28	96.11	87.75	85.40	25.30	24.47
T_8	50% fert.+ 50% CR	100% fert.	13.33	12.87	11.93	12.13	109.59	99.77	88.53	86.19	25.23	24.40
T_9	75% fert.+ 25% CR	75% fert.	14.40	13.87	12.00	13.13	112.78	94.41	88.13	86.94	25.47	24.07
T_{10}	50% fert.+ 50% GM	100% fert.	14.00	13.53	11.93	12.73	110.24	100.66	86.52	82.67	24.90	24.73
T_{11}	75% fert.+ 25% GM	75% fert.	15.13	13.73	13.40	12.80	114.82	98.55	87.83	83.80	25.20	24.27
T_{12}	Farmers practice	FP	11.47	11.17	11.40	10.57	104.73	79.99	80.12	79.11	24.07	23.60
CD (0.05)			3.260	2.663	2.106	2.466	7.990	8.289	3.608	6.078	NS	NS

Statistical differences due to different nutrient management practices on number of grains per panicle were found to be significant during *kharif* and *rabi* seasons. The average number of grains per panicle was the highest under T_7 (115.28) and T_{10} (100.66) during *kharif* and *rabi* respectively and it was found to be on par with all other INM treatments and T_5. The number of grains per panicle was found to be more when fertilizers were substituted with organic sources and the value increased with increasing levels of nutrients supplied purely through fertilizers during both seasons.

Data presented in Table 5 revealed that during both *kharif* and *rabi*, the highest value for per cent filled grains was recorded for T_6 (89.3 % and 87.12 % respectively). During *kharif*, 50 per cent substitution of inorganics with FYM or crop residue resulted in significantly higher per cent filled grains than the 100 per cent inorganic treatment (T_5), while 50 per cent substitution with green manure and 25 per cent substitution with any of the organics gave per cent filled grains on par with T_5. During *rabi*, all the organic substituted treatments gave per cent filled grains on par with T_5.

Though the thousand grain weight during both *kharif* and *rabi* seasons were not significantly influenced by the treatments, there was an increase in values with the substitution of fertilizers with organic manures.

4.2 EFFECT OF INTEGRATED NUTRIENT MANAGEMENT PRACTICES ON ROOT PARAMETERS

The effects of long term nutrient management practices on root parameters like root dry weight, root length and root volume are presented in Table 6.

A perusal of the data revealed that during *kharif*, root dry weight varied from the lowest value of 18.04 g $hill^{-1}$ in T_1 (control) to the highest of 30.75 g $hill^{-1}$ in T_7 (75% RDN as fertilizers + 25% N through FYM during *kharif* and 75% RDN as fertilizers during *rabi*). Among the inorganic treatments (T_2 to T_5), application of 100 per cent RDN as fertilizers during both seasons recorded the highest root dry weight of 29.71 g hill^{-1}. Substitution of 25 per cent N through any of the organics recorded higher root dry weight as compared to 50 per cent substitution, the differences, however, were not significant.

During *rabi,* the highest root dry weight of 25.97 g hill^{-1} was recorded for T_{10} (50% RDN + 50% N through green manure during *kharif* followed by 100% RDN during *rabi*) and the lowest value of 14.01 g hill^{-1} for T_1 (control). Combined use of chemical fertilizers and organic manures recorded higher values and was on par with the inorganic treatments (T_4 and T_5) during both *kharif* and *rabi* seasons.

Though the root length and root volume were not significantly influenced by the treatments during *kharif* and *rabi*, higher values were obtained for INM treatments and the 100 per cent inorganic treatment. Substitution of 50 per cent N through any of the organic materials was found to increase the root volume over 25 per cent substitution.

4.3 EFFECT OF INTEGRATED NUTRIENT MANAGEMENT PRACTICE ON GRAIN AND STRAW YIELD OF RICE

Data on grain and straw yield of rice for *kharif* and *rabi* 2016-'17 as influenced by the different treatments are presented in Table 7 and Table 8.

The different treatments showed significant effect on grain yield during both *kharif* and *rabi*. Statistically significant and the highest grain yield (5770.00 kg ha^{-1}) was obtained during *kharif* for the treatment where 25 per cent of the N requirement as per KAU recommendation was substituted through FYM (T_7) and it was found to be on par with the treatment receiving green manure as the organic substitute at 25 per cent (T_{11}). Yield obtained for the treatment where recommended dose of nitrogen was substituted to the extent of 50 per cent by FYM or green manure and 25 per cent by crop residue or green manure were on par and also comparable with the 100 per cent inorganic treatment. Substitution of 50 per cent RDN by FYM, crop residue or green manure gave grain yield on par

Table 6. Effect of integrated nutrient management practices on root parameters

Treatment			Root dry weight (g hill^{-1})	Root dry weight (g hill^{-1})	Root length (cm)	Root length (cm)	Root volume (cm^3)	Root volume (cm^3)
	Kharif	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*
T_1	No fertilizers	No fert.	18.04	14.01	16.43	15.80	18.04	19.11
T_2	50% fertilizers	50% fert.	21.60	18.34	18.83	17.93	20.04	22.00
T_3	75% fertilizers	100% fert.	22.62	19.06	18.99	18.20	19.11	18.67
T_4	75% fertilizers	75% fert.	25.81	21.69	20.67	19.33	24.57	23.68
T_5	100% fertilizers	100% fert.	29.71	25.37	22.67	21.32	28.56	27.49
T_6	50% fert.+ 50% FYM	100% fert.	27.91	25.48	24.00	22.80	29.91	31.93
T_7	75% fert.+ 25% FYM	75% fert.	30.75	24.35	21.93	21.17	32.87	30.37
T_8	50% fert.+ 50% CR	100% fert.	27.53	25.95	23.20	21.57	27.89	31.83
T_9	75% fert.+ 25% CR	75% fert.	29.18	23.68	21.93	20.80	29.04	28.59
T_{10}	50% fert.+ 50% GM	100% fert.	27.02	25.97	23.43	21.90	28.74	29.41
T_{11}	75% fert.+ 25% GM	75% fert.	29.83	25.15	21.53	21.27	33.13	31.40
T_{12}	Farmers practice	FP	18.63	16.83	19.23	18.93	24.76	21.33
CD (0.05)			6.051	5.786	NS	NS	NS	NS

with each other and also with the 100 per cent inorganic treatment. But substitution of 50 per cent RDN by crop residue gave grain yield significantly less than 25 per cent FYM or green manure substitution. Yield for farmer's practice was significantly less compared to all INM treatments and the inorganic treatment receiving 75 to 100 per cent RDN. The treatment receiving no nutrient either as organics or inorganics (T_1) recorded significantly lower yield compared to all other treatments. Among the different organic sources, FYM produced the highest grain yield followed by green manure and crop residue.

A significant increase in the grain yield of rice during *rabi* was observed over control with the application of chemical fertilizers alone (T_2 to T_5) or in combination with organic manures (T_6 to T_{11}). During *rabi*, the highest grain yield (4950.00 kg ha^{-1}) was recorded by the treatment receiving 50 per cent substitution of fertilizers through crop residue during *kharif* and 100 per cent RDN during *rabi* (T_8). This was found to be on par with all other INM treatments and 100 per cent inorganic treatment. All the INM treatments and 100 per cent inorganic treatment registered significantly higher grain yield than the farmer's practice during *rabi*.

The highest system productivity was observed for treatment T_7 (10560.00 kg ha^{-1}) which was significantly higher than T_5 (9880 kg ha^{-1}). Substitution of fertilizers with organic manures, either through FYM, green manure or crop residue gave system productivity on par with each other. All INM treatments except T_7 was on par with the 100 per cent inorganic treatment (T_5). Farmer's practice gave system productivity significantly lower than the 100 per cent inorganic and all the INM treatments.

A perusal of the data revealed that different treatments produced significant effect on straw yield of rice during *kharif* and *rabi*. Significant increase in straw yield over control was observed with the application of chemical fertilizers alone at different levels (T_2 to T_5) or along with organic manures (T_6 to T_{11}). The highest straw yield during *kharif* was recorded for the treatment T_9 where 25 per cent RDN was substituted through crop residue which was on par with 50 per cent crop residue substitution but significantly higher than all other INM and inorganic treatments and also the farmer's practice. All INM treatments except T_9 gave yield of straw on par with each other. Substitution of 25 to 50 per cent RDN by either FYM or green manure gave straw yield on par with the 100 per cent inorganic treatment.

The highest straw yield during *rabi* was reported for the treatment T_6 (5783.33 kg ha^{-1}) and it was on par with T_7 (5516.67 kg ha^{-1}) and T_8 (5333.33 kg ha^{-1}). All INM treatments except T_6 gave straw yield on par with the 100 per cent inorganic treatment. The highest system productivity (13358.33 kg ha^{-1}) was given by T_9 where 25 per cent inorganics were substituted by crop residue and was on par with all treatments where 25 to 50 per cent inorganics were substituted by FYM, crop residue or green manure. Except T_9, all INM treatments gave system productivity on par with the 100 per cent inorganic treatment. Farmer's practice gave system productivity significantly less than all INM treatments and the 100 per cent inorganic treatment.

4.4 EFFECT OF INTEGRATED NUTRIENT MANAGEMENT PRACTICES ON NUTRIENT UPTAKE BY GRAIN AND STRAW

4.4.1 Nitrogen

The nitrogen uptake by grain and straw was significantly influenced by the application of varying levels of fertilizers and organic manures as presented in Table 9.

Substitution of 25 per cent N through FYM (T_7) resulted in the highest grain N uptake (64.89 kg ha^{-1}) during *kharif* which was on par with all other integrated treatments. Among the integrated treatments, T_7 and T_{11} showed significantly higher grain N uptake than T_5. Substitution of 25 per cent N through organic manures resulted in higher N uptake by grain in comparison with 50 per cent N substitution during *kharif*.

Table 7. Effect of integrated nutrient management practices on grain yield

Treatment			Grain yield (kg ha^{-1})		System productivity (kg ha^{-1})
	Kharif	*Rabi*	*Kharif*	*Rabi*	
T_1	No fertilizers	No fert.	3283.33	2880.00	6163.33
T_2	50% fertilizers	50% fert.	4540.00	3850.00	8390.00
T_3	75% fertilizers	100% fert.	4783.33	4265.00	9048.33
T_4	75% fertilizers	75% fert.	5008.33	4080.00	9088.33
T_5	100% fertilizers	100% fert.	5103.33	4776.67	9880.00
T_6	50% fert.+50% FYM	100% fert.	5411.67	4848.33	10260.00
T_7	75% fert.+25% FYM	75% fert.	5770.00	4790.00	10560.00
T_8	50% fert.+50% CR	100% fert.	5136.67	4950.00	10086.66
T_9	75% fert.+25% CR	75% fert.	5286.67	4816.67	10103.33
T_{10}	50% fert.+50% GM	100% fert.	5351.67	4780.00	10131.66
T_{11}	75% fert.+25% GM	75% fert.	5621.67	4693.33	10315.00
T_{12}	Farmers practice	FP	4620.00	3990.00	8610.00
CD (0.05)			345.897	480.313	640.620

Table 8.Effect of integrated nutrient management practices on straw yield

Treatment			Straw yield (kg ha^{-1})		System productivity (kg ha^{-1})
	Kharif	*Rabi*	*Kharif*	*Rabi*	
T_1	No fertilizers	No fert.	4206.67	3025.00	7231.66
T_2	50% fertilizers	50% fert.	5708.33	4766.67	10475.00
T_3	75% fertilizers	100% fert.	6756.67	4950.00	11706.66
T_4	75% fertilizers	75% fert.	6615.33	4933.33	11548.66
T_5	100% fertilizers	100% fert.	7267.67	5200.00	12467.66
T_6	50% fert.+ 50% FYM	100% fert.	7477.00	5783.33	13260.33
T_7	75% fert.+ 25% FYM	75% fert.	7600.00	5516.67	13116.66
T_8	50% fert.+ 50% CR	100% fert.	7926.67	5333.33	13260.00
T_9	75% fert.+ 25% CR	75% fert.	8201.67	5156.67	13358.33
T_{10}	50% fert.+ 50% GM	100% fert.	7581.33	5266.67	12848.00
T_{11}	75% fert.+ 25% GM	75% fert.	7657.67	5103.33	12761.00
T_{12}	Farmers practice	FP	5890.00	4848.33	10738.33
CD (0.05)			473.380	496.639	820.270

The highest grain N uptake during *rabi* (57.69 kg ha^{-1}) was observed for treatment T_{10} and it was on par with all other INM treatments and the 100 per cent inorganic treatment. These treatments were significantly superior over absolute control, farmer's practice and the treatments receiving inadequate nutrients.

Application of 50 per cent RDN through FYM and 50 per cent RDN through fertilizers during *kharif* followed by 100 per cent RDN as inorganics during *rabi* (T_6), registered the highest straw N uptake during *kharif* (37.12 kg ha^{-1}) and it was on par with all INM and the 100 per cent inorganic treatments. The treatments receiving 100 per cent RDN either through inorganics or as INM registered straw N uptake values significantly higher than absolute control, farmer's practice and the treatments receiving inadequate nutrients.

The highest straw N uptake during *rabi* was noticed for treatment T_6 (34.06 kg ha^{-1}) and was on par with T_7, T_8 and T_{10}. Application of 100 per cent fertilizers during both the seasons resulted in significantly higher straw N uptake (30.50 kg ha^{-1}) compared to all other inorganic treatments, absolute control and the farmer's practice and was on par with all integrated treatments except T_6. When different sources of organics were compared it was observed that N uptake in straw during *rabi* was the highest under FYM followed by crop residue and lowest under green manure. Substitution of 50 per cent N through any of the sources increased the N uptake by straw during *rabi* over 25 per cent N substitution, though the differences were not significant.

4.4.2 Phosphorus

Table 10 shows the effect of long term integrated nutrient management practices on the uptake of phosphorus by grain and straw during *kharif* and *rabi*.

The different treatments had significant effect on P uptake by rice grain and straw during both seasons. During *kharif*, the highest grain P uptake was observed for T_7 where 25 per cent N was supplied through FYM (30.22 kg ha^{-1}) which was on par with T_9 and T_{11}, where 25 per cent N was substituted through crop residue and green manure respectively. The treatment T_5 was found to be on par with all INM treatments except T_7. Among the integrated treatments, FYM incorporated plots showed the highest grain P uptake for each level of substitution followed by green manure and crop residue. Substitution of 25 per cent inorganics with any of the organic manures resulted in higher P uptake than the corresponding 50 per cent substitution.

During *rabi,* treatment T_6 showed the highest grain P uptake (31.57 kg ha^{-1}) with all INM treatments showing uptake values on par with T_5. Among the inorganic treated plots, maximum grain P uptake was recorded under T_5 (27.84 kg ha^{-1}). Farmer's practice gave a grain P uptake value of 17.54 kg ha^{-1} which was significantly lower than all INM treatments and T_5 and was on par with T_4, T_3 and T_2.

During *kharif* the range of variation in P uptake by straw was from 9.65 kg ha^{-1} under T_1 to 28.70 kg ha^{-1} under T_9. Treatment T_1 was significantly inferior over the rest of the treatments. Higher P uptake values were shown by the crop residue and green manure substituted treatments (T_8 to T_{11}) compared to FYM substituted plots (T_6 and T_7). Treatments T_5 and T_6 recorded P uptake values significantly lower than the 25 per cent crop residue (T_9) and the 25 and 50 per cent green manure substituted treatments (T_{10} and T_{11}).

The highest phosphorus uptake by straw (27.03 kg ha^{-1}) among the treatments was given by T_6 during *rabi* where 50 per cent N was substituted through FYM and 50 per cent RDN as fertilizers during *kharif* and 100 per cent RDN applied through fertilizers during *rabi* over the years. However it did not differ significantly from T_5, T_7, T_8 and T_9. Among the integrated treatments, green manure incorporated plots had the lowest phosphorus uptake irrespective of the level of substitution.

Table 9. Effect of integrated nutrient management practices on N uptake by grain and straw

Treatments			N uptake (kg ha^{-1})			
			Kharif		*Rabi*	
	Kharif	*Rabi*	Grain	Straw	Grain	Straw
T_1	No fertilizers	No fert.	27.47	14.71	22.36	12.27
T_2	50% fertilizers	50% fert.	39.16	20.56	31.74	17.53
T_3	75% fertilizers	100% fert.	43.65	24.86	39.03	25.11
T_4	75% fertilizers	75% fert.	50.34	24.10	35.70	21.70
T_5	100% fertilizers	100% fert.	56.31	31.23	49.45	30.50
T_6	50% fert.+ 50% FYM	100% fert.	60.52	37.12	51.12	34.06
T_7	75% fert.+ 25% FYM	75% fert.	64.89	35.12	52.36	32.10
T_8	50% fert.+ 50% CR	100% fert.	58.19	34.94	53.30	31.52
T_9	75% fert.+ 25% CR	75% fert.	60.06	35.55	49.96	29.96
T_{10}	50% fert.+ 50% GM	100% fert.	59.94	35.55	57.69	30.65
T_{11}	75% fert.+ 25% GM	75% fert.	63.56	31.40	49.52	29.41
T_{12}	Farmers practice	FP	45.03	21.13	33.69	22.91
CD (0.05)			6.957	6.051	7.303	3.536

Table 10. Effect of integrated nutrient management practices on P uptake by grain and straw

Treatments			P uptake (kg ha^{-1})			
			Kharif		*Rabi*	
	Kharif	*Rabi*	Grain	Straw	Grain	Straw
T_1	No fertilizers	No fert.	9.47	9.65	11.39	9.81
T_2	50% fertilizers	50% fert.	15.45	13.07	15.35	16.05
T_3	75% fertilizers	100% fert.	16.79	17.65	20.39	20.58
T_4	75% fertilizers	75% fert.	19.63	19.42	22.02	20.51
T_5	100% fertilizers	100% fert.	25.58	22.76	27.84	23.91
T_6	50% fert.+ 50% FYM	100% fert.	25.79	22.74	31.57	27.03
T_7	75% fert.+ 25% FYM	75% fert.	30.22	24.85	27.14	23.66
T_8	50% fert.+ 50% CR	100% fert.	24.79	25.52	29.34	23.92
T_9	75% fert.+ 25% CR	75% fert.	27.16	28.70	26.48	24.31
T_{10}	50% fert.+ 50% GM	100% fert.	25.49	26.94	26.77	22.82
T_{11}	75% fert.+ 25% GM	75% fert.	27.95	26.44	25.88	21.38
T_{12}	Farmers practice	FP	16.24	15.11	17.54	18.09
CD (0.05)			3.664	3.321	5.162	3.429

4.4.3 Potassium

Influence of long term integrated nutrient management practices on the uptake of potassium by grain and straw is presented in Table 11.

Potassium uptake by grain during *kharif* varied from 13.68 kg ha^{-1} in control to 31.27 kg ha^{-1} in T_6 (50% RDN as fertilizers + 50% as FYM during *kharif* and 50% RDN as fertilizers during *rabi*). All INM treatments (T_6 to T_{11}) gave uptake values for K on par with each other. Organic manure substitution at 50 per cent either through FYM, crop residue or green manure gave grain uptake values for K significantly higher than the 100 per cent inorganic treatment (T_5). Treatment T_4 receiving 75 per cent RDN through inorganics during both *kharif* and *rabi* showed grain K uptake on par with T_5 and all the 25 per cent organic manure substituted treatments.

The treatment effect was found to be significant with respect to grain K uptake during *rabi* also. Highest grain K uptake was noticed for T_{11} (22.65 kg ha^{-1}) compared to all other substituted treatments. All the organic manure substituted treatments were found to be on par. Treatments T_5 and T_4 also did not show any significant difference from the INM treatments.

The different treatments exhibited significant effect on straw K uptake during *kharif*, with an increase in K uptake values with integrated use of fertilizers and manures over purely inorganic treatment and the farmer's practice. All the INM treatments were on par with the highest K uptake recorded by T_8 (91.76 kg ha^{-1}). Among the organics used, crop residue incorporation showed the highest straw K uptake followed by green manure and the lowest by FYM.

Straw K uptake during *rabi* ranged from 25.67 kg ha^{-1} in control (T_1) to 58.35 kg ha^{-1} for T_7 (75% RDN as fertilizers and 25% as FYM during *kharif* and 75% RDN as fertilizers during *rabi*). Treatment T_7 was found to be statistically on par with all other INM treatments and the 100 per cent inorganic treatment. K uptake values were found to be enhanced with increasing levels of fertilizer application viz., 50, 75 and 100 per cent RDN to both the crops.

4.4.4 Calcium

The uptake of calcium by rice straw and grain as influenced by long term integrated nutrient management practices is presented in the Table 12.

Observations on grain calcium uptake showed that the integrated nutrient management treatments had significant effect on the uptake values. 50 per cent substitution of RDN through FYM during *kharif* and 100 per cent RDN as fertilizers during *rabi* (T_6) resulted in significantly higher calcium uptake by grain during *kharif* (7.95 kg ha^{-1}) compared to all other treatments. Grain Ca uptake was remarkably higher for FYM substituted treatments, either at 50 or 25 per cent, followed by green manure and crop residue. Treatments receiving 50 per cent substitution of inorganics with organic manures recorded higher values compared to 25 per cent substitution.

Grain calcium uptake during *rabi* was also significantly influenced by varying levels of nutrient supply. Uptake of calcium was the highest in treatment T_{10} (4.75 kg ha^{-1}) and was on par with T_6 (4.57 kg ha^{-1}). Among the organic manures applied, green manure showed the highest uptake values followed by FYM and the lowest by crop residue. 100 per cent inorganic treatment (T_5) was statistically on par with 25 per cent FYM or green manure substituted treatments and 75 per cent RDN applied as fertilizers.

In the case of straw, the range of variation in calcium uptake during *kharif* was from 13.77 kg ha^{-1} under control (T_1) to 29.36 kg ha^{-1} in T_7 (75% RDN + 25% N through FYM during *kharif* and 100% RDN as fertilizers during *rabi*). Straw calcium uptake by T_7 was on par with all other INM treatments. Application of 50, 75 and 100 per cent RDN as fertilizers alone significantly increased the calcium uptake over control, with the highest value under T_5 which

Table 11. Effect of integrated nutrient management practices on K uptake by grain and straw

Treatments			K uptake (kg ha^{-1})			
			Kharif		*Rabi*	
	Kharif	*Rabi*	Grain	Straw	Grain	Straw
T_1	No fertilizers	No fert.	13.68	38.56	8.76	25.67
T_2	50% fertilizers	50% fert.	18.16	58.69	11.66	36.17
T_3	75% fertilizers	100% fert.	21.44	67.71	15.10	39.03
T_4	75% fertilizers	75% fert.	25.68	71.84	19.10	44.44
T_5	100% fertilizers	100% fert.	24.61	72.80	18.35	52.01
T_6	50% fert.+ 50% FYM	100% fert.	31.27	81.32	20.19	55.29
T_7	75% fert.+ 25% FYM	75% fert.	28.67	85.71	19.24	58.35
T_8	50% fert.+ 50% CR	100% fert.	29.71	91.76	20.74	53.30
T_9	75% fert.+ 25% CR	75% fert.	28.01	87.86	20.02	53.90
T_{10}	50% fert.+ 50% GM	100% fert.	29.17	88.80	19.17	54.04
T_{11}	75% fert.+ 25% GM	75% fert.	27.12	81.82	22.65	51.95
T_{12}	Farmers practice	FP	19.23	64.93	14.70	41.86
CD (0.05)			4.242	10.581	5.113	9.874

Table 12. Effect of integrated nutrient management practices on Ca uptake by grain and straw

Treatments			Ca uptake (kg ha^{-1})			
			Kharif		*Rabi*	
	Kharif	*Rabi*	Grain	Straw	Grain	Straw
T1	No fertilizers	No fert.	1.18	13.77	1.09	6.50
T2	50% fertilizers	50% fert.	1.80	18.71	1.67	14.66
T3	75% fertilizers	100% fert.	2.14	20.36	1.83	16.25
T4	75% fertilizers	75% fert.	2.68	18.79	2.94	15.69
T5	100% fertilizers	100% fert.	3.14	23.99	3.30	15.71
T6	50% fert.+ 50% FYM	100% fert.	7.95	28.86	4.57	16.49
T7	75% fert.+ 25% FYM	75% fert.	6.23	29.36	3.48	14.94
T8	50% fert.+ 50% CR	100% fert.	3.17	27.69	2.26	15.85
T9	75% fert.+ 25% CR	75% fert.	2.69	27.68	2.30	16.86
T10	50% fert.+ 50% GM	100% fert.	4.71	26.68	4.75	15.54
T11	75% fert.+ 25% GM	75% fert.	3.43	25.78	3.69	15.18
T12	Farmers practice	FP	1.76	14.49	1.27	15.44
CD (0.05)			1.359	3.667	1.34	3.024

was on par with T_{10}, T_{11} and T_3. Among the organics, FYM showed maximum calcium uptake followed by crop residue and least by green manure.

The treatment effects, though significant for straw calcium uptake during *rabi*, was not consistent. All the treatments except control gave calcium uptake on par with each other. Treatment T_9 recorded the highest straw calcium uptake (16.86 kg ha^{-1}). Integrated treatments did not show any consistent increase over inorganic treatments and the farmer's practice. Lowest calcium uptake by grain and straw was registered by the unfertilized plot (T_1) during both seasons.

4.4.5 Magnesium

Influence of long term nutrient management practices on the uptake of magnesium by straw and grain is presented in Table 13.

The uptake of magnesium, as influenced by different treatments, by grain during *kharif* ranged from 2.82 kg ha^{-1} in T_1 to 5.81 kg ha^{-1} in T_6 (50% RDN + 50% N through FYM during *kharif* followed by 100% RDN during *rabi)*. All INM treatments gave grain uptake values on par with T_6 and was significantly higher than the 100 per cent inorganic treatment (T_5). Among organics, the highest uptake was recorded for FYM substitution followed by green manure and lowest for crop residue. The farmer's practice (T_{12}) also increased the magnesium uptake significantly over control.

During *rabi*, grain magnesium uptake was the highest under treatment T_5 (5.28 kg ha^{-1}), which was on par with all other INM treatments except T_9. Among the integrated treatments, T_{10} registered the highest value (5.25 kg ha^{-1}). Farmer's practice recorded an uptake of 3.89 kg ha^{-1}, which was on par with T_2, T_3 and T_4.

Observations revealed that the integrated nutrient management treatments improved the straw magnesium uptake during *kharif* compared to the purely inorganic treatments with a substitution of 50 per cent RDN through crop residue giving the highest value (8.18 kg ha^{-1}). The uptake values were significantly higher for the INM treatments compared to the 100 per cent inorganic treatment (6.60 kg ha^{-1}) which was on par with the treatments receiving inadequate nutrients and the farmer's practice.

The highest magnesium uptake by straw during *rabi* was for treatment T_6 (5.42 kg ha^{-1}) and the lowest (2.64 kg ha^{-1}) for T_1. The magnesium uptake by T_6 was statistically on par with all other INM treatments and the inorganic treatments T_5 and T_3. Application of 100 per cent RDN as fertilizers alone (T_5) recorded a significant increase (4.84 kg ha^{-1}) in magnesium uptake over control. All the organic manure substituted treatments (T_6 to T_{11}) were found to be on par showing equal effect of all the organic sources used on the uptake of magnesium.

4.4.6 Iron

The effect of long term integrated nutrient management practices on iron uptake by grain and straw is presented in Table 14.

The nutrient management practices significantly influenced the uptake of iron by grain during *kharif,* with the maximum value recorded in treatment T_7 (1.95 kg ha^{-1}) which was on par with treatment T_6, T_9, T_{10} and T_{11}. Grain iron uptake was higher for 25 per cent substituted treatments than 50 per cent, with FYM incorporation resulting in the highest value, followed by green manure and lowest for crop residue. Among the inorganic treatments (T_2 to T_5), 100 per cent RDN application during both the seasons registered an iron uptake of 1.36 kg ha^{-1} which was on par with all integrated treatments except T_7 and T_{11}.

The grain iron uptake during *rabi*, as influenced by different treatments ranged from 0.81 kg ha^{-1} in control to 2.04 kg ha^{-1} in T_6 (50% RDN as fertilizers + 50% as FYM during *kharif* and 100% RDN as fertilizers during *rabi*). 100 per cent inorganic treatment recorded an uptake value of 1.60 kg ha^{-1} which was on par with all other treatments except T_1 and T_2. Farmer's practice also did not show any significant difference from the INM treatments and the purely inorganic treatments.

Table 13. Effect of integrated nutrient management practices on Mg uptake by grain and straw

Treatments			Mg uptake (kg ha^{-1})			
			Kharif		*Rabi*	
	Kharif	*Rabi*	Grain	Straw	Grain	Straw
T_1	No fertilizers	No fert.	2.82	4.35	2.52	2.64
T_2	50% fertilizers	50% fert.	4.39	6.05	3.56	4.41
T_3	75% fertilizers	100% fert.	4.94	6.62	4.36	4.72
T_4	75% fertilizers	75% fert.	5.18	5.91	3.88	4.65
T_5	100% fertilizers	100% fert.	5.27	6.60	5.28	4.84
T_6	50% fert.+ 50% FYM	100% fert.	5.81	7.54	5.00	5.42
T_7	75% fert.+ 25% FYM	75% fert.	5.68	7.56	5.05	5.40
T_8	50% fert.+ 50% CR	100% fert.	5.41	8.18	4.76	5.10
T_9	75% fert.+ 25% CR	75% fert.	5.40	7.80	4.68	5.12
T_{10}	50% fert.+ 50% GM	100% fert.	5.67	7.92	5.25	5.36
T_{11}	75% fert.+ 25% GM	75% fert.	5.50	8.06	4.75	4.89
T_{12}	Farmers practice	FP	4.46	5.83	3.89	4.54
CD (0.05)			0.493	0.918	0.531	0.719

Table 14. Effect of integrated nutrient management practices on Fe uptake by grain and straw

Treatments			Fe uptake (kg ha^{-1})			
			Kharif		*Rabi*	
	Kharif	*Rabi*	Grain	Straw	Grain	Straw
T_1	No fertilizers	No fert.	1.09	1.97	0.81	1.89
T_2	50% fertilizers	50% fert.	1.10	3.27	0.88	3.27
T_3	75% fertilizers	100% fert.	1.22	3.87	1.23	3.81
T_4	75% fertilizers	75% fert.	1.25	3.76	0.94	3.48
T_5	100% fertilizers	100% fert.	1.36	4.24	1.60	4.05
T_6	50% fert.+ 50% FYM	100% fert.	1.75	5.03	2.04	4.61
T_7	75% fert.+ 25% FYM	75% fert.	1.95	5.25	1.52	4.38
T_8	50% fert.+ 50% CR	100% fert.	1.42	4.90	1.23	4.17
T_9	75% fert.+ 25% CR	75% fert.	1.75	5.15	1.16	4.68
T_{10}	50% fert.+ 50% GM	100% fert.	1.69	6.18	1.16	4.19
T_{11}	75% fert.+ 25% GM	75% fert.	1.94	5.61	1.44	4.04
T_{12}	Farmers practice	FP	1.19	3.38	1.59	3.44
CD (0.05)			0.400	1.310	0.671	0.941

The straw iron uptake during *kharif* was significantly influenced by different nutrient management practices. Treatment T_{10} (50% RDN as fertilizers + 50% as green manure during *kharif* and 100% RDN as fertilizers during *rabi*) which recorded the highest iron uptake by straw (6.18 kg ha^{-1}) was on par with all other integrated treatments.

Straw iron uptake during *rabi* was the highest in treatment T_9 (4.68 kg ha^{-1}) which was on par with all other INM treatments and the inorganic treatments T_5 and T_3. Among the organic manures used, crop residue showed the highest value followed by FYM and the lowest by green manure treatments. Farmer's practice was significantly superior over control and was on par with all treatments except T_9 and T_6.

4.4.7 Manganese

The results pertaining to the effect of long term integrated nutrient supply system on manganese uptake by grain and straw during *kharif* and *rabi* are presented in Table 15.

Grain manganese uptake during *kharif* was not significantly influenced by the various treatments.

During *rabi*, though the treatments were significant, none of the integrated treatments showed any consistent increase in uptake over the inorganic treatments. The highest grain manganese uptake during *rabi* was observed in T_7 (0.034 kg ha^{-1}) which was on par with T_6, T_{10}, T_5, T_4 and T_3. FYM substituted treatments resulted in the highest value followed by green manure and lowest by crop residue.

Integrated treatments had significant effect on straw manganese uptake during *kharif*. Substitution of 50 per cent fertilizers with crop residue registered the highest uptake (0.331 kg ha^{-1}) which was on par with 50 per cent FYM substitution (T_6) and 25 per cent crop residue substitution (T_9).

Significant differences in straw manganese uptake during *rabi* were obtained among treatments and the values ranged from 0.084 kg ha^{-1} for T_1 (control) to 0.216 kg ha^{-1} for T_6 (50% RDN as fertilizers + 50% as FYM during *kharif* and 100% RDN as fertilizers during *rabi*). Among the inorganic treatments, T_5 recorded the maximum uptake (0.181 kg ha^{-1}) which was on par with all integrated treatments and the farmer's practice. FYM substitution either at 50 or 25 per cent was found to be superior over the other integrated treatments.

4.4.8 Copper

The uptake of copper by straw and grain during *kharif* and *rabi* as influenced by different nutrient management practices is presented in Table 16. The different treatments did not show significant influence on copper uptake by grain during *kharif*. During *rabi*, T_{10} (substitution of 50 per cent RDN through green manure during *kharif* and 100 per cent RDN as fertilizers in *rabi*) recorded the highest grain copper uptake (0.062 kg ha^{-1}) which was on par with all INM treatments except T_6. 100 per cent inorganic treatment showed significantly lower uptake than T_{10} and T_7 and it was on par with all other treatments.

Effect of treatments on straw copper uptake during *kharif* was found significant. The highest copper uptake was noticed for the 50 per cent crop residue substituted treatment (0.102 kg ha^{-1}) which was on par with T_5 and all other INM treatments except T_{10}. 100 per cent inorganic treatment gave higher straw copper uptake (0.083 kg ha^{-1}) which was on par with all other INM treatments. Among the organic manures, highest increase was recorded for crop residue incorporation followed by FYM and the lowest for green manure. Substitution of 25 per cent RDN with FYM and green manure proved significantly superior over their respective 50 per cent substitution while it was reverse in case of crop residue.

Copper uptake by straw during *rabi* was significantly influenced by the different nutrient management practices. Significantly higher straw copper uptake (0.107 kg ha^{-1}) was observed for T_{10} (50% RDN as fertilizers + 50% as green manure during *kharif* and 100% RDN as fertilizers during *rabi*) which was on par

Table 15. Effect of integrated nutrient management practices on Mn uptake by grain and straw

Treatments			Mn uptake (kg ha^{-1})			
			Kharif		*Rabi*	
	Kharif	*Rabi*	Grain	Straw	Grain	Straw
T_1	No fertilizers	No fert.	0.023	0.149	0.016	0.084
T_2	50% fertilizers	50% fert.	0.021	0.141	0.014	0.101
T_3	75% fertilizers	100% fert.	0.023	0.188	0.025	0.105
T_4	75% fertilizers	75% fert.	0.020	0.163	0.024	0.121
T_5	100% fertilizers	100% fert.	0.026	0.193	0.025	0.181
T_6	50% fert.+ 50% FYM	100% fert.	0.035	0.284	0.028	0.216
T_7	75% fert.+ 25% FYM	75% fert.	0.036	0.204	0.034	0.184
T_8	50% fert.+ 50% CR	100% fert.	0.021	0.331	0.024	0.157
T_9	75% fert.+ 25% CR	75% fert.	0.029	0.261	0.023	0.187
T_{10}	50% fert.+ 50% GM	100% fert.	0.027	0.204	0.033	0.140
T_{11}	75% fert.+ 25% GM	75% fert.	0.026	0.217	0.027	0.189
T_{12}	Farmers practice	FP	0.021	0.144	0.024	0.145
CD (0.05)			NS	0.070	0.009	0.056

Table 16. Effect of integrated nutrient management practices on Cu uptake by grain and straw

Treatments			Cu uptake (kg ha^{-1})			
			Kharif		*Rabi*	
	Kharif	*Rabi*	Grain	Straw	Grain	Straw
T_1	No fertilizers	No fert.	0.037	0.032	0.029	0.049
T_2	50% fertilizers	50% fert.	0.031	0.056	0.051	0.059
T_3	75% fertilizers	100% fert.	0.036	0.064	0.049	0.064
T_4	75% fertilizers	75% fert.	0.055	0.068	0.031	0.083
T_5	100% fertilizers	100% fert.	0.064	0.083	0.030	0.059
T_6	50% fert.+ 50% FYM	100% fert.	0.031	0.085	0.034	0.089
T_7	75% fert.+ 25% FYM	75% fert.	0.043	0.089	0.058	0.059
T_8	50% fert.+ 50% CR	100% fert.	0.038	0.102	0.050	0.069
T_9	75% fert.+ 25% CR	75% fert.	0.058	0.079	0.046	0.077
T_{10}	50% fert.+ 50% GM	100% fert.	0.061	0.068	0.062	0.107
T_{11}	75% fert.+ 25% GM	75% fert.	0.032	0.076	0.056	0.075
T_{12}	Farmers practice	FP	0.044	0.052	0.022	0.057
CD (0.05)			NS	0.026	0.02	0.028

with T_4, T_6, T_9 and T_{11}. Among the inorganic treatments, the highest copper uptake (0.083 kg ha^{-1}) was observed for the treatment where 75 per cent RDN as fertilizers was applied during *kharif* and *rabi* (T_4) and was on par with all INM treatments except T_7.

4.4.9 Zinc

The effect of treatments on the uptake of zinc by grain and straw during *kharif* and *rabi* is shown in the Table 17.

The values for grain zinc uptake showed that the treatment effect was significant during *kharif*. The treatment T_6 (50 % RDN + 50 % RDN through FYM during *kharif* followed by 100% RDN during *rabi*) recorded the highest value (0.159 kg ha^{-1}) and was on par with treatment T_7 (0.150 kg ha^{-1}). The 100 per cent inorganic treatment also gave significantly higher value (0.133 kg ha^{-1}) which was on par with T_9, T_{10} and T_{12}. Among the organics, FYM substitution either at 50 or 25 per cent registered the highest zinc uptake. Farmer's practice (T_{12}) also resulted in significant increase in zinc uptake over the other treatments.

The uptake of zinc by grain during *rabi* was not significantly influenced by the various nutrient management practices.

All nutrient management treatments had significant effect on straw zinc uptake during *kharif* and varied from 0.130 kg ha^{-1} in T_1 to 0.454 kg ha^{-1} in T_6. Differences in zinc uptake by rice straw among the integrated treatments (T_6 to T_{11}) were not significant. When rate of substitution with organics were compared it was observed that zinc uptake was the highest under 50 per cent N substitution over 25 per cent N substitution, however, the differences were not significant.

Data revealed that different nutrient management practices had exerted significant effect on the straw zinc uptake during *rabi*. The treatment T_6 (50% RDN as fertilizers + 50% RDN as FYM during *kharif* and 100% RDN as fertilizers during *rabi*) recorded the highest zinc uptake (0.444 kg ha^{-1}) and was on par with T_7, T_9 and T_{10}. On comparing the inorganic treatments, the highest uptake was given by T_4 (0.279 kg ha^{-1}) and the differences were not significant. Farmer's practice gave zinc uptake on par with INM treatments (T_8 and T_{11}) and the inorganic treatments.

4.4.10 Boron

The effect of different integrated nutrient management treatments on the uptake of boron by grain and straw is presented in Table 18.

Significantly higher grain boron uptake was observed with the integrated nutrient management treatments compared to the inorganic treatments and farmers practice. The highest boron uptake by grain during *kharif* was observed for the substitution of 50 per cent N through green manure (0.062 kg ha^{-1}) and it was on par with other integrated treatments and 75 to 100 per cent inorganic treatments. When rates of substitution were compared it was observed that boron uptake was highest under 50 per cent N substitution over 25 per cent N substitution, though differences were not significant.

Data on grain boron uptake during *rabi* indicated that the values were in general higher for the integrated nutrient management treatments. Increasing the level of substitution through any of the organic sources in general, produced an increasing trend in grain boron uptake. Among the integrated treatments, significantly higher uptake (0.059 kg ha^{-1}) was observed for the treatment T_8 (50% RDN as fertilizers + 50% RDN through crop residue during *kharif* and 100% RDN as fertilizers during *rabi*). 100 per cent inorganic treatment gave grain boron uptake (0.040 kg ha^{-1}) values on par with all INM treatments, farmer's practice and treatments T_3 and T_4.

Data revealed that all integrated treatments and the 100 per cent inorganic treatment had significant effect on straw boron uptake during *kharif*. Among the integrated treatments, substitution of 50 per cent RDN through crop residue gave the highest straw boron uptake (0.079 kg ha^{-1}). 100 per cent inorganic treatment

Table 17. Effect of integrated nutrient management practices on Zn uptake by grain and straw

Treatments			Zn uptake (kg ha^{-1})			
			Kharif		*Rabi*	
	Kharif	*Rabi*	Grain	Straw	Grain	Straw
T1	No fertilizers	No fert.	0.079	0.130	0.095	0.110
T2	50% fertilizers	50% fert.	0.091	0.252	0.159	0.241
T3	75% fertilizers	100% fert.	0.113	0.291	0.137	0.268
T4	75% fertilizers	75% fert.	0.116	0.275	0.105	0.279
T5	100% fertilizers	100% fert.	0.133	0.243	0.139	0.236
T6	50% fert.+ 50% FYM	100% fert.	0.159	0.449	0.153	0.444
T7	75% fert.+ 25% FYM	75% fert.	0.150	0.359	0.156	0.414
T8	50% fert.+ 50% CR	100% fert.	0.113	0.454	0.151	0.283
T9	75% fert.+ 25% CR	75% fert.	0.127	0.382	0.143	0.419
T10	50% fert.+ 50% GM	100% fert.	0.138	0.395	0.136	0.393
T11	75% fert.+ 25% GM	75% fert.	0.110	0.379	0.146	0.275
T12	Farmers practice	FP	0.131	0.157	0.121	0.241
CD (0.05)			0.017	0.151	NS	0.103

Table 18. Effect of integrated nutrient management practices on B uptake by grain and straw

Treatments			B uptake (kg ha^{-1})			
			Kharif		*Rabi*	
	Kharif	*Rabi*	Grain	Straw	Grain	Straw
T_1	No fertilizers	No fert.	0.010	0.012	0.009	0.009
T_2	50% fertilizers	50% fert.	0.027	0.027	0.010	0.018
T_3	75% fertilizers	100% fert.	0.047	0.043	0.025	0.027
T_4	75% fertilizers	75% fert.	0.045	0.041	0.024	0.038
T_5	100% fertilizers	100% fert.	0.047	0.063	0.040	0.048
T_6	50% fert.+ 50% FYM	100% fert.	0.056	0.073	0.041	0.051
T_7	75% fert.+ 25% FYM	75% fert.	0.051	0.065	0.049	0.042
T_8	50% fert.+ 50% CR	100% fert.	0.058	0.079	0.059	0.043
T_9	75% fert.+ 25% CR	75% fert.	0.054	0.063	0.044	0.059
T_{10}	50% fert.+ 50% GM	100% fert.	0.062	0.077	0.044	0.053
T_{11}	75% fert.+ 25% GM	75% fert.	0.051	0.067	0.035	0.045
T_{12}	Farmers practice	FP	0.033	0.025	0.039	0.025
CD (0.05)			0.018	0.017	0.023	0.018

(T_5) recorded boron uptake (0.063 kg ha^{-1}) on par with all INM treatments and significantly superior to the other inorganic treatments. Substitution of 50 per cent RDN with any of the organic manures also proved significantly superior to their respective 25 per cent substitution.

The data on the effect of different treatments on straw boron uptake during *rabi* revealed that maximum value was for T_9 (0.059 kg ha^{-1}) which was statistically on par with all INM treatments and the 100 per cent inorganic treatment. Among the graded doses of inorganic fertilizers, T_5 showed the highest value (0.048 kg ha^{-1}) followed by T_4 (0.038 kg ha^{-1}).

4.5 EFFECT OF INTEGRATED NUTRIENT MANAGEMENT PRACTICES ON SOIL PHYSICAL PROPERTIES

4.5.1 Bulk Density

Bulk density of soil showed significant variation among the different treatments after *kharif* and *rabi* seasons (Table 19).

Before the start of the present study in *kharif* 2016, the lowest and highest bulk density was recorded in T_6 (1.13 Mg m^{-3}) and T_1 (1.29 Mg m^{-3}) respectively.

After the harvest of *kharif* rice also almost similar trend was shown as that of the initial values, varying from a minimum of 1.12 Mg m^{-3} in plots which received 50 per cent N substituted through FYM during *kharif* followed by 100 per cent RDN during *rabi* (T_6) to a maximum of 1.29 Mg m^{-3} under control (T_1). Bulk density was generally lower for the FYM substituted treatments and the plots receiving 50 per cent substitution of either crop residue or green manure.

The bulk density of soil after *rabi* crop differed significantly under different treatments and it varied from 1.11 to 1.29 Mg m^{-3}. The bulk density was lowest in the plots receiving 75 per cent RDN as inorganics and 25 per cent N through crop residue in *kharif* followed by 75 per cent RDN during *rabi* (T_9) and the highest in control (T_1). Farmer's practice (T_{12}) also resulted in significant reduction in bulk density over control.

4.5.2 Water holding capacity (WHC)

Table 20 shows the effect of different nutrient management practices on water holding capacity (WHC) of soil before and after each crop.

Before the start of the study during *kharif* 2016-'17, the lowest value of 37.51 per cent for WHC was recorded in T_1 (control) plots while the highest value of 46.68 per cent was in T_9 (75% RDN + 25% N through crop residues during *kharif* and 75% RDN during *rabi*). As for the initial sample, lowest WHC was obtained for T_1 and highest for T_9, which was on par with T_8 and T_6 after both *kharif* and *rabi*.

4.6 EFFECT OF INTEGRATED NUTRIENT MANAGEMENT PRACTICES ON SOIL CHEMICAL PROPERTIES

4.6.1 Soil pH

The treatment effects on the soil reaction before and after each crop is presented in the Table 21.

The pH values did not vary appreciably among the treatments before *kharif* crop and ranged from 5.01 (T_4 and T_6) to 5.18 (T_9). Effect of different treatments on soil pH was significant after *kharif* crop with the values ranging from 4.79 to 5.28. Soil pH was lowered significantly due to the integration of organic manures through either FYM, crop residue or green manure and for the farmer's practice, though the differences were not significant compared to 100 per cent inorganics. The highest soil pH was recorded in control and lowest in the plots receiving 50 per cent RDN along with 50 per cent N through green manure during *kharif* followed by 100 per cent RDN during *rabi* (T_{10}). The soil pH ranged from 5.10 (T_9) to 5.33 (T_1) after *rabi* with the differences being non significant under various nutrient management practices.

Table 19. Effect of integrated nutrient management practices on bulk density of soil

Treatments			Bulk density (Mg m^{-3})		
Kharif		*Rabi*	Before *kharif*	After *kharif*	After *rabi*
T_1	No fertilizers	No fert.	1.29	1.29	1.29
T_2	50% fertilizers	50% fert.	1.26	1.26	1.24
T_3	75% fertilizers	100% fert.	1.27	1.27	1.26
T_4	75% fertilizers	75% fert.	1.24	1.23	1.22
T_5	100% fertilizers	100% fert.	1.27	1.27	1.27
T_6	50% fert.+ 50% FYM	100% fert.	1.13	1.12	1.13
T_7	75% fert.+ 25% FYM	75% fert.	1.15	1.15	1.13
T_8	50% fert.+ 50% CR	100% fert.	1.18	1.16	1.15
T_9	75% fert.+ 25% CR	75% fert.	1.15	1.13	1.11
T_{10}	50% fert.+ 50% GM	100% fert.	1.16	1.17	1.17
T_{11}	75% fert.+ 25% GM	75% fert.	1.14	1.13	1.16
T_{12}	Farmers practice	FP	1.22	1.25	1.24
CD (0.05)			0.039	0.034	0.048

Table 20. Effect of integrated nutrient management practices on WHC of soil

Treatments			WHC (%)		
	Kharif	*Rabi*	Before *kharif*	After *kharif*	Before *rabi*
T_1	No fertilizers	No fert.	37.51	38.72	38.28
T_2	50% fertilizers	50% fert.	38.54	39.04	40.05
T_3	75% fertilizers	100% fert.	38.31	39.35	41.00
T_4	75% fertilizers	75% fert.	38.16	39.65	40.01
T_5	100% fertilizers	100% fert.	38.93	40.35	41.66
T_6	50% fert.+ 50% FYM	100% fert.	43.46	45.98	47.07
T_7	75% fert.+ 25% FYM	75% fert.	42.21	44.72	44.99
T_8	50% fert.+ 50% CR	100% fert.	45.75	46.50	47.13
T_9	75% fert.+ 25% CR	75% fert.	46.68	47.14	47.47
T_{10}	50% fert.+ 50% GM	100% fert.	44.43	45.00	45.05
T_{11}	75% fert.+ 25% GM	75% fert.	41.79	42.85	42.22
T_{12}	Farmers practice	FP	41.72	42.73	43.10
CD (0.05)			1.521	1.942	1.898

All the treatments irrespective of the nutrient management practices recorded lower pH values than unfertilized control. The treatments where 25 and 50 per cent of the recommended nitrogen was substituted through FYM, green manure and crop residue (T_6 to T_{11}) recorded lower pH values than the plots receiving inorganic fertilizers alone (T_2 to T_5). Among the inorganic treatments, soil pH was found to be decreased with increasing fertilizer doses from 50 to 100 per cent and the lowest pH was reported in T_5 during both the seasons.

4.6.2 Electrical Conductivity (EC)

Table 22 shows the effect of long term integrated nutrient management practices on electrical conductivity of soil. The data indicate that the various organic and inorganic treatments had no significant effect on soil EC.

4.6.3 Cation Exchange Capacity (CEC)

The data in Table 23 show the impact of long term integrated nutrient management treatments on the CEC of the soil before and after each crop.

The different treatments significantly influenced the CEC of soil after each season. Before *kharif* 2016-'17, the values of CEC ranged from a minimum of 5.20 c mol (p+) kg-^{1} in T_1 (control) to a maximum of 7.77 c mol (p+) kg^{-1} in T_6 (50% RDN as fertilizers + 50% N through FYM during *kharif* and 100% RDN as fertilizers during *rabi)*.

After *kharif* crop CEC of soil varied significantly, the values ranging from 5.43 c mol (p+) kg^{-1} in T_1 (control) to 7.87 c mol (p+) kg^{-1} in T_6 (50% RDN as fertilizers + 50% N through FYM during *kharif* and 100% RDN through inorganics during *rabi*). The CEC values were higher in all the treatments with integrated use of organics and chemical fertilizers over 100 per cent RDN as inorganics (T_5), but the differences were found non-significant. Among the different organic sources, the treatments receiving FYM recorded higher CEC followed by green manure and crop residue. Farmer's practice (T_{12}) recorded a

Table 21. Effect of integrated nutrient management practices on pH of soil

Treatments			pH		
	Kharif	*Rabi*	Before *kharif*	After *kharif*	After *rabi*
T_1	No fertilizers	No fert.	5.11	5.28	5.33
T_2	50% fertilizers	50% fert.	5.03	5.20	5.23
T_3	75% fertilizers	100% fert.	5.09	5.16	5.24
T_4	75% fertilizers	75% fert.	5.01	5.13	5.19
T_5	100% fertilizers	100% fert.	5.10	5.06	5.11
T_6	50% fert.+ 50% FYM	100% fert.	5.01	4.88	5.16
T_7	75% fert.+ 25% FYM	75% fert.	5.10	4.91	5.11
T_8	50% fert.+ 50% CR	100% fert.	5.12	4.83	5.18
T_9	75% fert.+ 25% CR	75% fert.	5.18	4.98	5.10
T_{10}	50% fert.+ 50% GM	100% fert.	5.12	4.79	5.20
T_{11}	75% fert.+ 25% GM	75% fert.	5.13	4.98	5.15
T_{12}	Farmers practice	FP	5.09	5.03	5.19
CD (0.05)			NS	0.288	NS

Table 22. Effect of integrated nutrient management practices on EC of soil

Treatments			EC (dS m^{-1})		
	Kharif	*Rabi*	Before *kharif*	After *kharif*	After *rabi*
T_1	No fertilizers	No fert.	0.255	0.253	0.259
T_2	50% fertilizers	50% fert.	0.246	0.242	0.243
T_3	75% fertilizers	100% fert.	0.246	0.239	0.240
T_4	75% fertilizers	75% fert.	0.241	0.234	0.237
T_5	100% fertilizers	100% fert.	0.236	0.216	0.221
T_6	50% fert.+ 50% FYM	100% fert.	0.200	0.191	0.183
T_7	75% fert.+ 25% FYM	75% fert.	0.226	0.213	0.200
T_8	50% fert.+ 50% CR	100% fert.	0.224	0.207	0.187
T_9	75% fert.+ 25% CR	75% fert.	0.227	0.221	0.217
T_{10}	50% fert.+ 50% GM	100% fert.	0.225	0.192	0.179
T_{11}	75% fert.+ 25% GM	75% fert.	0.228	0.204	0.213
T_{12}	Farmers practice	FP	0.244	0.231	0.223
CD (0.05)			NS	NS	NS

CEC of 6.93 c mol (p+) kg^{-1} and was statistically on par with the integrated treatments (T_6 to T_{11}) and the inorganic treatment receiving 100 per cent nutrients (T_5).

During the *rabi* season values of CEC followed almost similar trend as in *kharif* and ranged from 5.63 c mol (p+) kg^{-1} in T_1 to 7.93 c mol (p+) kg^{-1} in T_6. Treatments substituting 50 per cent RDN with any organic manures (T_6, T_8 and T_{10}) recorded higher CEC and were on par with T_7, T_{11}, T_9, T_{12}, T_4 and T_5. Application of 100 per cent RDN alone to both the crops (T_5) registered the highest CEC (7.27 c mol (p+) kg^{-1}) among the inorganic treatments.

4.6.4 Organic Carbon (OC)

The influence of long term integrated nutrient management practices on soil organic carbon content before and after each crop is presented in Table 24.

In the initial soil before the *kharif* crop of 2016-17, organic carbon content varied from 1.30 % under control to 1.70 % for the treatment receiving 50 per cent RDN plus 50 per cent N through FYM during *kharif* followed by 100 per cent RDN during *rabi* (T_6). Though organic carbon content of soil after *kharif* and *rabi* crops were not significantly affected by the treatments, they were generally higher than the values obtained before *kharif.*

4.6.5 Available Nitrogen

The results pertaining to the effect of different treatments on available nitrogen in soil are given in Table 25.

Application of varying levels of nutrients did not show any significant variation in available N status of the soil before *kharif* season.

Chemical fertilizers either alone or in combination with organic manures improved the available N content of soil significantly over control after both seasons. Maximum value recorded after *kharif* and *rabi* in plots receiving 50 per

Table 23. Effect of integrated nutrient management practices on CEC of soil

Treatments			CEC (c mol (p+) kg-[1])		
	Kharif	*Rabi*	Before *Kharif*	After *Kharif*	After *Rabi*
T_1	No fertilizers	No fert.	5.20	5.43	5.63
T_2	50% fertilizers	50% fert.	5.90	6.27	6.40
T_3	75% fertilizers	100% fert.	6.07	6.57	6.70
T_4	75% fertilizers	75% fert.	6.37	6.87	7.10
T_5	100% fertilizers	100% fert.	6.67	7.10	7.27
T_6	50% fert.+ 50% FYM	100% fert.	7.77	7.87	7.93
T_7	75% fert.+ 25% FYM	75% fert.	7.30	7.43	7.60
T_8	50% fert.+ 50% CR	100% fert.	7.47	7.63	7.90
T_9	75% fert.+ 25% CR	75% fert.	7.03	7.27	7.37
T_{10}	50% fert.+ 50% GM	100% fert.	7.63	7.77	7.87
T_{11}	75% fert.+ 25% GM	75% fert.	7.20	7.30	7.43
T_{12}	Farmers practice	FP	6.70	6.93	6.83
CD (0.05)			1.179	0.942	1.136

Table 24. Effect of integrated nutrient management practices on soil organic carbon

Treatments			Organic carbon (%)		
	Kharif	*Rabi*	Before *Kharif*	After *Kharif*	After *Rabi*
T_1	No fertilizers	No fert.	1.30	1.36	1.39
T_2	50% fertilizers	50% fert.	1.41	1.49	1.54
T_3	75% fertilizers	100% fert.	1.42	1.46	1.51
T_4	75% fertilizers	75% fert.	1.42	1.45	1.47
T_5	100% fertilizers	100% fert.	1.51	1.57	1.59
T_6	50% fert.+ 50% FYM	100% fert.	1.70	1.71	1.74
T_7	75% fert.+ 25% FYM	75% fert.	1.64	1.68	1.68
T_8	50% fert.+ 50% CR	100% fert.	1.67	1.70	1.71
T_9	75% fert.+ 25% CR	75% fert.	1.62	1.64	1.68
T_{10}	50% fert.+ 50% GM	100% fert.	1.69	1.70	1.72
T_{11}	75% fert.+ 25% GM	75% fert.	1.59	1.61	1.68
T_{12}	Farmers practice	FP	1.51	1.55	1.61
CD (0.05)			0.240	NS	NS

cent RDN+ 50 per cent N through FYM in *kharif* followed by 100 per cent RDN in *rabi* (T_6) was 280.15 kg ha^{-1} and 284.33 kg ha^{-1} respectively and were on par with all treatments except T_1, T_2 and T_3. Among the graded doses of nutrients as fertilizers alone, 100 per cent RDN (T_5) registered the maximum available N (275.97 kg ha^{-1} after *kharif* and 280.15 kg ha^{-1} after *rabi*) which was on par with all the integrated treatments (T_6 to T_{11}). Farmers practice (T_{12}) recorded available N content of 242.52 kg ha^{-1} and 246.70 kg ha^{-1} after *kharif* and *rabi* respectively.

4.6.6 Available Phosphorus

The available phosphorus (P) status of soil was significantly influenced by long term application of varying levels of fertilizers and manures (Table 25).

A perusal of the data revealed that available P before *kharif* rice varied significantly ranging from the lowest of 31.39 kg ha^{-1} for no nutrient control (T_1) to the highest of 45.45 kg ha^{-1} under 75 per cent RDN+ 25 per cent N through FYM in *kharif* followed by 75 per cent RDN in *rabi* (T_7). The second best treatment T_{10} receiving substitution of 50 per cent fertilizers with green manure (40.39 kg ha^{-1}) was on par with T_4, T_5, T_6, T_8 and T_{11}.

The available P content of the soil after *kharif* showed the maximum value for T_7 (46.95 kg ha^{-1}) and minimum value for T_1 (32.14 kg ha^{-1}). Substitution of 25 per cent N through any of the organic sources resulted in significantly lower available P content in comparison to their 50 per cent substitution except in FYM. Treatments T_6, T_8 and T_{10} were on par with the treatment receiving 100 percent RDN as fertilizers alone (T_5).

The data revealed that the available P content of soil after *rabi* varied from the lowest value of 32.80 to the highest value of 48.63 kg ha^{-1} in T_1 and T_7 respectively. The second best treatment T_8 (50% RDN as fertilizers + 50% as crop residues during *kharif* and 100% RDN as fertilizers during *rabi*) did not differ significantly from treatments T_4, T_5, T_6, T_{10} and T_{11}. Among the inorganic treatments, application of 100 per cent RDN (T_5) alone registered the highest available P (42.07 kg ha^{-1}) followed by T_4 (39.73 kg ha^{-1}). Among the plots treated with different organics, FYM at 25 per cent substitution recorded the highest available P content followed by crop residue and green manure. The plots which received farmers' practice (T_{12}) also recorded significant increase in values over T_1 and T_2.

4.6.7 Available Potassium

The results in Table 25 revealed that the available K content in soil before and after each crop was significantly influenced by the application of different treatments.

Available K content of soil before the experiment varied from a minimum of 104.80 kg ha^{-1} under T_1 to a maximum of 165.20 kg ha^{-1} under T_8 where 50% RDN + 50% N through crop residue during *kharif* followed by 100% RDN during *rabi* was applied. Treatment T_8 was found to be on par with all other INM treatments except T_{11}.

After harvest of *kharif* rice, the available K content varied from 99.15 kg ha^{-1} in T_1 to 158.45 kg ha^{-1} in T_8, which was on par with all other INM treatments and T_5 and T_3. Substitution of 25 or 50 per cent inorganics by crop residue gave higher available K compared to other treatments. The plots which received 50 per cent N substituted with different organic materials (T_6, T_8 and T_{10}) recorded a significant increase in available K content over the plots where 25 per cent N was substituted (T_7, T_9 and T_{11}).

Similar to *kharif*, soil available K content after *rabi* also recorded the highest value (166.30 kg ha^{-1}) for treatment T_8 and the lowest (108.50 kg ha^{-1}) for T_1. Application of organic manures along with chemical fertilizers increased the available K content of the soil over 100 per cent inorganic treatment (T_5). Among the inorganic treatments, 100 per cent RDN application during both the seasons (T_5) recorded the maximum value of 140.00 kg ha^{-1}. The plots which received

Table 25. Effect of integrated nutrient management practices on available N, P and K in soil

Treatments			Available N (kg ha^{-1})			Available P (kg ha^{-1})			Available K (kg ha^{-1})		
	Kharif	*Rabi*	Before *Kharif*	After *Kharif*	After *Rabi*	Before *Kharif*	After *Kharif*	After *Rabi*	Before *Kharif*	After *Kharif*	After *Rabi*
T_1	No fertilizers	No fert.	200.70	204.89	209.07	31.39	32.14	32.80	104.80	99.15	108.50
T_2	50% fertilizers	50% fert.	225.79	234.15	238.34	34.30	34.95	35.33	112.80	106.40	112.00
T_3	75% fertilizers	100% fert.	234.15	238.34	242.52	35.80	36.55	37.76	135.20	128.03	134.40
T_4	75% fertilizers	75% fert.	242.52	246.70	250.88	37.58	39.36	39.73	124.30	114.91	123.20
T_5	100% fertilizers	100% fert.	263.42	275.97	280.15	39.36	40.57	42.07	138.85	128.80	140.00
T_6	50% fert.+ 50% FYM	100% fert.	271.79	280.15	284.33	38.70	41.04	40.29	156.80	139.86	151.20
T_7	75% fert.+ 25% FYM	75% fert.	259.24	263.42	267.61	45.45	46.95	48.63	151.20	132.13	143.60
T_8	50% fert.+ 50% CR	100% fert.	259.24	271.79	271.79	39.45	41.89	43.67	165.20	158.45	166.30
T_9	75% fert.+ 25% CR	75% fert.	250.88	255.06	263.42	36.36	36.26	38.04	159.53	149.33	157.20
T_{10}	50% fert.+ 50% GM	100% fert.	267.61	275.97	280.15	40.39	41.32	42.36	158.03	145.60	145.60
T_{11}	75% fert.+ 25% GM	75% fert.	255.06	259.24	271.79	37.67	38.70	39.45	140.40	135.73	149.50
T_{12}	Farmers practice	FP	238.34	242.52	246.70	35.14	35.23	36.83	134.80	123.25	128.80
CD (0.05)			NS	40.676	38.653	3.905	3.731	4.424	17.967	31.990	25.981

farmer's practice (T_{12}) also recorded lower available K status of 123.25 kg ha^{-1} and 128.80 kg ha^{-1} respectively after *kharif* and *rabi* seasons.

4.6.8 Exchangeable Calcium

The fertility status of soil in terms of exchangeable calcium as affected by long term integrated nutrient management practices before and after each rice crop is tabulated in Table 26.

The data pertaining to the exchangeable Ca content of soil before the experiment revealed that the treatment T_3 recorded the highest value (598.63 mg kg^{-1}). Among the integrated treatments,T_8 gave the highest value (586.69 mg kg^{-1}), and crop residue substitution either at 50 or 25 per cent was found to be superior over other organics used.

The exchangeable Ca content in soil after *kharif* rice crop was not significantly affected by continuous application of varying levels of fertilizers and manures.

Analysis of post harvest soil after *rabi* crop showed significant variation among the treatments. Fifty per cent substitution of RDN through crop residue recorded the highest exchangeable Ca content in soil (655.69 mg kg^{-1}).

4.6.9 Exchangeable Magnesium

Exchangeable magnesium content in soil before and after each crop was significantly influenced by long term nutrient management practices (Table 27).

Before *kharif* 2016-'17, soil exchangeable Mg status showed significant variation among the treatments and increased from 50.69 mg kg^{-1} for T_5 to 84.31 mg kg^{-1} for T_8 (50% RDN as fertilizers + 50% as crop residue during *kharif* and 100% RDN as fertilizers during *rabi*).

The highest exchangeable Mg content in soil after *kharif* was observed in treatment T_9 (74.94 mg kg^{-1}) and it was statistically on par with the treatments T_1,

Table 26. Effect of integrated nutrient management practices on exchangeable calcium content in soil

Treatments			Exchangeable Ca (kg ha^{-1})		
	Kharif	*Rabi*	Before *Kharif*	After *Kharif*	After *Rabi*
T_1	No fertilizers	No fert.	524.50	563.38	636.88
T_2	50% fertilizers	50% fert.	457.31	398.44	491.06
T_3	75% fertilizers	100% fert.	598.63	510.31	566.63
T_4	75% fertilizers	75% fert.	520.56	405.69	504.00
T_5	100% fertilizers	100% fert.	551.94	545.38	539.19
T_6	50% fert.+ 50% FYM	100% fert.	531.19	432.50	595.63
T_7	75% fert.+ 25% FYM	75% fert.	404.19	380.00	449.56
T_8	50% fert.+ 50% CR	100% fert.	586.69	517.31	655.69
T_9	75% fert.+ 25% CR	75% fert.	540.06	416.19	587.69
T_{10}	50% fert.+ 50% GM	100% fert.	451.94	480.81	474.75
T_{11}	75% fert.+ 25% GM	75% fert.	455.06	537.69	493.06
T_{12}	Farmers practice	FP	482.94	433.31	474.99
CD (0.05)			74.421	NS	115.357

Table 27. Effect of integrated nutrient management practices on exchangeable magnesium content in soil

Treatments			Exchangeable Mg (kg ha^{-1})		
	Kharif	*Rabi*	Before *Kharif*	After *Kharif*	After *Rabi*
T_1	No fertilizers	No fert.	81.50	67.94	78.69
T_2	50% fertilizers	50% fert.	67.31	54.25	66.94
T_3	75% fertilizers	100% fert.	81.63	70.25	73.13
T_4	75% fertilizers	75% fert.	76.44	71.25	74.25
T_5	100% fertilizers	100% fert.	50.69	56.44	71.13
T_6	50% fert.+ 50% FYM	100% fert.	77.63	44.19	80.94
T_7	75% fert.+ 25% FYM	75% fert.	68.25	46.38	72.44
T_8	50% fert.+ 50% CR	100% fert.	84.31	72.06	84.25
T_9	75% fert.+ 25% CR	75% fert.	79.69	74.94	85.31
T_{10}	50% fert.+ 50% GM	100% fert.	72.31	50.38	68.81
T_{11}	75% fert.+ 25% GM	75% fert.	78.06	64.81	71.44
T_{12}	Farmers practice	FP	72.06	30.39	66.06
CD (0.05)			14.322	17.939	NS

T_3, T_4, T_8 and T_{11}. Among the inorganic treatments, T_4 (71.25 mg kg^{-1}) proved best followed by T_3 (70.25 mg kg^{-1}) and both were on par with the integrated treatments (T_8 to T_{11}). The integrated treatments did not show any consistent increase in exchangeable Mg over the inorganic treatments. Among the organics, crop residue recorded the highest exchangeable Mg content followed by green manure and lowest by FYM. Lowest exchangeable Mg content was noticed for farmer's practice (30.39 mg kg^{-1}).

The data presented shows that long term integrated nutrient management practices could not exert any significant influence on exchangeable Mg content in soil after *rabi*.

4.6.10 Available Sulphur

Table 28 presents the influence of long term integrated nutrient management practices on available sulphur in soil before and after *kharif* and *rabi* seasons.

Though the treatments failed to show any significant influence on available S content of soil before the experiment and after *kharif* crop, there was an increase in values for integrated treatments over fertilizer application alone.

The data on available S content of soil after harvest of rice in *rabi* indicated that the integrated treatments were on par with T_5 which registered the maximum value (7.75 mg kg^{-1}) and also with T_4. Substitution of 50 per cent N through any of the organic sources was found to increase the available S content over 25 per cent N substitution through organics. Among the different organics, highest increase was recorded for FYM followed by crop residue and the minimum for green manure. Farmer's practice recorded available S content of (5.51 mg kg^{-1}) which was significantly lower than 100 per cent inorganic treatment (T_5) but superior to the unfertilized control.

4.6.11 Available Iron

The treatment effects on the available iron content in soil before and after each crop is shown in the Table 29.

The data revealed that the available Fe contents of soil before the experiment ranged from 94.37 to 273.25 mg kg^{-1} in T_{10} (50% N substituted through green manure) and T_4 (75% RDN as fertilizers during *kharif* and *rabi*), respectively.

Perusal of the data in Table 29 revealed that after *kharif* crop, the available Fe content of soil varied from 137.09 mg kg^{-1} in T_{12} to 299.55 mg kg^{-1} in T_6. Substitution of chemical fertilizers with FYM or crop residue either at 25 or 50 per cent level (T_6, T_7, T_8 and T_9) recorded higher soil available Fe over other treatments and the highest was in FYM followed by crop residue and lowest in green manure. Among the inorganic treatments, T_4 recorded the highest available Fe content (182.30 mg kg^{-1}) though the differences were not significant.

The long term nutrient management practices had no significant effect on the available iron content in soil after *rabi* crop.

4.6.12 Available Manganese

The impact of long term nutrient management practices on available Mn in soil before and after *kharif* and *rabi* crops presented in Table 30 revealed that the treatment effects were not significant.

4.6.13 Available Copper

Effect of long term nutrient management practices on available copper status of soil before and after each crop is presented in the Table 31.

The effect of different treatments on available Cu content of soil samples before *kharif* was significant with the highest value (9.94 mg kg^{-1}) for treatment T_6 (50% RDN along with 50% N through FYM during *kharif* followed by 100%

Table 28. Effect of integrated nutrient management practices on available sulfur content in soil

Treatments			Available S (mg kg^{-1})		
	Kharif	*Rabi*	Before *Kharif*	After *Kharif*	After *Rabi*
T_1	No fertilizers	No fert.	2.29	2.95	3.04
T_2	50% fertilizers	50% fert.	3.92	4.01	4.32
T_3	75% fertilizers	100% fert.	5.55	5.64	6.17
T_4	75% fertilizers	75% fert.	6.21	6.25	6.61
T_5	100% fertilizers	100% fert.	7.14	7.58	7.75
T_6	50% fert.+ 50% FYM	100% fert.	6.43	6.78	7.18
T_7	75% fert.+ 25% FYM	75% fert.	5.20	6.47	6.96
T_8	50% fert.+ 50% CR	100% fert.	6.30	6.65	7.09
T_9	75% fert.+ 25% CR	75% fert.	5.02	6.34	6.65
T_{10}	50% fert.+ 50% GM	100% fert.	5.99	6.61	6.96
T_{11}	75% fert.+ 25% GM	75% fert.	4.80	5.90	6.43
T_{12}	Farmers practice	FP	4.18	5.29	5.51
CD (0.05)			NS	NS	1.49

Table 29. Effect of integrated nutrient management practices on available iron content in soil

Treatments			Available Fe (mg kg^{-1})		
	Kharif	*Rabi*	Before *Kharif*	After *Kharif*	After *Rabi*
T_1	No fertilizers	No fert.	211.80	183.50	201.45
T_2	50% fertilizers	50% fert.	155.00	161.15	192.75
T_3	75% fertilizers	100% fert.	174.55	171.90	188.95
T_4	75% fertilizers	75% fert.	273.25	182.30	216.30
T_5	100% fertilizers	100% fert.	220.45	151.40	286.80
T_6	50% fert.+ 50% FYM	100% fert.	228.60	299.55	229.05
T_7	75% fert.+ 25% FYM	75% fert.	221.25	216.75	188.75
T_8	50% fert.+ 50% CR	100% fert.	166.50	190.25	245.85
T_9	75% fert.+ 25% CR	75% fert.	225.15	226.95	229.15
T_{10}	50% fert.+ 50% GM	100% fert.	94.37	155.60	205.95
T_{11}	75% fert.+ 25% GM	75% fert.	137.51	149.95	235.60
T_{12}	Farmers practice	FP	207.25	137.09	204.00
CD (0.05)			55.779	39.448	NS

Table 30. Effect of integrated nutrient management practices on available manganese content in soil

Treatments			Available Mn (mg kg $^{-1}$)		
	Kharif	*Rabi*	Before *kharif*	After *kharif*	After *rabi*
T_1	No fertilizers	No fert.	2.55	2.11	2.98
T_2	50% fertilizers	50% fert.	2.36	2.28	2.47
T_3	75% fertilizers	100% fert.	3.55	3.13	3.06
T_4	75% fertilizers	75% fert.	3.02	2.50	2.93
T_5	100% fertilizers	100% fert.	1.58	2.10	2.82
T_6	50% fert.+ 50% FYM	100% fert.	2.82	1.91	2.27
T_7	75% fert.+ 25% FYM	75% fert.	2.04	2.13	2.78
T_8	50% fert.+ 50% CR	100% fert.	2.16	2.59	2.84
T_9	75% fert.+ 25% CR	75% fert.	2.86	2.48	2.67
T_{10}	50% fert.+ 50% GM	100% fert.	1.78	1.78	2.39
T_{11}	75% fert.+ 25% GM	75% fert.	2.51	2.20	2.17
T_{12}	Farmers practice	FP	3.49	3.27	3.50
CD (0.05)			NS	NS	NS

Table 31. Effect of integrated nutrient management practices on available copper content in soil

Treatments			Available Cu (mg kg $^{-1}$)		
	Kharif	*Rabi*	Before *kharif*	After *kharif*	After *rabi*
T_1	No fertilizers	No fert.	8.77	6.55	8.64
T_2	50% fertilizers	50% fert.	8.53	8.32	7.75
T_3	75% fertilizers	100% fert.	8.07	8.16	6.74
T_4	75% fertilizers	75% fert.	9.16	7.44	7.06
T_5	100% fertilizers	100% fert.	7.95	6.95	6.78
T_6	50% fert.+ 50% FYM	100% fert.	9.94	7.72	6.74
T_7	75% fert.+ 25% FYM	75% fert.	8.12	6.99	7.30
T_8	50% fert.+ 50% CR	100% fert.	8.00	7.33	6.91
T_9	75% fert.+ 25% CR	75% fert.	8.53	8.98	7.12
T_{10}	50% fert.+ 50% GM	100% fert.	7.59	6.94	8.23
T_{11}	75% fert.+ 25% GM	75% fert.	9.18	6.68	6.94
T_{12}	Farmers practice	FP	8.05	6.38	6.01
CD (0.05)			1.154	NS	NS

RDN as fertilizers during *rabi)*. Though available Cu content was significantly affected by treatments, there was not any significant and consistent increase in the integrated treatments over inorganic treatments.

Data revealed that application of varying doses of fertilizers and manures could not exert any significant effect on available Cu content of soil after *kharif* and *rabi* crop.

4.6.14 Available Zinc

The effect of long term integrated nutrient management practices on available zinc content in soil before and after *kharif* and *rabi* seasons is presented in Table 32 showed that the treatment effects were not significant.

4.6.15 Available Boron

Impact of long term integrated nutrient management practices on available B content in soil before and after *kharif* and *rabi* crop is presented in Table 33.

The treatment effect was found to be significant with respect to available B content of soil before *kharif* and varied from 0.118 to 0.292 mg kg^{-1} in T_1 and T_7, respectively. All the integrated treatments resulted in significantly higher available B content values compared to 100 percent RDN as fertilizers (T_5).

During *kharif*, all the integrated treatments gave B content on par with T_5 and T_4 with T_6 (50% RDN as fertilizers + 50% N through FYM during *kharif* and 100% RDN as fertilizers during *rabi*) recording the highest available B content (0.295 mg kg^{-1}). Farmer's practice gave lower values for available B content (0.187 mg kg^{-1}) which was on par with T_3 and T_2.

During *rabi*, available B content of soil varied from 0.139 mg kg^{-1} in T_1 (control) to 0.336 mg kg^{-1} in T_6 (50% RDN as fertilizers + 50% N through FYM during *kharif* and 100% RDN as fertilizers during *rabi*). Application of 100 per cent RDN as fertilizers alone registered an available B content of 0.298 mg kg^{-1}

Table 32. Effect of integrated nutrient management practices on available zinc content in soil

Treatments			Available Zn (mg kg^{-1})		
	Kharif	*Rabi*	Before *kharif*	After *kharif*	After *rabi*
T_1	No fertilizers	No fert.	6.99	5.25	6.08
T_2	50% fertilizers	50% fert.	9.04	5.84	3.77
T_3	75% fertilizers	100% fert.	7.64	4.00	5.56
T_4	75% fertilizers	75% fert.	6.17	5.04	5.24
T_5	100% fertilizers	100% fert.	7.04	4.97	4.04
T_6	50% fert.+ 50% FYM	100% fert.	6.09	4.93	6.12
T_7	75% fert.+ 25% FYM	75% fert.	6.42	4.95	4.93
T_8	50% fert.+ 50% CR	100% fert.	6.69	5.66	5.23
T_9	75% fert.+ 25% CR	75% fert.	8.74	6.55	6.28
T_{10}	50% fert.+ 50% GM	100% fert.	4.54	3.11	3.93
T_{11}	75% fert.+ 25% GM	75% fert.	3.22	4.21	5.02
T_{12}	Farmers practice	FP	6.81	3.57	4.60
CD (0.05)			NS	NS	NS

Table 33. Effect of integrated nutrient management practices on available boron content in soil

Treatments			Available B (mg kg^{-1})		
	Kharif	*Rabi*	Before *kharif*	After *kharif*	After *rabi*
T_1	No fertilizers	No fert.	0.118	0.130	0.139
T_2	50% fertilizers	50% fert.	0.135	0.167	0.179
T_3	75% fertilizers	100% fert.	0.164	0.178	0.234
T_4	75% fertilizers	75% fert.	0.180	0.242	0.272
T_5	100% fertilizers	100% fert.	0.222	0.277	0.298
T_6	50% fert.+ 50% FYM	100% fert.	0.241	0.295	0.336
T_7	75% fert.+ 25% FYM	75% fert.	0.292	0.282	0.305
T_8	50% fert.+ 50% CR	100% fert.	0.232	0.293	0.316
T_9	75% fert.+ 25% CR	75% fert.	0.283	0.268	0.287
T_{10}	50% fert.+ 50% GM	100% fert.	0.247	0.289	0.301
T_{11}	75% fert.+ 25% GM	75% fert.	0.258	0.272	0.284
T_{12}	Farmers practice	FP	0.158	0.187	0.219
CD (0.05)			0.035	0.055	0.067

which was on par with all treatments except T_{12}, T_2 and T_1. Among the organic manure applied plots, FYM recorded the highest available B content followed by crop residue and lowest in green manure. Fifty per cent organic manure substitution through any of the sources and 25 per cent substitution through FYM were found to have higher soil available B compared to 100 per cent inorganics during both *kharif* and *rabi*.

4.7 EFFECT OF INTEGRATED NUTRIENT MANAGEMENT PRACTICES ON SOIL BIOLOGICAL PROPERTIES

4.7.1 Enzyme Activity

4.7.1.1 Dehydrogenase

The dehydrogenase activity of soil as influenced by long term nutrient management treatments have been presented in Table 34.

The treatment effects were found to be non significant with respect to dehydrogenase activity of soil during *kharif* and *rabi* seasons. Dehydrogenase activity did not show any consistent increase due to integrated nutrient management. Data further showed that higher organic manure substitution, ie. 50 per cent substitution of RDN produced more dehydrogenase activity in soil than 25 per cent substitution with any of the organic sources.

4.7.1.2 Urease

Urease activity in soil during *kharif* was not significantly influenced by the treatments (Table 34).

Data revealed that T_6 gave the highest urease activity of 100.79 mg of urea hydrolyzed g^{-1} of soil h^{-1} which was on par with the urease activity of T_{10} (98.21 mg of urea hydrolyzed g^{-1} of soil h^{-1}) during *rabi*. Substitution of 50 per cent N through any of the organics recorded higher urease activity as compared to 25 per cent substitution, the differences, however, were not significant. Farmer's practice

(T_{12}) registered 86.88 mg of urea hydrolyzed g^{-1} of soil h^{-1} which was on par with the 100 per cent inorganic treatment. Treatment T_5 recorded the highest urease activity (86.05 mg of urea hydrolyzed g^{-1} of soil h^{-1}) among the inorganic treatments but was statistically on par with INM treatments except T_6 and T_{10}. Minimum urease activity was observed under unfertilized control plot (T_1) during both seasons.

4.7.1.3 Acid Phosphatase

The acid phosphatase activity in soil as influenced by different nutrient management practices are presented in Table 34.

The nutrient management practices significantly influenced the acid phosphatase activity, with the maximum value (40.45 μg of p-nitrophenol released g^{-1} soil h^{-1}) recorded in treatment T_{10} (50% RDN as fertilizers + 50% as green manure during *kharif* and 100% RDN as fertilizers during *rabi*) and the minimum (14.09 μg of p-nitrophenol released g^{-1} soil h^{-1}) recorded in T_1 (control). The acid phosphatase activity increased with increase in graded doses of fertilizers from 26.22 μg of p-nitrophenol released g^{-1} soil h^{-1} in T_2 to 39.09 μg of p-nitrophenol released g^{-1} soil h^{-1} in T_5.

During *rabi* also the effect of different treatments on acid phosphatase activity in soil was significant. It was highest (41.86 μg of p-nitrophenol released g^{-1} soil h^{-1}) in treatment T_8 which was on par with T_6, T_7 and T_{10} and lowest (19.82 μg of p-nitrophenol released g^{-1} soil h^{-1}) in T_1 (control).

4.7.1.4 .Alkaline Phosphatase

The results pertaining to the effect of different treatments on the alkaline phosphatase activity in soil are given in Table 34. Alkaline phosphatase activity in soil during *kharif* and *rabi* did not show any significant variation among the different nutrient management practices.

Table 34. Effect of integrated nutrient management practices on enzyme activities in soil

Treatments			Dehydrogenase (µg of TPF released g^{-1} soil 24 h^{-1})		Urease (mg of urea hydrolyzed g^{-1} of soil h^{-1})		Acid phosphatase (µg of p-nitrophenol released g^{-1}soil h^{-1})		Alkaline phosphatase (µg of p-nitrophenol released g^{-1} soil h^{-1})	
	Kharif	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*
T_1	No fertilizers	No fert.	174.47	188.68	64.06	75.30	14.09	19.82	5.64	6.14
T_2	50% fertilizers	50% fert.	242.13	257.87	71.47	80.88	26.22	28.18	6.32	8.77
T_3	75% fertilizers	100% fert.	238.01	239.35	70.06	80.13	26.82	27.04	5.86	7.18
T_4	75% fertilizers	75% fert.	262.57	284.65	70.56	82.47	30.32	32.63	6.41	8.82
T_5	100% fertilizers	100% fert.	276.59	300.19	74.89	86.05	35.00	34.27	7.68	9.64
T_6	50% fert.+ 50% FYM	100% fert.	288.77	301.73	74.47	100.79	39.09	39.22	7.95	9.82
T_7	75% fert.+ 25% FYM	75% fert.	276.39	296.16	71.14	90.30	34.72	35.13	7.82	9.45
T_8	50% fert.+ 50% CR	100% fert.	266.89	312.77	74.39	90.71	34.81	41.86	7.54	8.82
T_9	75% fert.+ 25% CR	75% fert.	247.79	285.80	76.55	83.97	32.31	32.95	7.36	8.36
T_{10}	50% fert.+ 50% GM	100% fert.	286.09	317.56	74.97	98.21	40.45	41.36	7.27	9.14
T_{11}	75% fert.+ 25% GM	75% fert.	265.55	290.12	72.55	88.55	34.09	32.54	6.23	8.45
T_{12}	Farmers practice	FP	255.86	282.44	69.39	86.88	29.95	31.36	6.09	8.00
CD (0.05)			NS	NS	NS	6.859	6.888	7.239	NS	NS

4.7.2 Microbial Count

The influence of long term integrated nutrient management practices on soil microbial count during *kharif* and *rabi* is presented in Table 35.

Data revealed that application of varying doses of fertilizers and manures exerted significant effect on microbial count of soil during *kharif* and *rabi* seasons. Treatment T_6, where 50 per cent of the recommended N was substituted through FYM gave the highest count of bacteria (8.40 log cfu g^{-1} soil), fungi (5.21 log cfu g^{-1} soil) and actinomycetes (4.97 log cfu g^{-1} soil) during *kharif*. *Azospirillum* count was highest (3.63 log cfu g^{-1} soil) under treatment T_{10}, where 50 per cent of the recommended N was substituted through green manure.

During *rabi*, the highest count of bacteria (8.46 log cfu g^{-1} soil) and fungi (5.26 log cfu g^{-1} soil) was noted for the treatment T_{10} (50% of the recommended N was substituted through green manure) and T_8 (50% of the recommended N was substituted through crop residue) respectively. Treatment T_6 where 50 per cent of the recommended N was substituted through FYM showed the highest count of actinomycetes (4.99 log cfu g^{-1} soil) and *Azospirillum* (3.75 log cfu g^{-1} soil).

4.8 EFFECT OF INTEGRATED NUTRIENT MANAGEMENT PRACTICES ON ECONOMICS OF CULTIVATION

There was significant difference between treatments with regard to B:C ratio (Table 36). Highest B:C ratio of 1.46 was recorded by T_7 which was on par with 100 per cent inorganic treatment and all other INM treatments except T_8. B:C ratio for farmer's practice (1.18) was significantly less compared to INM treatments and the 75 to 100 per cent inorganic treatments. Fifty per cent substitution of inorganics with either FYM or crop residue significantly reduced the B:C ratio. Treatment T_1 with a B:C ratio less than one registered a net loss of Rs.12,629/-.

Table 35. Effect of integrated nutrient management practices on microbial count in soil

Treatments			Bacteria log cfu /g soil		Fungi log cfu / g soil		Actinomycetes log cfu / g soil		*Azospirillum* log cfu g^{-1} Soil	
	Kharif	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*
T_1	No fertilizers	No fert.	7.97	8.10	4.85	4.86	4.00	4.18	3.33	3.23
T_2	50% fertilizers	50% fert.	8.01	7.98	4.94	5.03	4.86	4.20	3.30	3.16
T_3	75% fertilizers	100% fert.	7.93	8.17	4.86	4.90	4.35	4.54	3.25	3.03
T_4	75% fertilizers	75% fert.	8.12	8.12	4.82	4.87	4.24	4.24	3.23	3.16
T_5	100% fertilizers	100% fert.	8.28	8.29	4.96	5.06	4.54	4.79	3.37	3.27
T_6	50% fert.+ 50% FYM	100% fert.	8.40	8.43	5.21	5.25	4.97	4.99	3.61	3.75
T_7	75% fert.+ 25% FYM	75% fert.	8.36	8.30	5.06	5.11	4.80	4.96	3.58	3.51
T_8	50% fert.+ 50% CR	100% fert.	8.39	8.44	5.14	5.26	4.81	4.96	3.54	3.55
T_9	75% fert.+ 25% CR	75% fert.	8.36	8.29	5.01	5.13	4.74	4.83	3.52	3.53
T_{10}	50% fert.+ 50% GM	100% fert.	8.38	8.46	5.18	5.23	4.83	4.84	3.63	3.50
T_{11}	75% fert.+ 25% GM	75% fert.	8.31	8.34	5.02	5.16	4.81	4.63	3.55	3.46
T_{12}	Farmers practice	FP	8.32	8.31	4.93	5.09	4.66	4.79	3.30	3.34
CD (0.05)			0.074	0.141	0.072	0.081	0.123	0.186	0.169	0.168

Table 36. Effect of integrated nutrient management practices on economics of cultivation

Treatments			Cost of cultivation	Total returns	Net returns	B:C ratio
	Kharif	*Rabi*				
T_1	No fertilizers	No fert.	168849.00	156220.00	-12629.00	0.93
T_2	50% fertilizers	50% fert.	178778.00	213920.00	35142.00	1.20
T_3	75% fertilizers	100% fert.	179034.00	231525.00	52491.00	1.29
T_4	75% fertilizers	75% fert.	181970.00	232129.00	50159.00	1.28
T_5	100% fertilizers	100% fert.	192251.00	270534.00	78283.00	1.41
T_6	50% fert.+ 50% FYM	100% fert.	188696.00	257942.00	69246.00	1.37
T_7	75% fert.+ 25% FYM	75% fert.	191960.30	280843.33	88883.03	1.46
T_8	50% fert.+ 50% CR	100% fert.	181555.00	244360.00	62805.00	1.35
T_9	75% fert.+ 25% CR	75% fert.	176973.70	250246.67	73272.97	1.41
T_{10}	50% fert.+ 50% GM	100% fert.	177809.30	249984.33	72175.03	1.41
T_{11}	75% fert.+ 25% GM	75% fert.	180711.69	254287.00	73575.31	1.41
T_{12}	Farmers practice	FP	185609.00	219506.67	33897.67	1.18
	CD (0.05)					0.109

Discussion

5. DISCUSSION

The Experimental findings emanating from the present investigation '*Impact of long term integrated nutrient management system on soil health and rice productivity*' conducted at Integrated Farming System Research Station, Karamana, during the year 2016-'17, with the objective of assessing the long term effect of substitution of inorganic fertilizers with different organics on soil physical, chemical and biological properties, soil organic carbon and to study their impact on rice productivity have been discussed in this chapter.

5.1 EFFECT OF INTEGRATED NUTRIENT MANAGEMENT PRACTICES ON YIELD ATTRIBUTES OF RICE

5.1.1 Number of Total and Productive Tillers per Hill

Tillering is an important trait for grain production and is thereby a deciding factor of rice yield. All the organic substituted treatments (T_6 to T_{11}) gave total number of tillers statistically on par with the 100 percent inorganic treatment (T_5) during *kharif*, with the treatment T_{11} (15.13) giving the highest value (Fig. 3). During *rabi* also the same trend was observed, with the INM treatments and T_5 giving total tillers on par with each other and the highest total number of tillers being recorded for T_9 (13.87).

Application of organics in combination with inorganics improves the organic carbon content of these treatments (Table 24) and, enhanced the availability of nutrients especially nitrogen (Table 25) which plays a vital role in cell division. The more solubility of phosphorus also stimulates root growth and tillering. Moreover, the organic sources offer more balanced nutrition to the plants, including micro nutrients which favourably affect the total number of tillers. The nutrients are released slowly in a phased manner so that the effect of organic matter substitution is available to the succeeding *rabi* crop also. Similar results have been obtained by Miller (2007) and Mirza *et al*. (2010).

The highest number of productive tillers per hill (Fig. 4) was observed for the integrated treatments T_7 (13.93) and T_9 (13.13) during *kharif* and *rabi* respectively and were on par with all other INM treatments and the 100 per cent inorganic treatment (T_5). A reduction in nutrient supply through inorganic fertilizers did not affect adversely the number of productive tillers since it was compensated by nutrient release from the applied organics. Continuous and controlled supply of nutrients particularly nitrogen, proportionate to the requirement of the crop at critical growth stages might be the reason for more number of productive tillers (Jeet *et al.*, 2014).

Among the organic manure substituted treatments, numerically lesser number of total and productive tillers was observed for the crop residue substituted plots compared to FYM and green manure substitution, during both *kharif* and *rabi*. This might be due to the slow decomposition rate of the applied paddy husk and stubbles and the slower rate of release of nutrients to the crop compared to FYM and green manure. Thus there is mismatch between crop nutrient requirement and supply from organic sources which limits plant growth, especially during *kharif* season.

5.1.2 Number of Grains per Panicle

The number of grains per panicle contributes materially towards ultimate grain yield. The highest number of grains per panicle (Fig. 5) was observed when fertilizers were substituted with FYM at 25 percent (115.28) during *kharif* and with crop residue (100.66) at 50 per cent during *rabi.* This was on par with all other INM treatments and the 100 per cent inorganic treatment. The improvement in number of grains per panicle by the substitution of inorganic fertilizers with organic sources might be due to the improved metabolic activities leading to heightened translocation of metabolites as a result of adequate and balanced supply of essential nutrient elements and also due to their increased uptake. Similar conclusions were also made by Siavoshi *et al.* (2011).

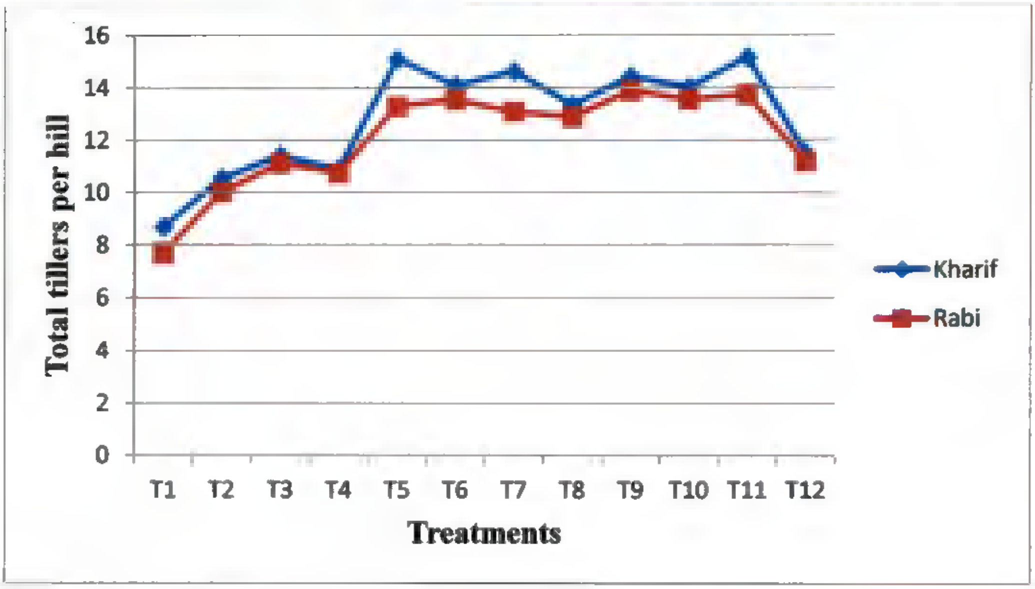

Fig. 3. Effect of integrated nutrient management practices on total tillers per hill

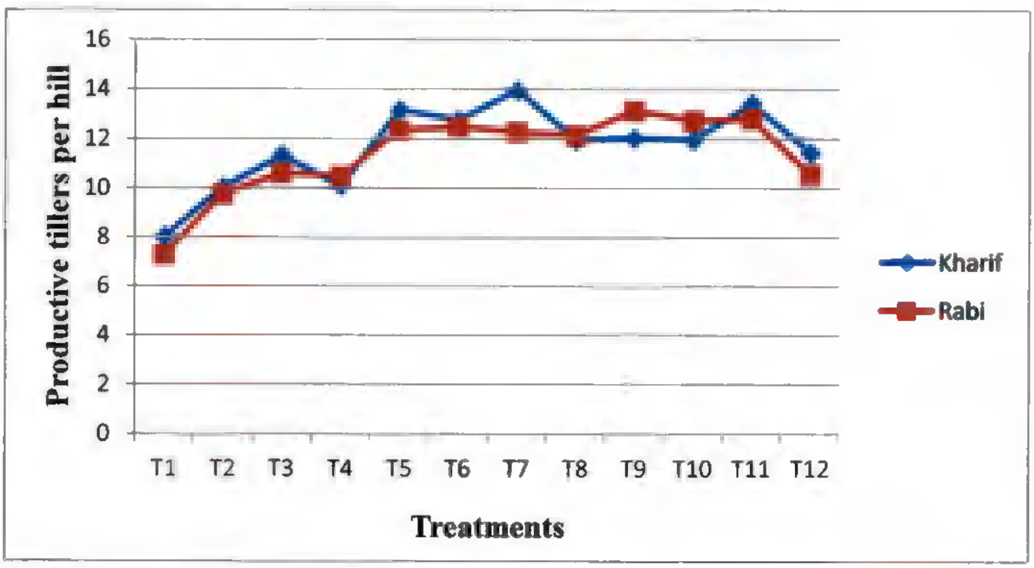

Fig.4. Effect of integrated nutrient management practices on productive tillers per hill

Chemical fertilisers provide nutrients which are readily soluble in soil solution and there by immediately available to plants. On the contrary, the nutrient availability from organic sources is microbially mediated, which is slow and steady and leads to improved physical conditions of the soils. This might have resulted in the numerical reduction in number of grains per panicle for the INM treatments, especially at 50 per cent substitution during *kharif.* During *rabi*, this effect was reversed, probably due to the improved physical, chemical and microbial conditions of the soil due to higher organic manure addition in *kharif.* Similar results were also reported by Seshadri *et al.* (2005) and Mirza *et al.* (2010).

5.1.3 Per cent Filled Grains

The 50 per cent FYM substituted treatment (T_6) showed the highest per cent filled grains (Fig. 6) during *kharif* (89.3%) and *rabi* (87.12%). It was significantly superior to the 100 per cent inorganic treatment during *kharif* and was found to be on par with all other INM treatments and the 100 per cent inorganic treatment during *rabi*. Thus, though the total number of grains per panicle was comparatively less for the 50 per cent organic substituted treatments, grain filling was better for treatments receiving higher organic manure addition. This enhancement in filled grain percentage obtained might be the result of proper partitioning of large amount of carbohydrates and mobile nutrients from the source to the sink. The results are in agreement with the findings of Shiralipur *et al.* (1992) and Kumar and Singh (2006).

The per cent filled grains showed an increasing trend with increase in the levels of RDN as fertilizers alone. It might be due to the ready availability of nutrients from the inorganic sources.

5.1.4 Thousand Grain Weight

The different integrated nutrient management practices failed to exert any significant influence on the thousand grain weight (Table 5). Similar results have

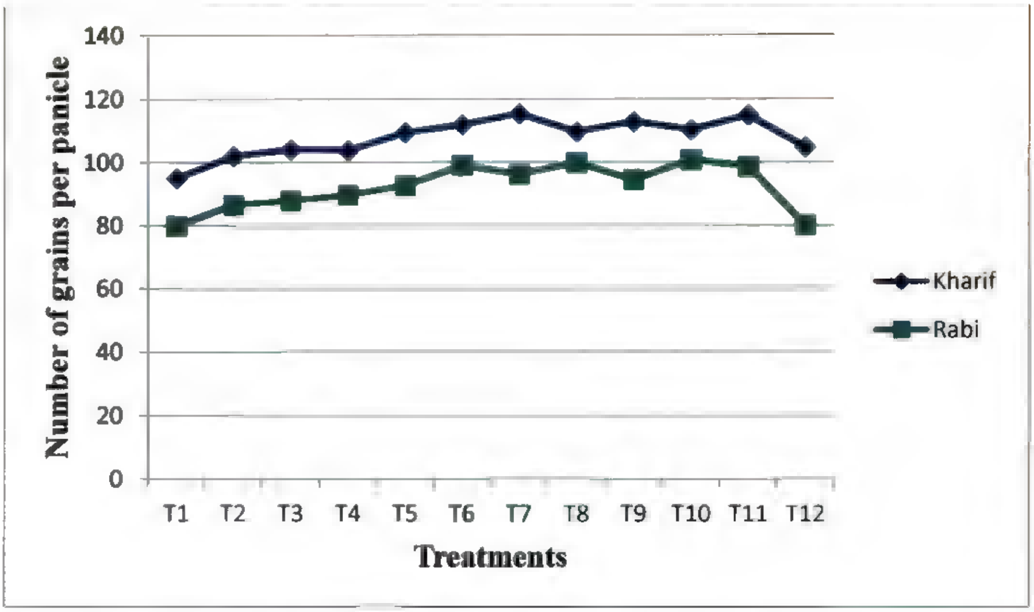

Fig. 5. Effect of integrated nutrient management practices on number of grains per panicle

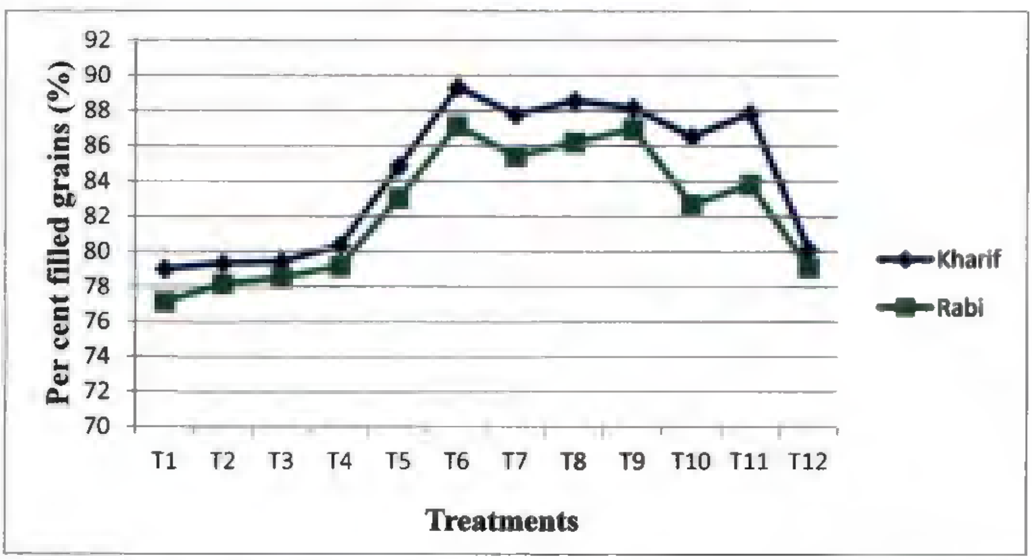

Fig. 6. Effect of integrated nutrient management practices on per cent filled grains

been reported by Kundu *et al.* (2010), who observed non-significant differences in thousand grain weight in response to the integrated use of organics and chemical fertilizers.

5.2 EFFECT OF INTEGRATED NUTRIENT MANAGEMENT PRACTICES ON ROOT PARAMETERS

5.2.1 Root Dry Weight

Root dry weight (Table 6) increased with increase in nutrient supply to the crop either through inorganics or through inorganics substituted with organics at 25 or 50 per cent by any of the sources viz. FYM, crop residues or green manure. Integrated use of fertilizers and manures markedly increased the root dry weight which was on par with the 100 per cent inorganic treatment. 25 per cent FYM substitution recorded the highest root dry weight during *kharif* (30.75 g $hill^{-1}$) while 50 per cent crop residue substitution (25.97 g $hill^{-1}$) was superior during *rabi*. Incorporation of organic manure in the soil can bring beneficial effects on crop root growth by improving the physical and chemical environments of rhizosphere soil. The increase in root dry weight as a result of integrated use of mineral fertilizers and organic manures was also reported by Rakesh *et al.* (2001) and Mandal *et al.* (2003).

5.2.2 Root Volume

Root length and root volume (Table 6) were not significantly influenced by the various treatments. But there was an increase in values for the organic manure applied treatments compared to control and the treatments receiving inadequate nutrients. This might be due to the increased root proliferation under better soil conditions especially reduction in bulk density in organic manure applied plots.

5.3 EFFECT OF INTEGRATED NUTRIENT MANAGEMENT PRACTICES ON GRAIN AND STRAW YIELD OF RICE

5.3.1 Grain Yield

Application of manures integrated with chemical fertilizers had stimulatory effect on grain yield of rice during *kharif* and *rabi* (Fig. 7). During *kharif*, substitution with 25 per cent FYM resulted in the highest grain yield (5770.00 kg ha^{-1}) which was on par with T_{11} receiving green manure as the organic substitute at 25 per cent. Substitution of RDN to the extent of 50 per cent by FYM (T_6) or green manure (T_{10}) and 25 per cent by crop residue (T_8) or green leaf manure (T_{11}) were on par and comparable with the 100 per cent inorganic treatment (T_5). The higher yield obtained might be attributed to steady supply of nutrients throughout the crop growth period coupled with better assimilation of nutrients. It can also be due to the increased microbial population and activities of hydrolytic enzymes favouring conducive physical environment leading to better root activity and higher nutrient absorption. This results in better plant growth and superior yield attributes responsible for high yield. Similar results were reported by Selvi *et al.* (2005) and Mishra *et al.* (2008). Among the different organic sources, FYM proved to be better in increasing the grain yield probably due to better efficiency in supplying nutrients especially secondary and micronutrients, leading to improved growth and dry matter partitioning.

Substitution of 50 per cent RDN by crop residue (T_8) gave grain yield significantly less than that obtained from 50 per cent FYM (T_6) or green manure (T_{10}) substitution. The better decomposition rate of the applied FYM and green leaf manure and the faster rate of release of nutrients to the crop compared to crop residue might have contributed to better yield (Thakur *et al.*, 2011).

Grain yield obtained from the farmers' practice was also significantly less than all INM treatments (T_6 to T_{11}) and the inorganic treatment receiving 75 to 100 per cent recommended dose of nutrients (T_4 and T_5). The inadequate application of P and K and the resultant imbalanced nutrition can cause a disruption in the normal metabolic activities leading to reduced grain productivity.

During *rabi*, the highest grain yield (4950.00 kg ha^{-1}) was registered by the treatment receiving 50 per cent crop residue substitution whereas the corresponding grain yield for *kharif* was comparatively less though on par with the 100 per cent inorganics. Substitution of slow to decompose crop residues with wide C:N ratio for inorganics, caused yield reduction during *kharif* probably due to prolonged immobilization of soil available nutrients. Such temporary locking up of nutrients got eliminated during *rabi*, and hence grain yields for T_8 and other INM treatments were on par.

Highest system productivity (Fig. 7) was recorded for the treatment T_7 (10560.00 kg ha^{-1}) during *kharif* and did not differ significantly from other integrated treatments. Significant increase in system productivity with the substitution of inorganic fertilizers by various organic manures, is due to improved yield contributing factors which is the ultimate outcome of enhanced physico-chemical and biological properties of the soil due to the added organic manures. All organic sources were on par in improving the system productivity though minor variations were noticed during the two crop seasons.

5.3.2 Straw Yield

Among the treatments, significantly higher straw yield (Fig. 8) during *kharif* (8201.67 kg ha^{-1}) was registered by T_9 receiving 25 per cent crop residue substitution though the grain yield for this treatment was slightly less. This might be due to slow mineralisation of the difficultly decomposable paddy husk and straw leading to comparatively less available nutrients during the critical stages than FYM and green leaf manure. Yield of straw was on par for all INM treatments other than T_9 and was higher for 25 per cent substitution than 50 per cent for all the organic sources. Increase in straw yield compared to all inorganic treatments might be due to the favourable effect of integrated nutrient management on the proliferation of roots, microbial activity and soil physico-chemical properties, thereby increasing the uptake of plant nutrients from the soil and ultimately the vegetative growth of plants. Similar results were also obtained by Sarwar (2008) and Sohel *et al*. (2016). Integration of organic manures and chemical fertilizers has an additional benefit contributed by satisfying the initial nutrient requirement from inorganics and from slowly mineralising organic substitutes during later growth stages resulting in better crop performance in terms of growth and yield. Similar findings were also reported by Roy *et al.* (2001) and Sarker *et al*. (2004).

Application of nutrients either alone or along with organic manures caused a significant increase in straw yield of rice during *rabi* over control with the treatment substituting 50 per cent RDN through FYM giving the highest value (5783.33 kg ha^{-1}) during *rabi* (Table 8). Organic manures work like slow release fertilizers and less than 40% N, 30% P and 75% K becomes available to the immediate crop and the rest of these plant nutrients become available to the subsequent crops due to residual effect (Gaur, 1984). Inadequate nutrient application for T_2 to T_4 and imbalanced nutrient applied to T_{12} (Farmers' practice) produced significantly lesser straw yields compared to the treatments receiving recommended dose of nutrients either through inorganics or through inorganics substituted by organics to the extent of 25 to 50 per cent. The omission of chemical fertilizers and organic manures in control resulted in low yield due to continuous mining of nutrients.

Straw system productivity (Fig. 8) was highest for treatment T_9 (13358.33 kg ha^{-1}) during *rabi* and did not differ significantly from the other integrated treatments. The improvement in growth and yield attributes due to combined application of fertilizers and organic manures might be responsible for the increase in system productivity.

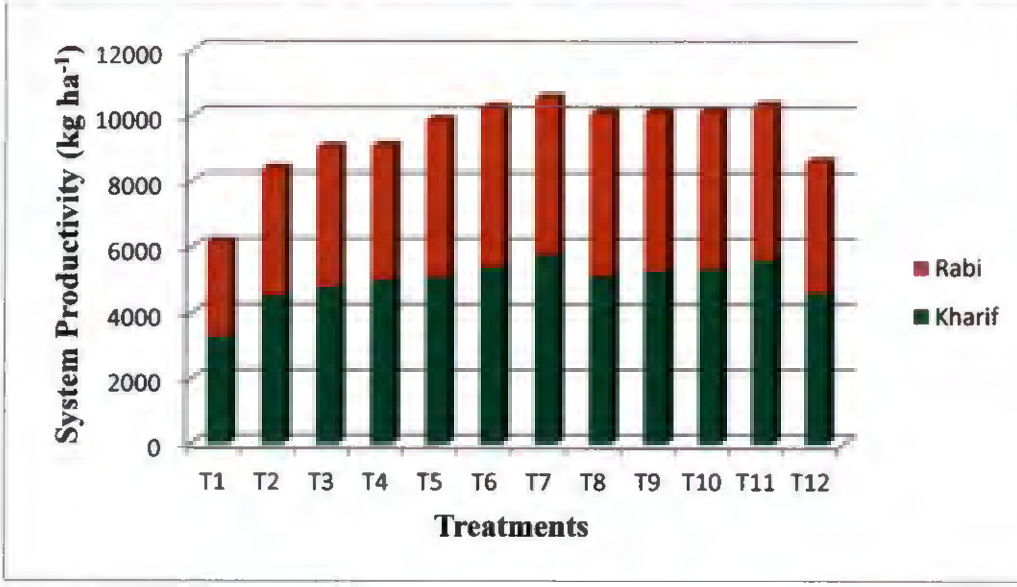

Fig. 7. Effect of integrated nutrient management practices on grain system productivity

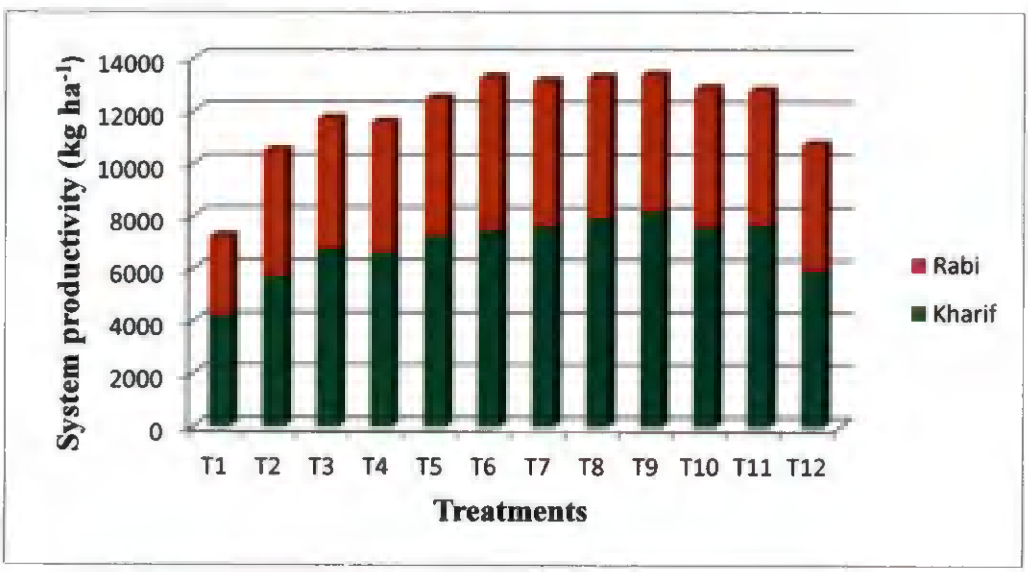

Fig. 8. Effect of integrated nutrient management practices on straw system productivity

5.4 EFFECT OF INTEGRATED NUTRIENT MANAGEMENT PRACTICES ON NUTRIENT UPTAKE BY GRAIN AND STRAW

5.4.1 Nitrogen

Integration of inorganics with organics significantly increased the N uptake of the crop in comparison to application of organics alone during both *kharif* (Fig. 9) and *rabi* (Fig. 10). Substitution of 25 per cent inorganics through FYM (T_7) resulted in the highest grain N uptake (64.89 kg ha^{-1}) during *kharif* which was on par with all other integrated treatments. The uptake of N by grain for the 25 per cent FYM and green leaf manure substituted plots were also significantly higher than the 100 per cent inorganic treatment. The highest grain N uptake during *rabi* (57.69 kg ha^{-1}) was observed for treatment T_{10} where 50 per cent RDN was substituted by green manures and was on par with all other INM treatments and the 100 per cent inorganic treatment. Highest straw N uptake during *kharif* and *rabi* was recorded for the 50 per cent FYM substituted treatment (T_6). Steady supply of N over a longer period of time from the organic sources and the stimulating effect of nitrogen on soil microbial activity and improvement of soil physical environment favoured increased N uptake in the combination treatments. The higher dry matter production as well as nitrogen concentration with combined use of organics and inorganics might have also contributed to better uptake of nitrogen. Similar results have also been reported by Laxminarayana (2006) and Mitra *et al*. (2010).

5.4.2 Phosphorus

Highest grain P uptake was noticed for substitution of 25 per cent N through FYM (T_7) during *kharif* (Fig. 11) and substitution of 50 percent N through FYM (T_6) during *rabi* (Fig. 12). Straw P uptake during *kharif* and *rabi* was highest for the combination treatments T_9 (25% crop residue substitution) and T_6 (50% FYM substitution) respectively. The solubilizing action of organic acids produced during decomposition of farmyard manure and due to stimulated

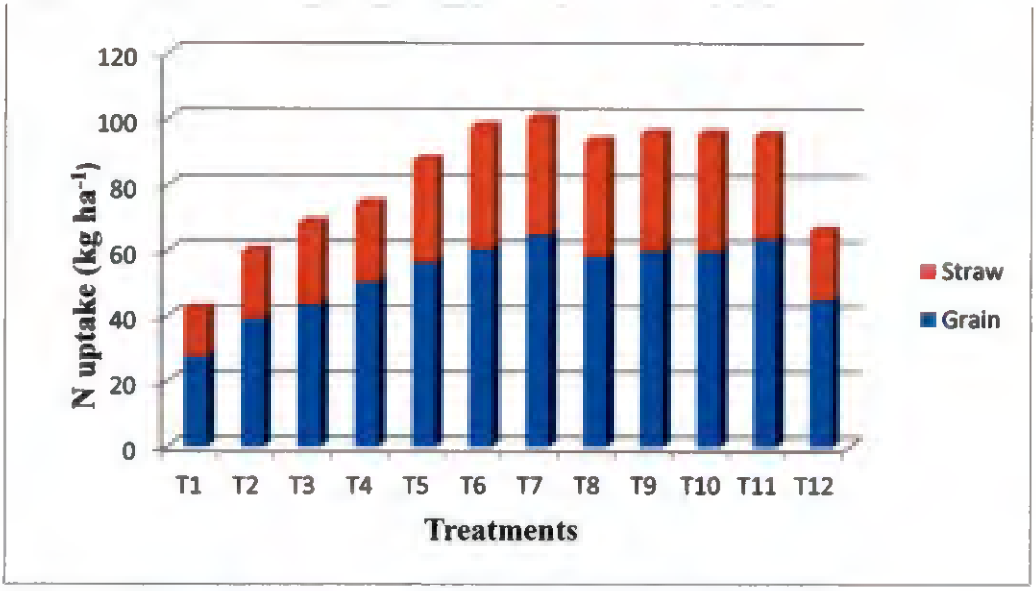

Fig. 9. Effect of integrated nutrient management practices on N uptake during *kharif*

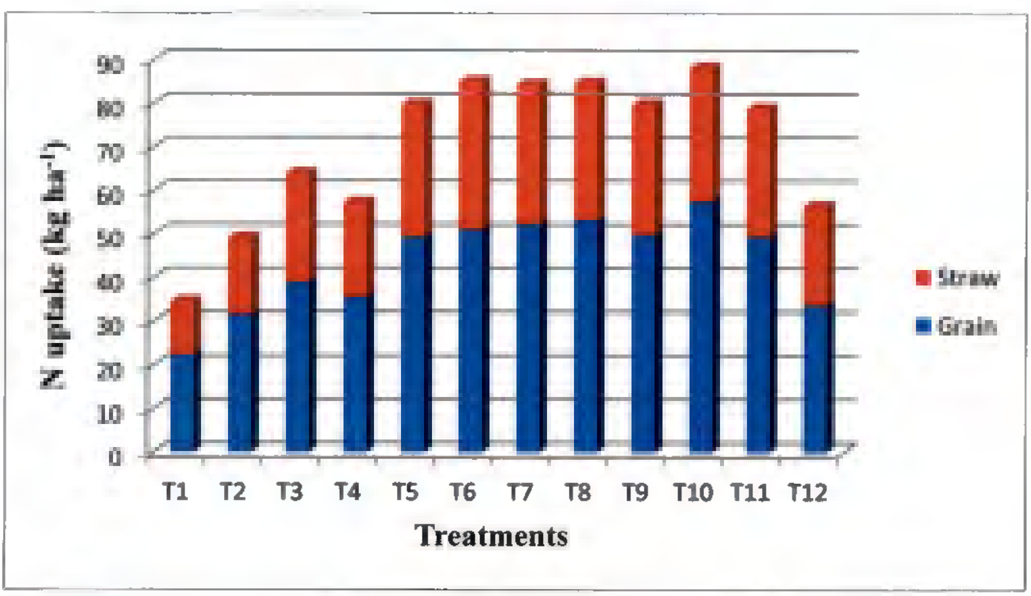

Fig. 10. Effect of integrated nutrient management practices on N uptake during *rabi*

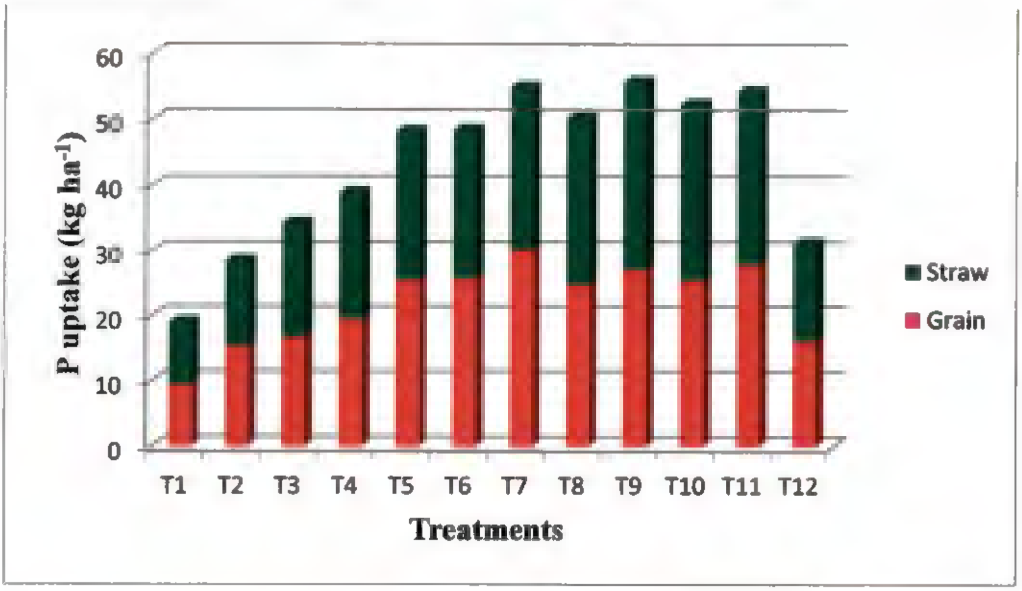

Fig. 11. Effect of integrated nutrient management practices on P uptake during *kharif*

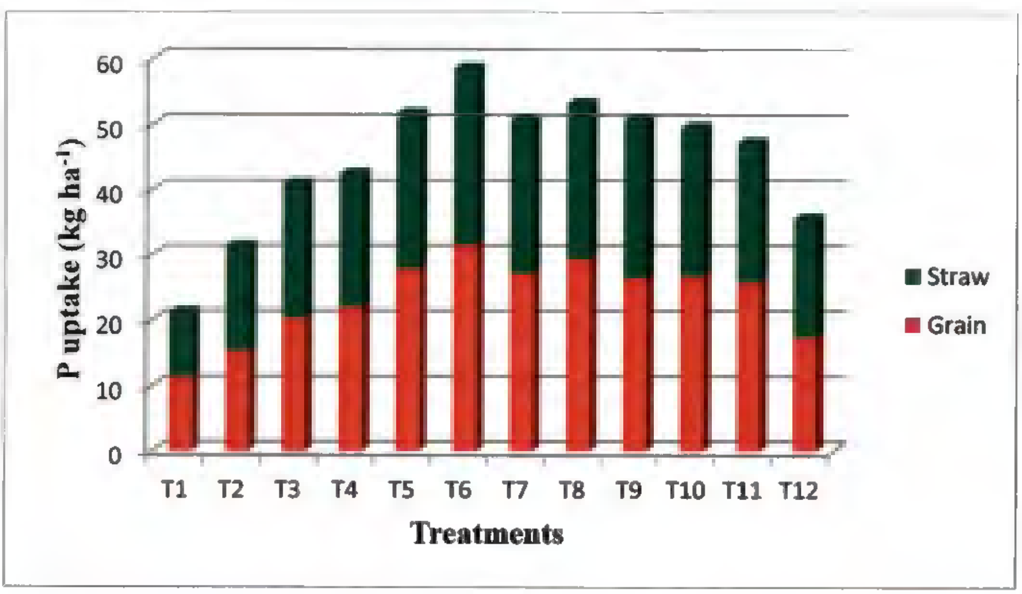

Fig. 12. Effect of integrated nutrient management practices on P uptake during *rabi*

microbial growth in soil might have increased the release of native P, and favoured root growth which had finally led to increased P uptake. Incorporation of organics like FYM, crop residues or green leaf manures along with inorganic P increased the availability of P to the crop and also enhanced the mobility of P. Such results corroborates with the findings of Dwivedi *et al.* (2007) and Bahadur *et al.* (2012).

5.4.3 Potassium

Potassium uptake by grain during *kharif* (Fig. 13) varied from 13.68 kg ha^{-1} in control to 31.27 kg ha^{-1} in T_6 (50% RDN as fertilizers + 50% as FYM during *kharif* and 50% RDN as fertilizers during *rabi*). All INM treatments (T_6 to T_{11}) gave uptake values for K on par with each other. During *rabi*, the highest grain K uptake was noticed for T_{11} (22.65 kg ha^{-1}) which was on par with all other INM treatments and the inorganic treatments T_5 and T_4 (Fig. 14).

All the INM treatments were on par with T_8 which recorded the highest straw K uptake (91.76 kg ha^{-1}) during *kharif*. Straw K uptake during *rabi* ranged from 25.67 kg ha^{-1} in control (T_1) to 58.35 kg ha^{-1} in T_7 (75% RDN as fertilizers and 25% as FYM during *kharif* and 75% RDN as fertilizers during *rabi*). Treatment T_7 was found to be statistically on par with all other INM treatments and the 100 per cent inorganic treatment. The increased uptake of K by rice over and above the total K application may be ascribed to the release of K from the K bearing minerals and to the organic acids produced during decomposition of applied organic resources. Similar results were also observed by Mohapatra *et al.* (2008).

Thus, recommended doses of N, P, and K fertilizers (T_5) resulted in lower uptake of these nutrients when compared to conjunctive use of 25 to 50 per cent RDN substituted either by FYM, crop residues or green manure. Lower nutrient recovery of the added chemical fertilizers from the 100 per cent inorganic N, P and K treatment may probably be due to loss of these nutrients through leaching

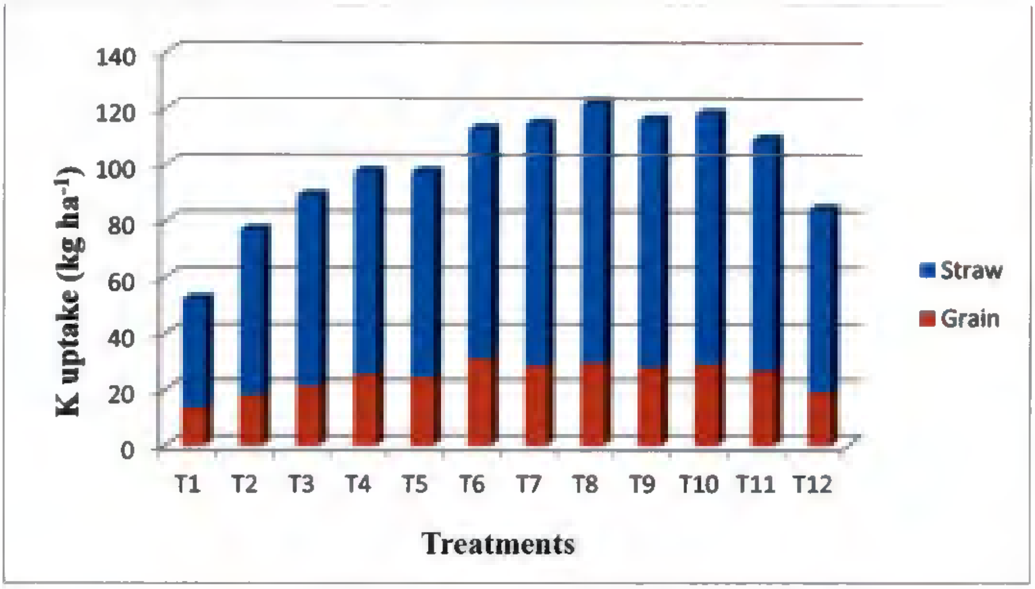

Fig. 13. Effect of integrated nutrient management practices on K uptake during *kharif*

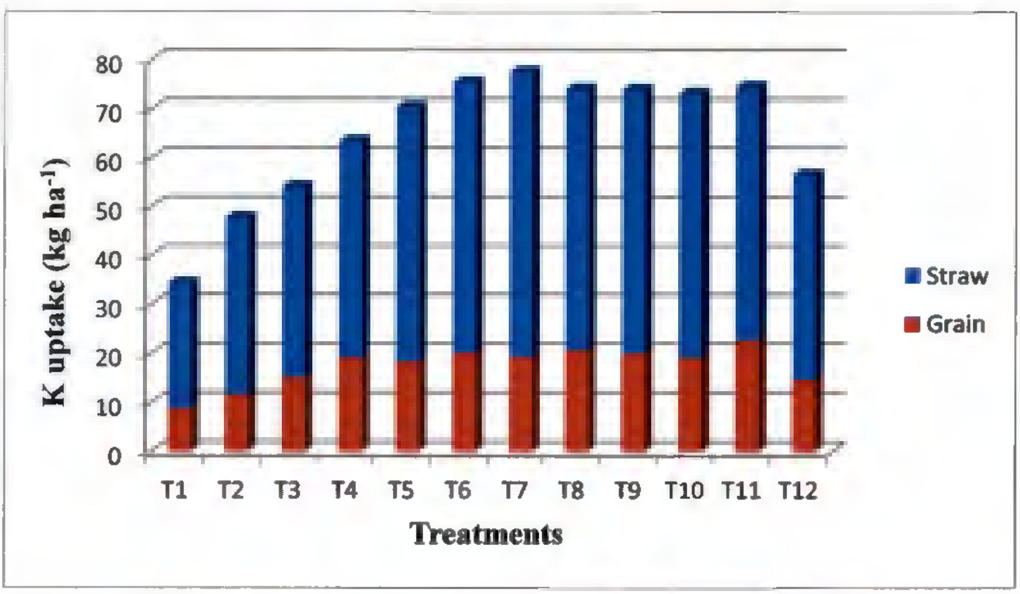

Fig. 14. Effect of integrated nutrient management practices on K uptake during *rabi*

and fixation in the coarse textured acid upland soil. On the other hand, higher nutrient uptake from the INM treatments may be due to enhanced nutrient retention and reduced fixation capacity of soils (Singh *et al.*, 2011). The lower NPK uptake by farmer's practice and the treatments T_1 to T_4, is due to no or inadequate nutrient supply. The favourable effect of incorporation of FYM in soil for higher NPK uptake by rice was also reported by Sharma *et al.* (2001).

5.4.4 Calcium

Grain Ca uptake during *kharif* (Fig. 15) was remarkably higher for the FYM substituted treatments, either at 50 or 25 per cent, followed by green manure and crop residue. During *rabi* also grain uptake of calcium was the highest in treatment T_{10} (4.75 kg ha^{-1}) followed by T_6 (4.57 kg ha^{-1}) (Fig. 16). During *kharif*, the highest straw calcium uptake by T_7 was on par with all other INM treatments. Similar increase in uptake by rice due to combined application of inorganic fertilizers and organics was reported by Singh *et al.* (2009) and Gogoi *et al.* (2010) in an Inceptisol of Assam. The treatment effects, though significant in the case of straw calcium uptake during *rabi*, was not consistent.

5.4.5 Magnesium

The maximum grain Mg uptake (Fig. 15) during *kharif* was given by treatment T_6 and was on par with all INM treatments and was significantly higher than the 100 per cent inorganic treatment (T_5). During *rabi*, grain magnesium uptake (Fig. 16) was in general on par for all INM treatments and the 100 per cent inorganic treatment (T_5). The straw Mg uptake during *kharif* was significantly higher for the INM treatments compared to the 100 per cent inorganic treatment (6.60 kg ha^{-1}), with the maximum value recorded for T_8 (8.18 kg ha^{-1}). The highest magnesium uptake by straw during *rabi* was also for the treatment T_6 (5.42 kg ha^{-1}) which was on par with all other INM treatments and the 100 per cent inorganic treatment (T_5). The increase in Mg uptake in the organic manure substituted plots may be due to the extra amount of nutrients supplied by these

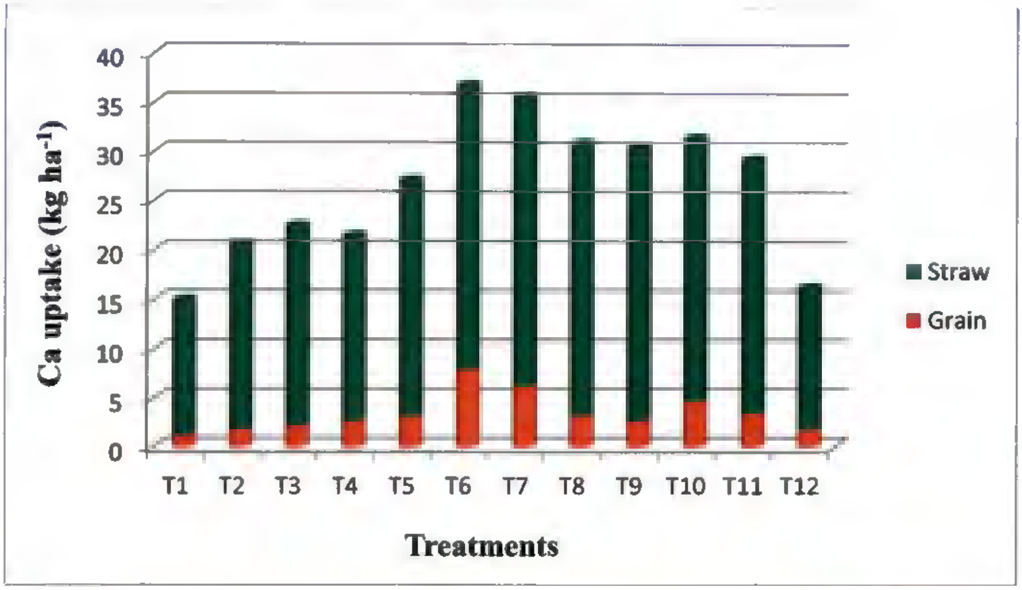

Fig. 15. Effect of integrated nutrient management practices on Ca uptake during *kharif*

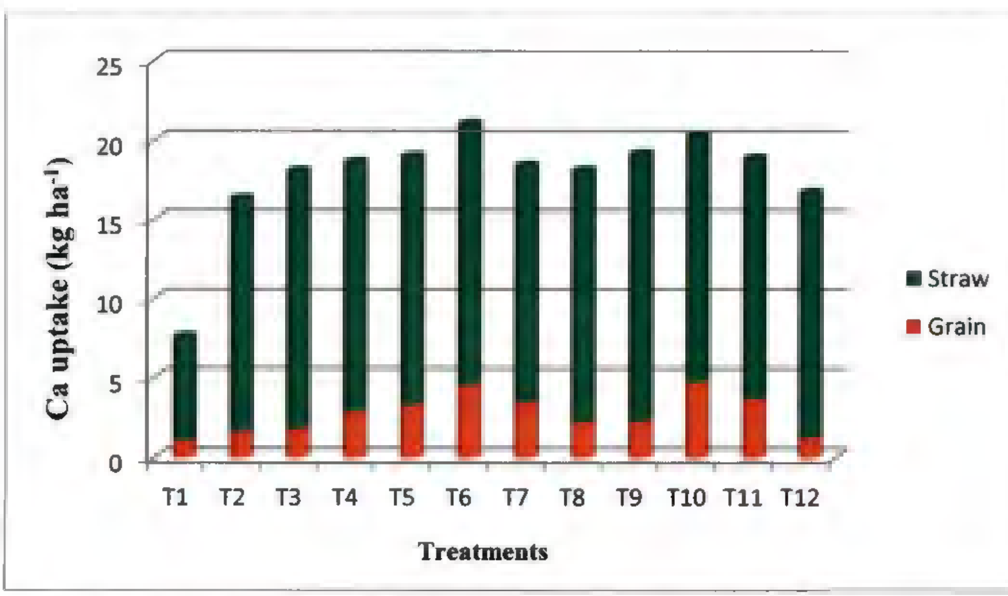

Fig. 16. Effect of integrated nutrient management practices on Ca uptake during *rabi*

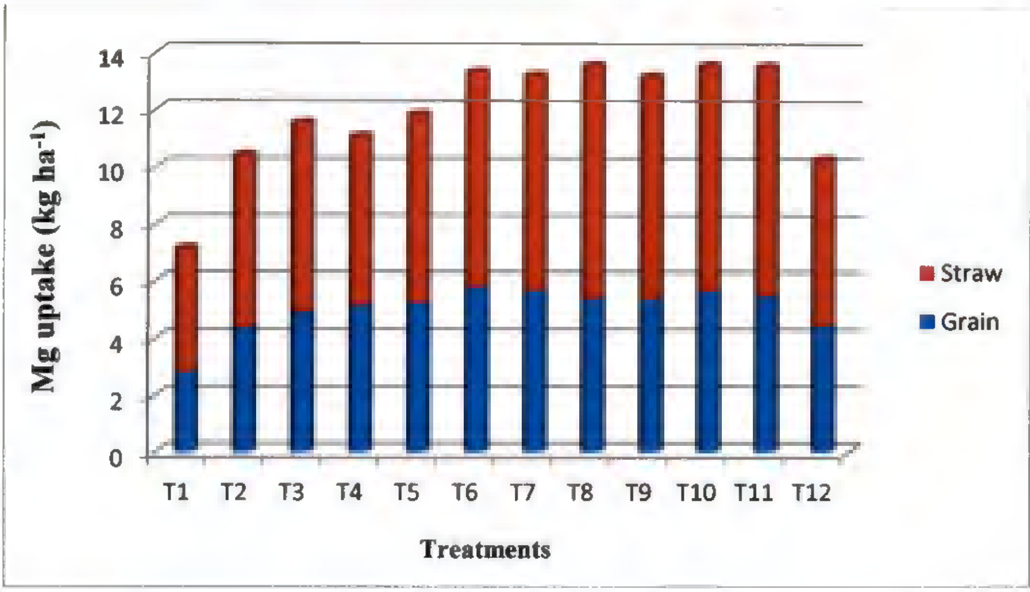

Fig. 17. Effect of integrated nutrient management practices on Mg uptake during *kharif*

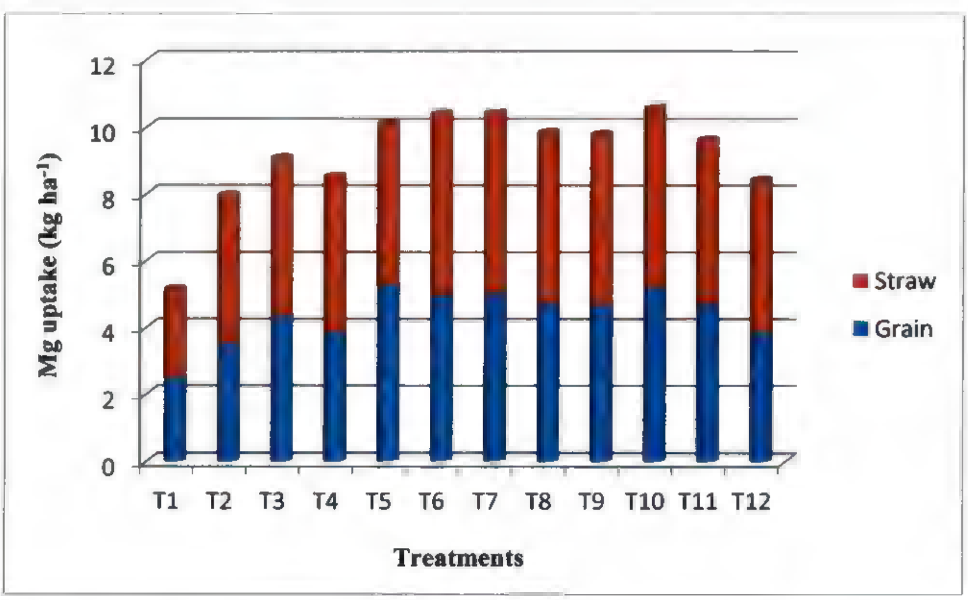

Fig.18. Effect of integrated nutrient management practices on Mg uptake during *rabi*

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organics and the conducive physical environment provided, which helped in better root growth and absorption of nutrients from the native as well as applied sources (Bharadwaj and Omanwar, 1992).

5.4.6 Iron

Nutrient management practices significantly influenced the uptake of iron by grain during *kharif* (Fig. 19) with the maximum value recorded in the 25 per cent FYM substituted treatment T_7 (1.95 kg ha^{-1}). Grain iron uptake during *rabi* (Fig. 20) was also highest for the 50 per cent FYM substituted treatment T_6 (2.04 kg ha^{-1}). Straw iron uptake during *kharif* was the highest for the 25 per cent green manure substituted T_{10} (6.18 kg ha^{-1}) and was on par with all other integrated treatments. During *rabi,* straw iron uptake was highest in the integrated treatment T_9 (4.68 kg ha^{-1}) which was on par with all other INM treatments and the 100 per cent inorganic treatment (T_5). Thus organic substitution increased the iron content and ultimately iron uptake by the crop. This may be due to the formation of organic chelates, which decreased the susceptibility of the element to adsorption, fixation and precipitation resulting in their enhanced availability and thereby uptake. Kher (1993) and Chandel *et al.* (2013) also reported similar results.

5.4.7 Manganese

Grain Mn uptake during *kharif* was not significantly influenced by the various treatments (Fig. 21). During *rabi*, though the treatment effects were significant, none of the integrated treatments showed any consistent increase over the inorganic treatments (Fig. 22). The highest value was recorded for T_7 (0.034 kg ha^{-1}) receiving 25 per cent N substituted with FYM. Integrated treatments had significant effect on straw manganese uptake during *kharif* with the highest value for T_8 (0.331 kg ha^{-1}) which was on par with T_6 and T_9. FYM substitution either at 50 or 25 per cent recorded the highest straw Mn uptake during *rabi*. The improved soil physico-chemical properties due to organic manure addition and availability of Mn at a slow rate for longer time with the use of organics might be responsible

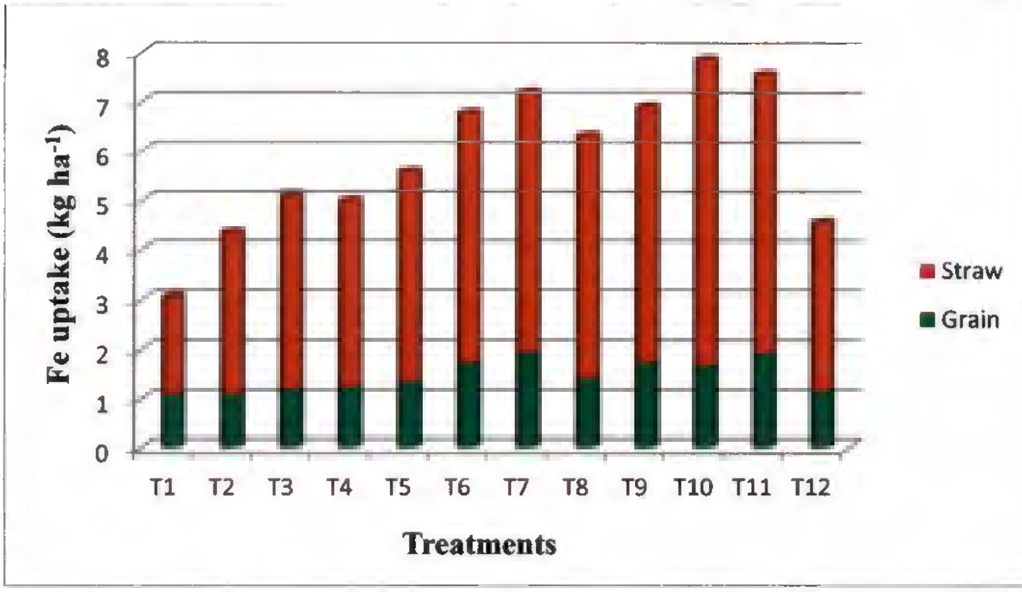

Fig.19. Effect of integrated nutrient management practices on Fe uptake during *kharif*

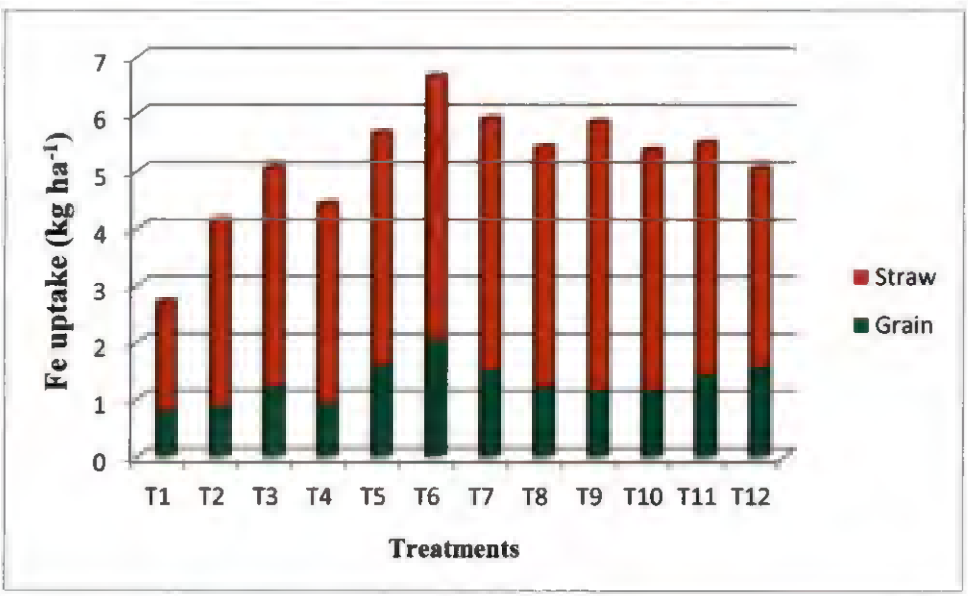

Fig. 20. Effect of integrated nutrient management practices on Fe uptake during *rabi*

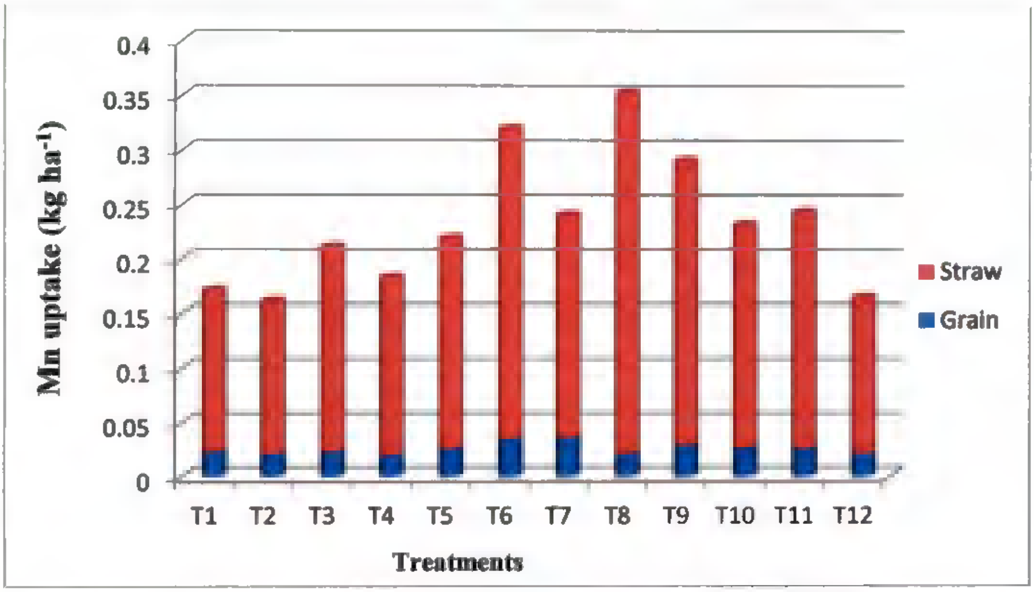

Fig. 21. Effect of integrated nutrient management practices on Mn uptake during *kharif*

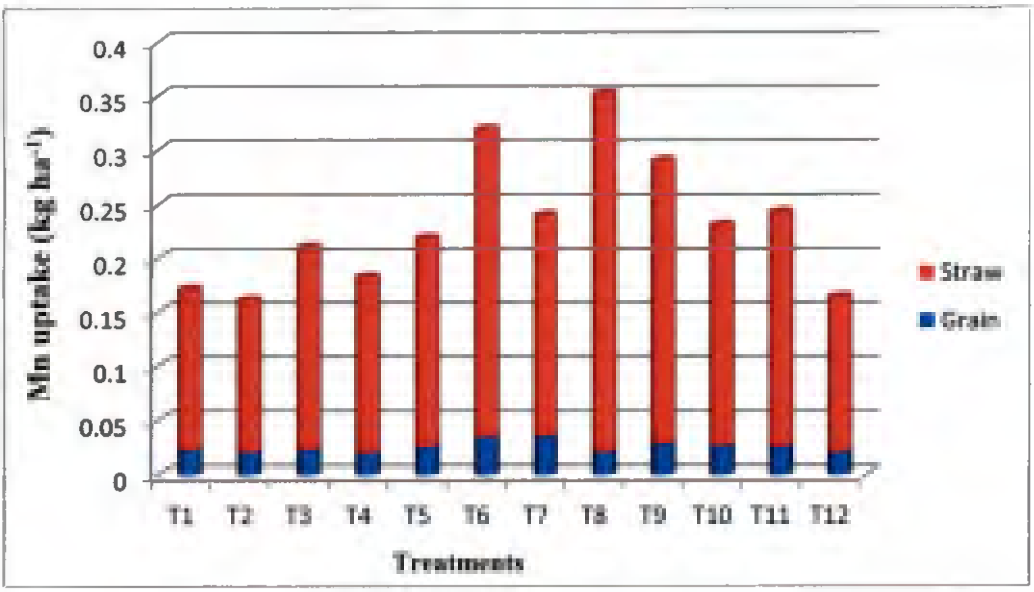

Fig. 22. Effect of integrated nutrient management practices on Mn uptake during *rabi*

for higher uptake of Mn. Similar results have previously been reported by Dhaliwal and Walia (2008).

5.4.8 Copper

The different treatments did not show significant influence on copper uptake by grain during *kharif* (Fig. 23). During *rabi*, T_{10} with 50 per cent green manure substitution recorded the highest grain copper uptake (0.062 kg ha^{-1}) which was in general on par with all INM treatments (Fig. 24).. Highest straw copper uptake during *kharif* was reported for T_8 (0.102 kg ha^{-1}) which was on par with T_5 and all other INM treatments except T_{10}. The copper uptake by straw during *rabi* was highest for T_{10} which might be due to higher supply of copper through enhanced availability from the soil due to incorporation of organics. This was in line with the finding of Singh *et al.* (2013). The chelating action of organic compounds released during decomposition of FYM, crop residue and green manure, might have increased the availability of copper by preventing fixation, oxidation, precipitation and leaching.

5.4.9 Zinc

FYM substitution either at 50 percent N (0.159 kg ha^{-1}) or at 25 per cent (0.150 kg ha^{-1}) registered significantly higher grain zinc uptake during *kharif* (Fig. 25). The uptake of zinc by grain during *rabi* was not significantly influenced by the various nutrient management practices (Fig. 26). Zinc uptake by rice straw during *kharif* was higher for the integrated treatments (T_6 to T_{11}) which were on par with each other. The 50 per cent N substitution through any of the organic sources showed higher values over 25 per cent substitution. Straw zinc uptake during *rabi* was higher for the FYM substituted treatments. Treatment T_6 recorded the highest straw zinc uptake (0.444 kg ha^{-1}) during *rabi* and was on par with 25 per cent N substitution through FYM or crop residue and 50 per cent N with green manure. These approaches are in concurrence with the findings of Lal and Mathur

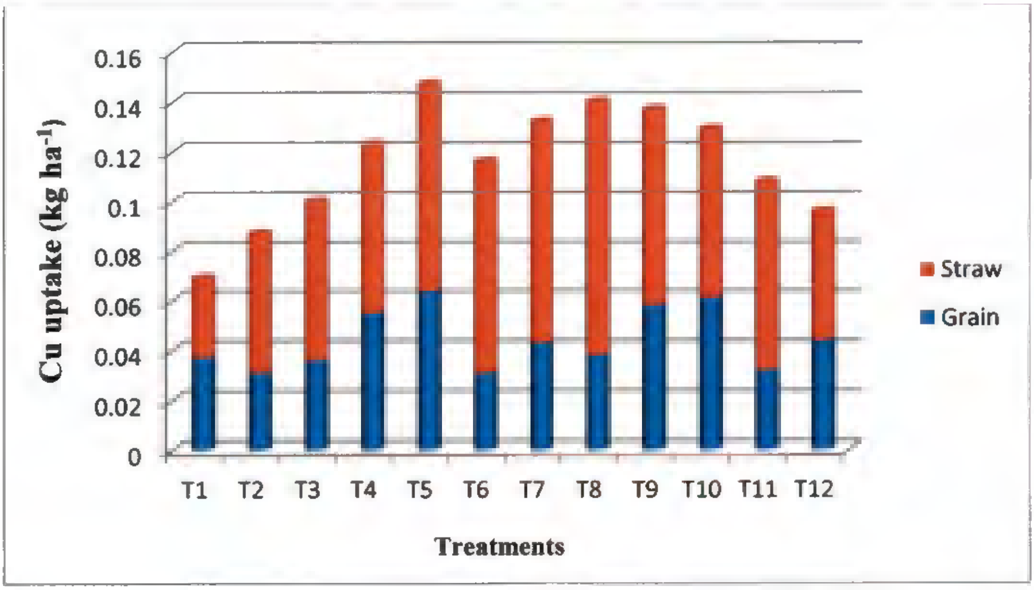

Fig. 23. Effect of integrated nutrient management practices on Cu uptake during *kharif*

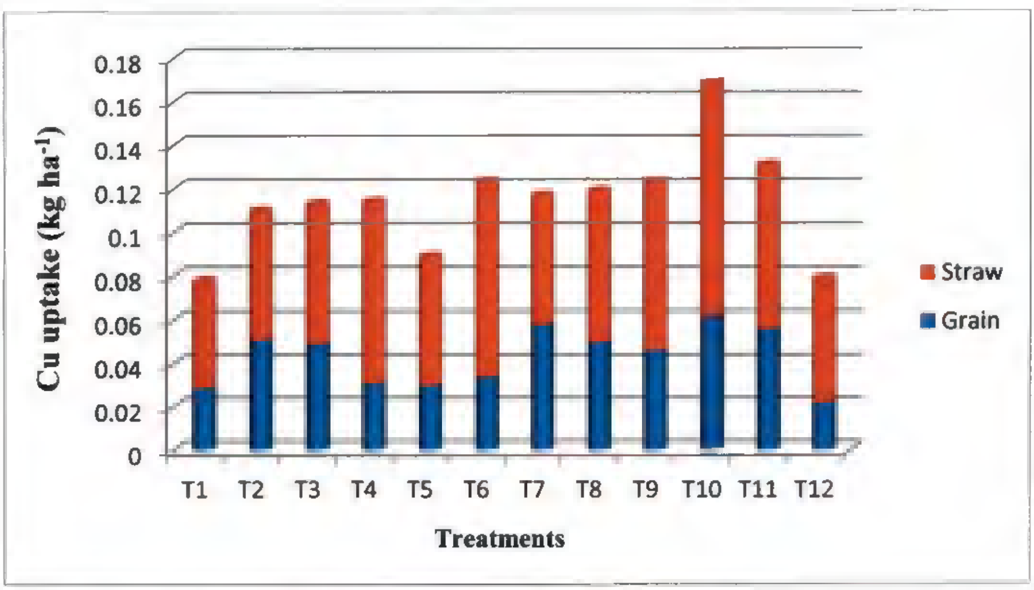

Fig. 24. Effect of integrated nutrient management practices on Cu uptake during *rabi*

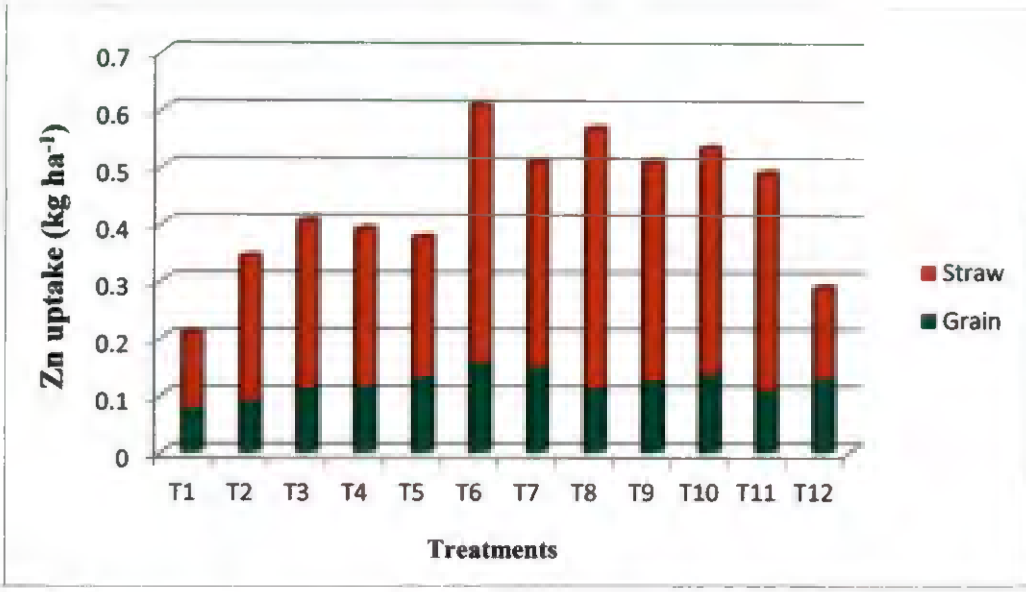

Fig. 25. Effect of integrated nutrient management practices on Zn uptake during *kharif*

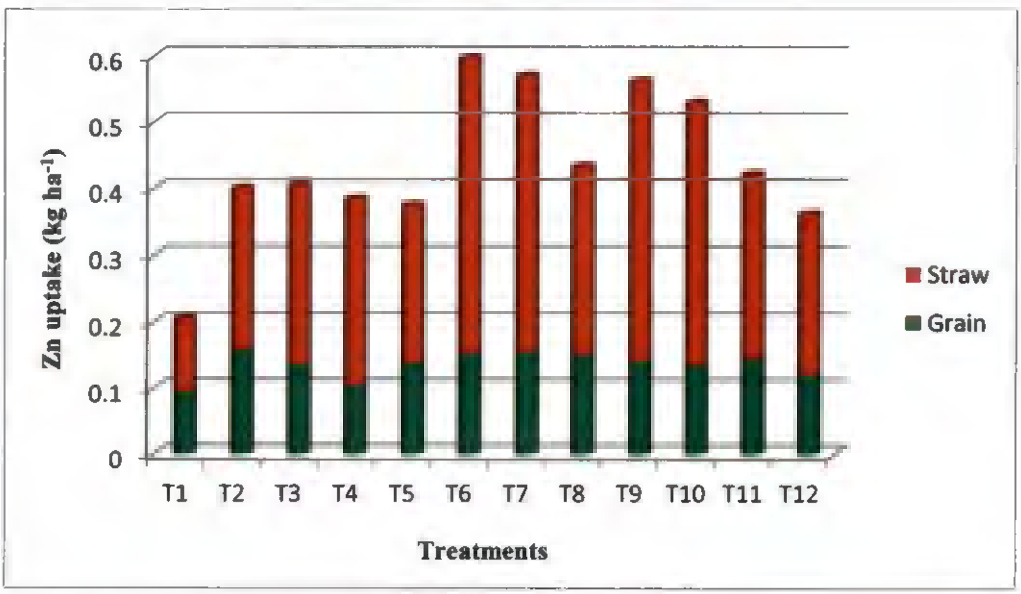

Fig. 26. Effect of integrated nutrient management practices on Zn uptake during *rabi*

(1989) and Meena *et al.* (2008) who reported increased zinc uptake due to organic substitution.

5.4.10 Boron

The highest boron uptake by grain during *kharif* (Fig. 27) was observed for the substitution of 50 per cent N through green manure (0.062 kg ha^{-1}) and it was on par with other integrated treatments and 75 to 100 per cent inorganic treatments. Among the integrated treatments, significantly higher grain boron uptake during *rabi* was observed for the treatment T_8 (0.059 kg ha^{-1}) (Fig. 28). Data on straw boron uptake revealed that the crop residue substituted treatments T_8 and T_9 recorded the highest value during *kharif* (0.077 kg ha^{-1}) and *rabi* (0.059 kg ha^{-1}) respectively. During *kharif*, substitution of 50 per cent RDN with any of the organic manures proved significantly superior to their respective 25 per cent substitution. Higher uptake of boron by combined addition of inorganics and organics might be due to release on mineralization or production of organic acids during their decomposition, which aids in solubilization of native nutrients in soil (Yadav and Kumar, 2000).

5.5 EFFECT OF INTEGRATED NUTRIENT MANAGEMENT PRACTICES ON PHYSICAL PROPERTIES OF SOIL

5.5.1 Bulk Density

Bulk density of soil was significantly lowered (Fig. 29) in the treatments where organics were substituted irrespective of the source when compared to the purely inorganic treatments. Bulk density was the lowest for the treatment receiving 50 per cent N substituted through FYM (1.12 Mg m^{-3}) during *kharif* (T_6) and 25 per cent N substituted through crop residue (1.11 Mg m^{-3}) during *rabi* (T_9). The decrease in bulk density may be ascribed to the addition of organic matter that resulted in good soil aggregation and more pore space. Certain polysaccharides formed during organic matter decomposition by the increased microbial activity in soil act as binding agents and helped in soil aggregation and

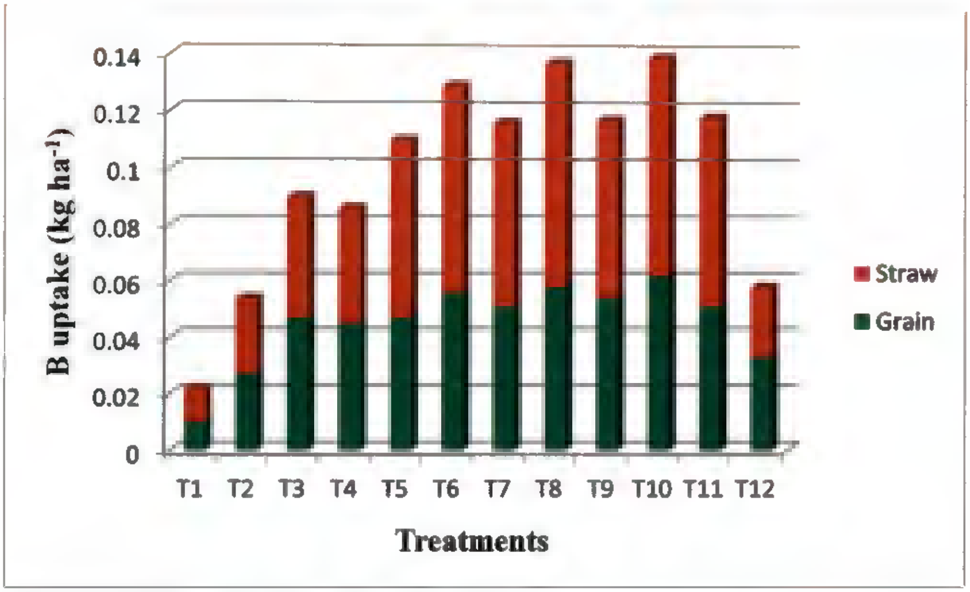

Fig. 27. Effect of integrated nutrient management practices on B uptake during *kharif*

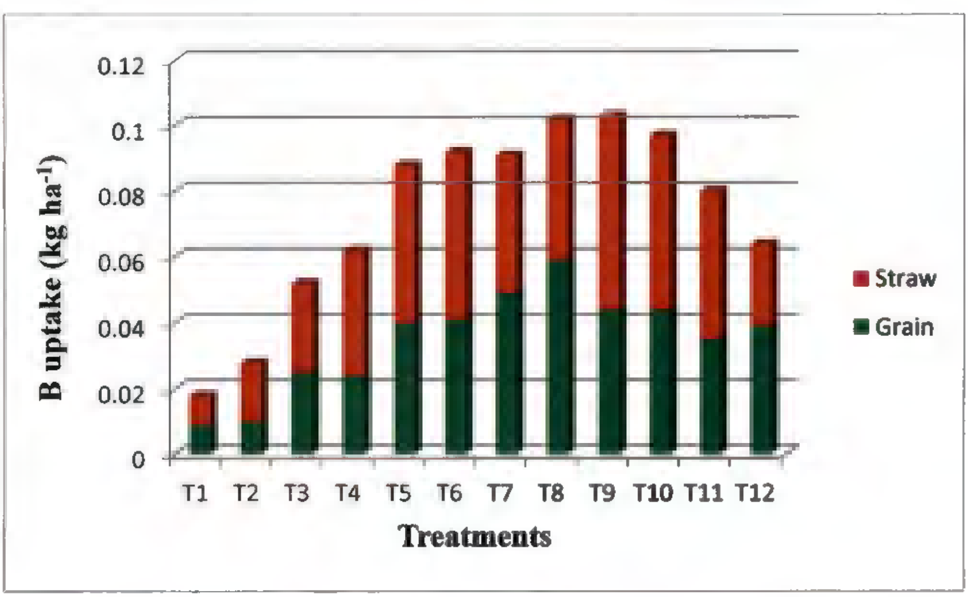

Fig. 28. Effect of integrated nutrient management practices on B uptake during *rabi*

improves the soil structure. Similar observations were also reported by Selvi *et al.* (2005), Gupta *et al.* (2006) and Chaudhary and Thakur (2007).

Bulk density for the purely inorganic treatments was found to be reduced or maintained compared to the initial value after *kharif* and *rabi*. Marginal reduction in bulk density in the fertilizer treated plots could be ascribed to the increased root biomass incorporation over the years that might have increased organic matter content of the soil (Bharadwaj and Omanwar, 1992). The highest bulk density recorded for the control treatment might be attributed to the deterioration of soil structure due to continuous cultivation without any nutrient addition.

5.5.2 Water Holding Capacity (WHC)

A significant increase in WHC of soil over the purely inorganic treatments was observed in treatments where inorganics were substituted with organics (Fig. 30). The highest WHC was recorded for the treatment substituting 25 per cent N through crop residue (T_9) during *kharif* (47.14%) and *rabi* (47.47%). Continuous addition of organic manures favourably influenced the WHC of soil which could be ascribed to the improvement in structural condition of soil. Similar results were also reported by Babhulkar *et al.* (2000) and Selvi *et al.* (2005).

Application of 50, 75 and 100 per cent RDN purely as inorganics to both the crops also increased the WHC of soil over the control, the differences amongst the values however, were not significant. This increase could be attributed to better root growth and biomass addition due to improved nutrition for these treatments compared to absolute control. Similar increase in available N in soil due to addition of inorganics alone was observed in wheat by Bellakki and Badanur (1997) and Subehia and Rana (2012).

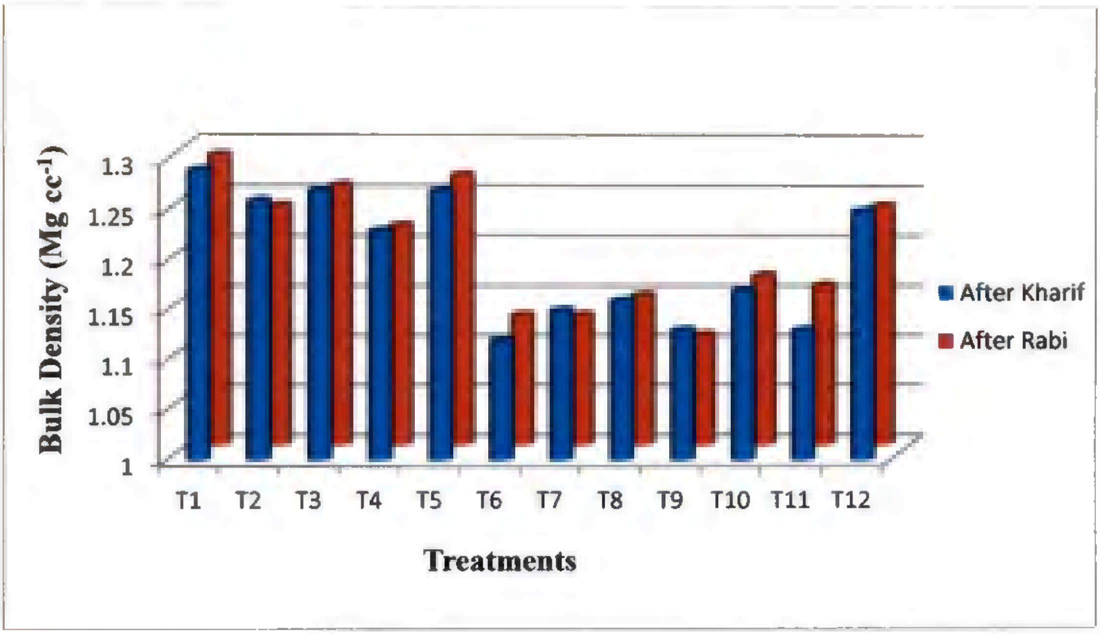

Fig. 29. Effect of integrated nutrient management practices on bulk density of soil

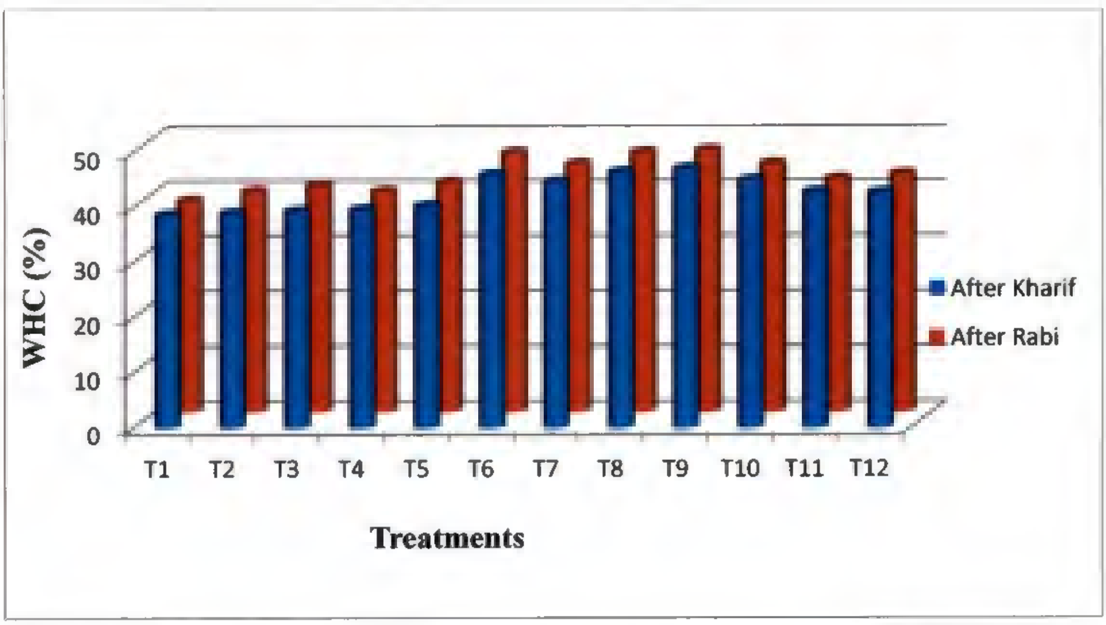

Fig. 30. Effect of integrated nutrient management practices on WHC of soil

5.6 EFFECT OF INTEGRATED NUTRIENT MANAGEMENT PRACTICES ON CHEMICAL PROPERTIES OF SOIL

5.6.1 Soil pH

The data revealed that the effect of different treatments on soil pH was not significant except after *kharif* crop (Table 21). Integrated use of inorganics and organic manures during *kharif* significantly decreased the soil pH compared to control. Soil pH ranged from a minimum of 4.79 for the treatment substituting 50 per cent N through green manure to a maximum value of 5.28 for control. This decline in soil pH may be ascribed to the production of organic acids following microbial decomposition of organic manure. These results are in line with the findings of Gupta *et al.* (2000) and Sharma *et al.* (2013). Comparative decline in pH due to the application of chemical fertilizers alone over the no nutrient control could be attributed to the acid producing nature of nitrogenous fertilizers which upon nitrification release H^+ ions that are potential sources of soil acidity. This result confirms the earlier findings of Magdoff *et al.* (1997) and Saha *et al.* (2008 b) that most N-containing fertilizers tend to acidify soil.

5.6.2 Electrical Conductivity (EC)

The different nutrient management treatments had no significant effect on the EC of soil (Table 22).

5.6.3 Cation Exchange Capacity (CEC)

Application of chemical fertilizers either alone or substituted with different organics improved the CEC of the soil (Table 23) with the maximum value obtained for T_6 during *kharif* (7.87 c mol (p+) kg^{-1}) and *rabi* (7.93 c mol (p+) kg^{-1}). This increase can be due to the build up of higher amount of humus with the incorporation of organics which serves as a store house of exchangeable cations (Dhiman, 2007). Among the inorganic treatments, application of 100 per cent RDN registered the highest CEC after *kharif* (7.10 c mol (p+) kg^{-1}) and *rabi* (7.27

c mol (p+) kg^{-1}). The increase in CEC due to increasing fertilizer levels may also be explained on the basis of significant improvement in organic matter addition to the soil by way of roots and crop stubbles. Similar results were also reported by Babhulkar *et al*. (2000), Sharma *et al*. (2001) and Phogat *et al*. (2004).

On comparing the organic sources used, FYM recorded the highest CEC followed by crop residue and green manure. When different treatments were compared with their initial value of CEC it was observed that there was a significant increase in all the cases.

5.6.4 Organic Carbon

An increase in soil organic carbon (Table 24) was observed due to organic manure substitution during *kharif* compared to the purely inorganic treatments and the farmer's practice. Improvement in soil organic carbon status in plots treated with different organics may be due to the direct incorporation of organic matter in the soil and the subsequent decomposition of these materials (Sharma (2004) and Korwar *et al*. (2006). The slight increase in organic carbon due to the application of fertilizers alone from 50 to 100 per cent RDN (T_2 to T_5) can also be attributed to the contribution of higher biomass to the soil in the form of roots and stubbles. These results are in conformity with the findings of Gathala *et al*. (2007).

5.6.5 Available Nitrogen

The organic substituted treatments gave soil available N on par with the 75 to 100 per cent inorganic treatment, with the treatment substituting 50 percent N through FYM (T_6) recording the highest value after *kharif* (280.15 kg ha^{-1}) (Fig. 31) and *rabi* (284.33 kg ha^{-1}) (Fig. 32). Increase in available nitrogen with organic manure addition especially with FYM may be attributed to the direct addition of nitrogen to the available pool of soil and also to the enhanced microbial population (Table 35) leading to the conversion of organically bound N to inorganic form. The favourable soil conditions under organic manure application might have facilitated the mineralization of soil N resulting in a build-up of available N. Panwar (2008) also reported similar increase in available N in soil with the combined application of FYM and inorganic fertilizers.

While comparing the three sources of organics, crop residue was found to be inferior in increasing the soil available N during *kharif*. This might be due to the high C: N ratio of the material and slow decomposition resulting in more immobilization of N (Singh *et al.*, 2006). The increase in available N with the application of chemical fertilizers (T_2 to T_5) compared to the no nutrient control may possibly be due to the direct addition of inorganic N to the available pool of soil (Yadav *et al.*, 2005).

5.6.6 Available Phosphorus

Though soil available P was generally higher for all the treatments, T_7 with 25 per cent N substituted through FYM recorded significantly highest soil available P after *kharif* (46.95 kg ha^{-1}) (Fig. 31) and *rabi* (48.63 kg ha^{-1}) (Fig. 32). Substitution of inorganic fertilizers with any of the organic manures like FYM, green manures and crop residue had the beneficial effect of increasing the phosphorus availability. The increased availability of P may be due to the mineralization of organic P by microbial action and production of carbonic acid and other organic acids leading to solubilisation of the native soil P and enhanced P mobility. Organic matter may also reduce the fixation of phosphate by providing protective cover on sesquioxides and thus reduce the phosphte fixing capacity of the soil and increase the available P (Prasad *et al.*, 2010).

The increase in available P in soil with purely inorganic treatments compared to the no nutrient control during *kharif* and *rabi* may be due to the addition of P through fertilizers in excess of removal by the crop (Singh *et. al.*, 2008). Though the unfertilized control plots registered lower values for available P compared to the other treatments, the P status was generally high probably due to continuous addition of roots and crop stubbles over a long period of time and the relatively low uptake of P (Table 10).

5.6.7 Available Potassium

All integrated nutrient management treatments showed higher values for available K content in soil as compared to control and chemical fertilizers alone during *kharif* (Fig. 31) and *rabi* (Fig. 32). The highest available K in soil after *kharif* (158.45 kg ha^{-1}) and *rabi* (166.30 kg ha^{-1}) was observed for T_8 where 50 per cent N was substituted through crop residue. The plots which received 50 per cent N substituted with different organic materials (T_6, T_8 and T_{10}) recorded a significant increase in available K content over the plots where 25 per cent N was substituted (T_7, T_9 and T_{11}).

Application of organic manures improved the CEC of the soil (Table 23) and thus increased the retention of K in exchangeable form. The increase might be ascribed to the reduction of K fixation and increased release of K from the exchange sites due to clay - organic matter interaction, besides the direct addition of K to the available pool of the soil. This is in agreement with the findings of Singh *et al.* (2008) and Urkurkar *et al.* (2010).

The increase in available K due to inorganic fertilizer addition (T_2 to T_5) in comparison to control might be due to the direct addition of potassium to the available pool by the applied fertilizers. There was a decline in available K content of soil over the initial value in all treatments after *kharif*. Insufficient addition of K through fertilizers and FYM, and the higher removal by crops might be the possible reason for the general decrease in K availability of soil (Gogoi *et al.*, 2010).

5.6.8 Exchangeable Calcium

The exchangeable Ca content in soil after *kharif* rice crop was not significantly affected by the treatments (Table 26) while analysis of post harvest soil during *rabi* showed significant variation among the treatments. Fifty per cent substitution of N through crop residue recorded the highest exchangeable Ca

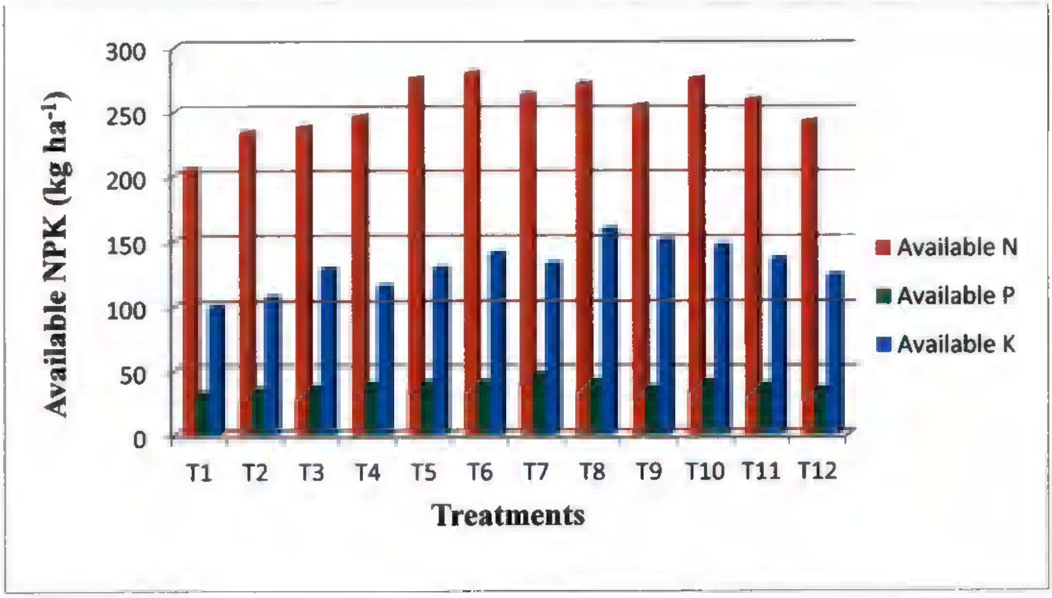

Fig. 31. Effect of integrated nutrient management practices on available NPK in soil during *kharif*

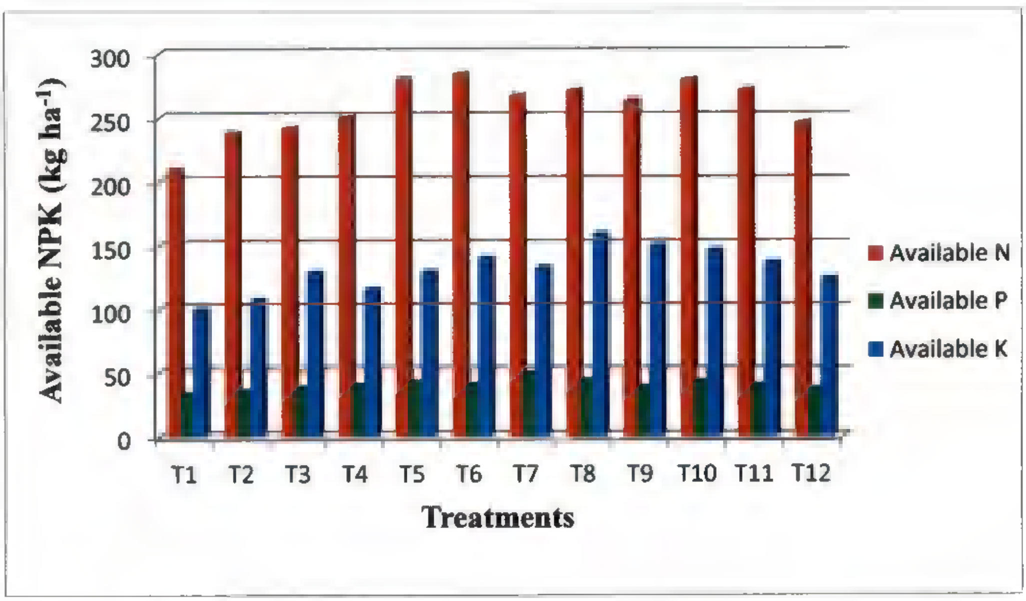

Fig. 32. Effect of integrated nutrient management practices on available NPK in soil during *rabi*

content in soil (655.69 mg kg^{-1}). The increase in the exchangeable calcium content of soil might be due to release of those nutrients from organic sources added along with inorganic fertilizers to the soil after mineralization. Further, the organic acids released from the decomposition of organic manures might have released calcium from the exchange sites in the soil. The above observation is in close agreement with the findings of Sanjivkumar (2014). But all the integrated treatments did not show any consistent increase over the purely inorganic treatments.

5.6.9 Exchangeable Magnesium

Though the effect of different treatments on exchangeable Mg content in soil after *kharif* was significant, all INM treatments did not show any consistent increase over the purely inorganic treatments (Table 27). Long term integrated nutrient management practices could not exert any significant influence on exchangeable Mg content in soil after *rabi*. Among the organics substituted, crop residue recorded the highest exchangeable Mg content followed by green manure and lowest by FYM during both seasons. There was a decrease in exchangeable Mg content in soil after the harvest of *kharif* crop irrespective of the treatments. This decrease might be attributed to lesser Mg content in the organic manure applied or higher removal of these nutrients from the soil by the crop. Similar results were reported by Gogoi *et al*. (2015).

5.6.10 Available Sulphur

The treatments failed to show any significant influence on available sulphur content of soil after *kharif* crop (Table 28). Soil available sulphur after *rabi* was maximum for T_5 (7.75 mg kg^{-1}) and was on par with all other INM treatments. Among the different organics, highest value was recorded for FYM followed by crop residue and the minimum in green manure. Addition of fertilizers along with organic manures helps in increased mineralisation and build up of available S in soil. Such results also correlated with the findings of Jagtap *et al*. (2007) and Gogoi *et al*. (2015).

5.6.11 Available Iron

The different nutrient management treatments exhibited significant effect on the available Fe content in soil after *kharif* and it was non significant after *rabi* (Table 29). Substitution of 50 per cent N with FYM (T_6) recorded significantly higher value over other treatments during *kharif.* An increase in the availability of Fe in soil with the application of FYM and green manure in rice-wheat cropping system has previously been reported by Kumar *et al.* (2008). Substitution of chemical fertilizers with FYM or crop residue either at 25 or 50 per cent level (T_6, T_7, T_8 and T_9) enhanced the soil available Fe content after *kharif* significantly over the farmer's practice. The increase in available Fe status in soil with organic manure substitution may be due to lowering of pH (Table 27) which is known to increase the solubility of metallic elements. Similar observations were also reported by Kher *et al.* (1993).

5.6.12 Available Manganese

No significant treatment differences were observed in available Mn content of soil before and after *kharif* and *rabi*, which were found to be above the critical level of deficiency (Table 30).

5.6.13 Available Copper

The different treatments had significant effect on soil available Cu before *kharif* (Table 31) with the highest value for the treatment receiving 50 per cent N substituted through FYM (9.94 mg kg^{-1}). Though the available Cu content was significantly affected by the treatments, the increase for integrated treatments over inorganic treatments was not consistent. The treatment effects were found to be non significant after *kharif* and *rabi* seasons. The chelating action of organic compounds released during decomposition of FYM, GM, and CR, might have increased Cu availability. Walia *et al.* (2014) also reported higher levels of available Cu due to combined use of manures and fertilizers.

5.6.14 Available Zinc

The effect of long term integrated nutrient management practices on available zinc content in soil before and after *kharif* and *rabi* seasons showed that the treatment effects were not significant (Table 32).

5.6.15 Available Boron

All the integrated treatments gave available B contents in soil statistically on par with 75 to 100 percent RDN as fertilizers after *kharif* and *rabi* (Table 33). Treatment T_6 with 50 per cent substitution of N with FYM, recorded the highest soil available B after *kharif* (0.295 mg kg^{-1}) and *rabi* (0.336 mg kg^{-1}). This may be ascribed to the better supply of boron from the applied organics.

Thus the results from the present study revealed that organic substituted plots recorded higher contents of available nutrients as it influenced the microbial activity (bacteria, fungi) that in turn enhanced the rate of decomposition of organic matter and solubility of nutrients. Goutami and Rani (2016) have also documented increased nutrient content by combined use of organic and mineral fertilizers.

5.7 EFFECT OF INTEGRATED NUTRIENT MANAGEMENT PRACTICES ON BIOLOGICAL PROPERTIES OF SOIL

5.7.1 Enzyme Activity

5.7.1.1 Dehydrogenase

The treatment effects were found to be non significant with respect to dehydrogenase activity of soil during *kharif* and *rabi* seasons (Table 34). Substitution of inorganics with organics viz., FYM, crop residues or green manure to the extent of 50 per cent showed a general increase in dehydrogenase activity over other treatments. The higher dehydrogenase activity under INM treatments could be attributed to the luxuriant root growth leading to a nutrient rich environment, which was more conducive for proliferation of the microorganisms for enhanced enzyme synthesis (Ramalakshmi *et al.*, 2014).

5.7.1.2 Urease

The urease activity was significantly affected by the different nutrient management practices only during *rabi* (Fig. 33). Substitution of 50 per cent N with FYM recorded the highest urease activity of 100.79 ppm of urea hydrolyzed g^{-1} of soil h^{-1} during *rabi*. This can be ascribed to the continuous application of organic manure, which acts as a source of carbon and an energy source for heterotrophs and provides adequate nutrition for the growth and multiplication of microorganisms (Table 35) thus improving the production of soil enzymes (Rai and Yadav, 2011).

Among the inorganic treatments, application of 100 per cent fertilizers (T_5) resulted in the highest urease activity during *kharif* (74.89 ppm of urea hydrolyzed g^{-1} of soil h^{-1}) and *rabi* (86.05 ppm of urea hydrolyzed g^{-1} of soil h^{-1}). This could be attributed to higher root biomass as a result of improved growth due to balanced fertilizer application. The absolute control recorded lower urease activities than all other treatments which could be attributed to a lack of sufficient substrate i.e, organic carbon which act as an energy source for proliferation of microbial population (Kanchikerimatha and Singh, 2001).

5.7.1.3 Acid Phosphatase

The different nutrient management practices exhibited significant effect on acid phosphatase activity during both *kharif* and *rabi* (Fig. 34). During *kharif*, maximum acid phosphatase activity was observed for the treatment T_{10} where 50 per cent N was substituted through green manure (40.45 μg of p-nitrophenol released g^{-1} soil h^{-1}). This could be attributed to additional supply of N and C substrates through applied green manure for supporting microbial activity in soil. The treatment receiving 100 per cent nutrients as fertilizers (T_5) also increased the acid phosphatase activity over the control and imbalanced fertilization treatments

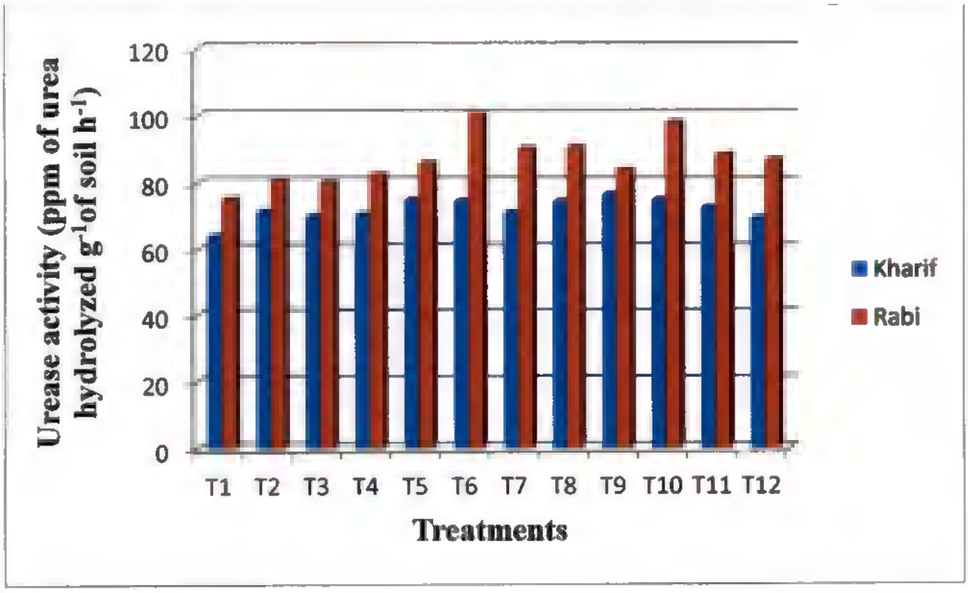

Fig.33. Effect of integrated nutrient management practices on urease activity in soil

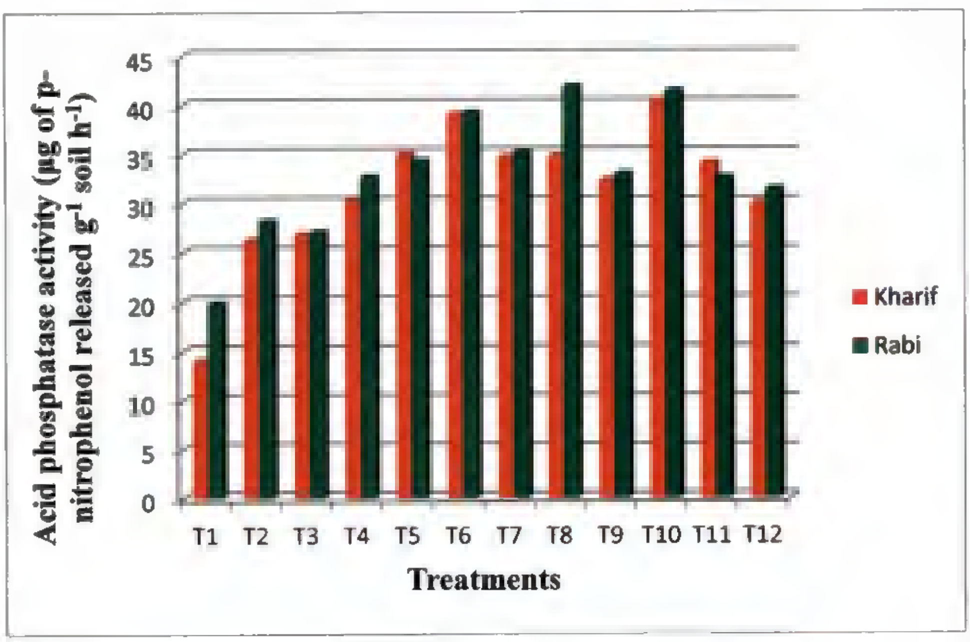

Fig. 34. Effect of integrated nutrient management practices on acid phosphatase activity in soil

Plate 2. Enzyme assay of dehydrogenase

Plate 3. Enzyme assay of phosphatase

Plate 4. Enzyme assay of urease

Bacteria

Fungi

Actinomycetes

Azospirillum

Plate 5. Microbial population studies in soil

(T_2 to T_4). Balanced fertilization supports higher plant biomass production and contributes greater return of organic residue in soil through stubbles, which in turn promote the growth and activities of microorganisms (Mishra *et al.*, 2008).

Substitution of 50 per cent N through crop residue (T_8) recorded the maximum acid phosphatase activity (41.85μg of p-nitrophenol released g^{-1} soilh^{-1}) during *rabi.* The increased phosphatase activity might be due to added amount of organic matter, which in turn increased the organic carbon (Table 24) and nitrogen content (Table 25) of soil. More pronounced effect of organic manure on soil enzyme activities in comparison to the inorganic fertilizers has also been reported by Bhatt *et al*. (2015).

5.7.1.4 Alkaline Phosphatase

Alkaline phosphatase activity in soil during *kharif* and *rabi* (Table 34) did not show any significant variation among the different nutrient management practices. Irrespective of the different treatments, acid phosphatase activity in soil was comparatively more than alkaline phosphatase activity during both seasons due to the acidic soil condition (Table 21). These results were in conformity with the findings of Eivazi and Tabatabai (1977).

5.7.2 Microbial Count

Different nutrient management practices significantly influenced the soil microbial population during *kharif* and *rabi* (Table 35). Substitution of 50 per cent N through FYM (T_6) gave the highest count of bacteria (8.40 log cfu g^{-1} soil), fungi (5.21 log cfu g^{-1} soil) and actinomycetes (4.97 log cfu g^{-1} soil) during *kharif. Azospirillum* count was highest (3.63 log cfu g^{-1} soil) under the treatment receiving 50 per cent of the recommended N substituted through green manure (T_{10}) during *kharif.* Integrated use of organic manures with fertilizers supplied large amount of readily available carbon in soil resulting in more microbial population as compared to the application of chemical fertilizers alone. In addition, incorporation of organic manure improves the soil physical environment, making it more congenial for the activity of microorganisms (Tejada *et al*., 2009).

During *rabi*, substitution of 50 per cent N through green manure (T_{10}) and crop residue (T_8) recorded the maximum count of bacteria (8.46 log cfu g^{-1} soil) and fungi (5.26 log cfu g^{-1} soil) respectively. Application of 50 per cent N as fertilizers along with 50 per cent N as FYM (T_6) gave the highest count of actinomycetes (4.99 x 10^3 cfu g^{-1} soil) and *Azospirillum* (3.75 log cfu g^{-1} soil). The increase in the microbial populations of the soil under organic amended treatments may be ascribed to the decomposition of FYM, green manure and crop residue as well as improvement in physical conditions of the soil, resulting in the better growth of microorganisms. These results are in line with the findings of Walia *et al*. (2014).

The application of inorganic fertilizers, irrespective of their dose, caused a significant reduction in the counts of bacteria, fungi, actinomycetes and *Azospirillum* in soil over the integrated treatments. Use of chemical fertilizers at sub-optimal level and in an imbalanced manner exhibited significantly lower microbial population in soil than at the optimum level of 100 per cent NPK. It may be due to depletion in native pools of plant nutrients in soil under these treatments which in turn reduced the production and addition of plant biomass (carbon substrate) in soil (Suresh *et al*., 1999).

5.8 EFFECT OF INTEGRATED NUTRIENT MANAGEMENT PRACTICES ON ECONOMICS OF CULTIVATION

Economic analysis reveals the feasibility of different nutrient management practices in a rice-rice cropping system. Different treatments significantly influenced the B:C ratio of the experiment.

Substitution of 25 per cent of the nutrient requirement (on nitrogen equivalent basis) through FYM showed the highest B:C ratio of 1.46. Thus though organic matter substitution as FYM to the tune of 50 per cent is more costly, the farmer will not incur significant loss due to the higher grain and straw yield (Table 7 and 8). Singh *et al.* (2011) also reported higher B:C ratio under the integrated use of organic and inorganic source of nutrients.

The farmer's practice and the treatments where nutrients were applied in rates less than the recommended dose recorded B:C ratio lower than those treatments receiving recommended dose of nutrients either as fully inorganic or as inorganics substituted by different types of organics either as FYM, crop residues or green manure. The control treatment registered significantly lower value with a net loss of Rs.12,629/-. This might be due to the lower grain and straw yields obtained from the unfertilized plot.

Summary

6. SUMMARY

The salient findings obtained from the study on "Impact of long term Integrated Nutrient Management system on soil health and rice productivity" are summarised in this chapter.

The study was conducted as part of an ongoing experiment under AICRP on Integrated Farming System viz. "Permanent plot experiment on integrated nutrient supply system for a cereal based crop sequence" which was started during *kharif* 1985-'86. The experiment was laid out in a randomized block design with three replications and twelve treatments viz. absolute control (T_1), 50% RDN as fertilizers during *kharif* and *rabi* (T_2), 50% RDN as fertilizers during *kharif* and 100% RDN as fertilizers during *rabi* (T_3), 75% RDN as fertilizers during *kharif* and *rabi* (T_4), 100% RDN as fertilizers during *kharif* and *rabi* (T_5) and substitution of 50% and 25% of RDN on nitrogen equivalent basis through organic manures viz. FYM (T_6 and T_7), crop residues (T_8 and T_9) and green manure (T_{10} and T_{11}) during *kharif* and 100% and 75% RDN as fertilizers respectively during *rabi* and a farmer's practice (T_{12}).

The soil of the experimental site before start of the experiment during *kharif* 1985-'86 was acidic in reaction, sandy clay in texture, medium in organic carbon (0.86%), low in available N (246.6 kg ha^{-1}), medium in available P (11.2 kg ha^{-1}) and available K (121.6 kg ha^{-1}).

The field experiment was conducted during *kharif* and *rabi* 2016-'17 using the medium duration rice variety Uma at Integrated Farming System Research Station, Karamana, Thiruvananthapuram, Kerala, to assess the impact of long term integrated nutrient management practices on soil physical, chemical and biological properties, soil organic carbon and their effect on rice productivity.

The conclusions drawn from the results obtained from the study, are summarized below.

The soil characteristics of the experimental site before *kharif* 2016-'17 revealed that the soil was strongly acidic in reaction, sandy clay in texture, low in CEC, medium to high in organic carbon, low in available N, high in available P, low to medium in available K, sufficient in available S, Fe, Mn, Cu, Zn and exchangeable Ca and deficient in available B and exchangeable Mg.

Total number of tillers for all organic substituted treatments were statistically on par with the 100 per cent inorganic treatment (T_5), with treatment T_{11} (15.13) and T_9 (13.87) showing the highest values during *kharif* and *rabi* respectively. The highest number of productive tillers per hill was registered for T_7 (13.93) and T_9 (13.13) during *kharif* and *rabi* respectively and was on par with all other INM treatments and T_5. Average number of grains per panicle was the highest under T_7 (115.28) and T_{10} (100.66) during *kharif* and *rabi* respectively and it was found to be on par with all other INM treatments and T_5. Treatment T_6 resulted in the highest per cent filled grains (89.30 and 87.12 %) during both seasons. The thousand grain weight was not significantly affected by the various integrated nutrient management practices.

Root dry weight for organic substituted treatments were on par with the 100 per cent inorganic treatment. T_7 recorded the highest root dry weight during *kharif* (30.75 g hill^{-1}) and T_{10} during *rabi* (25.97 g hill^{-1}). The root length and root volume were not significantly influenced by the treatments during both seasons.

Grain yield during *kharif* and *rabi* were significantly affected by the treatments. The highest value was obtained for T_7 (5770.00 kg ha^{-1}) during *kharif* which was significantly higher T_5. All other INM treatments gave grain yield on par with the 100 per cent inorganic treatment. During *rabi*, all INM treatments were on par with T_5 in terms of grain yield. Grain yield for farmer's practice was significantly lower than all INM and 100 per cent inorganic treatment during both seasons. The highest system productivity was observed for T_7 (10560.00 kg ha^{-1}) which was significantly higher than T_5 (9880.00 kg ha^{-1}). All other organic substituted treatments were on par with T_7 and T_5.

Straw yield during *kharif* was significantly higher for T_9 (8201.67 kg ha^{-1}) and T_8 (7926.67 kg ha^{-1}) compared to all other treatments. The highest straw yield during *rabi* was reported for treatment T_6 (5783.33 kg ha^{-1}) and it was on par with T_7 (5516.67 kg ha^{-1}) and T_8 (5333.33 kg ha^{-1}). All INM treatments except T_6 gave straw yield on par with the 100 per cent inorganic treatment. The highest system productivity was recorded for the treatment T_9 (13358.33 kg ha^{-1}).

All INM treatments gave grain N uptake on par with T_7 (64.89 kg ha^{-1}) and T_{11} (63.56 kg ha^{-1}), showing significantly higher uptake values than T_5. Grain N uptake during *rabi* was on par with all INM treatments and T_5, with the highest value for T_{10} (57.69 kg ha^{-1}). The treatment T_6 registered the highest straw N uptake during *kharif* (37.12 kg ha^{-1}) and it was on par with all INM and 100 per cent inorganic treatments. The highest straw N uptake during *rabi* was noticed for treatment T_6 (34.06 kg ha^{-1}) and was on par with T_7, T_8 and T_{10}.

The highest grain P uptake during *kharif* was recorded for T_7 (30.22 kg ha^{-1}) which was on par with other 25 per cent organic substituted treatments viz. T_9 and T_{11}. The treatment T_5 was found to be on par with all INM treatments except T_7. During *rabi,* T_6 showed the highest grain P uptake (31.57 kg ha^{-1}) with all INM treatments showing uptake values on par with T_5. Higher straw P uptake during *kharif* was shown by the crop residue and green manure substituted treatments (T_8 to T_{11}) compared to FYM substituted plots (T_6 and T_7). The highest P uptake by straw during *rabi* (27.03 kg ha^{-1}) for T_6 during *rabi* which was on par with T_5, T_7, T_8 and T_9.

Potassium uptake by grain during *kharif* varied from 13.68 kg ha^{-1} for control to 31.27 kg ha^{-1} for T_6. All INM treatments (T_6 to T_{11}) gave uptake values for K on par with each other. 50 per cent N substituted with organics gave grain uptake values for K significantly higher than T_5. Regarding the grain K uptake during *rabi*, all the organic manure substituted treatments were found to be on par with T_5, with the highest value for T_{11} (22.65 kg ha^{-1}). All the INM treatments were on par with the highest straw K uptake during *kharif* recorded by T_8 (91.76 kg

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ha^{-1}). T_7 showed the highest straw K uptake during *rabi* (58.35 kg ha^{-1}) and was found to be statistically on par with all other INM treatments and the 100 per cent inorganic treatment.

The INM treatment T_6 resulted in significantly higher calcium uptake by grain during *kharif* (7.95 kg ha^{-1}) compared to all other treatments. Grain Ca uptake during *rabi* was the highest in treatment T_{10} (4.75 kg ha^{-1}) and was on par with T_6 (4.57 kg ha^{-1}). 100 per cent inorganic treatment (T_5) was statistically on par with INM treatments (T_7 and T_{11}) and the inorganic treatment T_4. Highest straw calcium uptake during *kharif* obtained for T_7 (29.36 kg ha^{-1}) which was on par with all other INM treatments. The treatment effects, though significant in the case of straw calcium uptake during *rabi*, was not consistent.

Treatment T_6 (5.81 kg ha^{-1}) recorded the highest grain Mg uptake during *kharif* and was on par with all other INM treatments. All INM treatments except T_6 were on par with T_5. During *rabi*, grain Mg uptake was the highest under treatment T_5 (5.28 kg ha^{-1}), which was on par with all other INM treatments except T_9. During *kharif*, the straw Mg uptake values were significantly higher for the INM treatments compared to the 100 per cent inorganic treatment. The highest Mg uptake by straw during *rabi* was for treatment T_6 (5.42 kg ha^{-1}) which was statistically on par with all other INM treatments and the inorganic treatments T_5 and T_3.

Maximum grain Fe uptake during *kharif* was recorded in treatment T_7 (1.95 kg ha^{-1}) which was on par with T_6, T_9, T_{10} and T_{11}. Treatment T_5 registered an iron uptake of 1.36 kg ha^{-1} which was on par with all integrated treatments except T_7 and T_{11}. During *rabi*, highest grain Fe uptake was recorded for T_6 (2.04 kg ha^{-1}) which was on par with T_5. Treatment T_{10} recorded the highest iron uptake by straw during *kharif* (6.18 kg ha^{-1}) and was on par with all other integrated treatments. Straw iron uptake during *rabi* was the highest in T_9 (4.68 kg ha^{-1}) which was on par with all other INM treatments and the inorganic treatments, T_5 and T_3.

Grain Mn uptake during *kharif* was not significantly influenced by the various treatments. During *rabi*, though the treatment effects were significant, none of the integrated treatments showed any consistent increase over the inorganic treatments. Substitution of 50 per cent fertilizers with crop residue registered the highest straw Mn uptake during *kharif* (0.331 kg ha^{-1}) which was on par with 50 per cent FYM substitution (T_6) and 25 per cent crop residue substitution (T_9). Highest straw Mn uptake during *rabi* was obtained for T_6 (0.216 kg ha^{-1}). T_5 recorded an uptake of 0.181 kg ha^{-1} which was on par with all integrated treatments and the farmer's practice.

Treatment effects were insignificant with respect to grain Cu uptake during *kharif.* T_{10} recorded the highest grain copper uptake during *rabi* (0.062 kg ha^{-1}) which was on par with all INM treatments except T_6. 100 per cent inorganic treatment showed significantly lower uptake than T_{10} and T_7 and it was on par with all other treatments. The highest straw copper uptake during *kharif* was noticed for the 50 per cent crop residue substituted treatment (0.102 kg ha^{-1}) which was on par with T_5 and all other INM treatments except T_{10}. The highest straw copper uptake during *rabi* was observed for T_{10} (0.107 kg ha^{-1}).

FYM substitution either at 50 or 25 per cent N registered the highest grain Zn uptake during *kharif* but treatment effects were non significant during *rabi*. Highest straw Zn uptake was observed for T_8 (0.454 kg ha^{-1}) during *kharif* and T_6 (0.444 kg ha^{-1}) during *rabi* which were significantly superior to T_5.

Uptake of boron by grain and straw showed an increasing trend for the organic substituted treatments and the 100 per cent inorganic treatment during both *kharif* and *rabi* seasons though the difference was not significant.

Long term substitution of inorganics with organic manures also improved the physical properties of soil by decreasing the bulk density and improving the water holding capacity significantly over other treatments. Irrespective of the source of manure used, application of fertilizers along with organics showed similar effect on bulk density. Application of fertilizers substituted with organic manures significantly enhanced the water holding capacity of the soil over purely inorganic treatments.

Soil pH showed a significant decrease after *kharif* in treatments where organic manures were substituted compared to the purely inorganic treatments. Electrical conductivity of the soil was not influenced significantly due to different treatments during both the crop seasons. The treatment effect though non significant in the case of soil organic carbon content after *kharif* and *rabi*, showed numerical increase in values for INM treatments over purely inorganic treatment. The CEC values were higher in all the treatments where integrated use of organics and chemical fertilizers were tried when compared to 100 per cent RDN as inorganics (T_5), but the differences were found non-significant. T_6 showed the highest CEC after both seasons.

The organic substituted treatments gave soil available N on par with the 75 to 100 per cent inorganic treatment, with the treatment substituting 50 percent N through FYM (T_6) recording the highest value after *kharif* (280.15 kg ha^{-1}) and *rabi* (284.33 kg ha^{-1}). Soil available P was generally higher for all treatments with significantly higher values for the 25 per cent FYM substituted treatment (T_7) during *kharif* (46.95 kg ha^{-1}) and *rabi* (48.63 kg ha^{-1}). Available potassium in soil did not show any significant difference between INM and 100 per cent inorganic treatments with the highest value for T_8 during both seasons.

Though the exchangeable calcium and magnesium and available sulphur in soil were significantly influenced by the treatments, the INM treatments did not show any consistent increase over the purely inorganic treatment during both seasons. The effect of different treatments on soil available iron content after *kharif* was significant, with T_6 giving the highest value (299.55 mg kg^{-1}) but the effect was non significant during *rabi*. The various integrated nutrient management practices had no significant influence on available manganese, copper and zinc content in soil after *kharif* and *rabi*. All the integrated treatments gave available B contents in soil statistically on par with 75 to 100 percent RDN as fertilizers after *kharif* and *rabi* with the highest value for T_6.

The treatment effects were found to be non significant with respect to activity of dehydrogenase and alkaline phosphatase in soil during *kharif* and *rabi* seasons. Treatments did not show significant effect on urease activity in soil during *kharif* but T_6 recorded the highest urease activity (98.21 ppm of urea hydrolyzed g^{-1} of soil h^{-1}) during *rabi*. Highest acid phosphatase activity was recorded for T_{10} and T_8 during *kharif* and *rabi* respectively.

Population of bacteria, fungi, actinomycetes and *Azospirillum* were found to be significantly higher for all the INM treatments compared to the 100 per cent inorganic treatment during both seasons.

Economic analysis revealed the superiority of integrated nutrient management over purely inorganic treatments and farmers practice in the rice- rice cropping system and the highest B:C ratio (1.46) was exhibited by the treatment receiving 25 per cent substitution of recommended N with FYM during *kharif* and 75 per cent recommended N through fertilizers during *rabi* (T_7).

From the experiment, it was found that substitution of RDN up to 25 to 50 per cent gave grain yield either on par or significantly higher than the 100 per cent inorganic treatment. To achieve the maximum returns and highest productivity, 25 per cent nitrogen must be substituted as FYM during *kharif* and 75 per cent nutrients applied as fertilizers during *rabi*. Substitution of organic manures for inorganics has beneficial effect on soil health by improving physico-chemical properties, soil biological properties and nutrient availability resulting in enhanced grain and straw yield. Grain and straw productivity, nutrient uptake and soil chemical and biological characters were significantly lower for farmer's practice compared to INM treatments and 100 per cent inorganic treatment. Thus judicious substitution of organic manures for inorganics can improve the yield in a rice-rice cropping system. It can also save 25 per cent of fertilizers during both seasons or 50 per cent of fertilizers in *kharif* without any reduction in yield.

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IMPACT OF LONG TERM INTEGRATED NUTRIENT MANAGEMENT SYSTEM ON SOIL HEALTH AND RICE PRODUCTIVITY

by

RAKHI R.
(2015-11-038)

Abstract of thesis
Submitted in partial fulfilment of the
requirement for the degree of

MASTER OF SCIENCE IN AGRICULTURE

Faculty of Agriculture
Kerala Agricultural University

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
COLLEGE OF AGRICULTURE, VELLAYANI,
THIRUVANANTHAPURAM-695 522
KERALA, INDIA

2017

ABSTRACT

The investigation '*Impact of long term integrated nutrient management system on soil health and rice productivity*' was conducted at Integrated Farming Systems Research Station, Karamana, during *kharif* and *rabi,* 2016-'17, with medium duration rice variety Uma, to assess the impact of long term integrated nutrient management practices on soil physical, chemical and biological properties, soil organic carbon and to study their impact on rice productivity.

The experiment was laid out in a randomized block design with three replications and twelve treatments viz. absolute control (T_1), 50% RDN as fertilizers during *kharif* and *rabi* (T_2), 50% RDN as fertilizers during *kharif* and 100% RDN as fertilizers during *rabi* (T_3), 75% RDN as fertilizers during *kharif* and *rabi* (T_4), 100% RDN as fertilizers during *kharif* and *rabi* (T_5) and substitution of 50% and 25% of RDN on nitrogen equivalent basis through organic manures viz. FYM (T_6 and T_7), crop residues (T_8 and T_9) and green manure (T_{10} and T_{11}) during *kharif* and 100% and 75% RDN as fertilizers respectively during *rabi* and a farmer's practice (T_{12}).

The soil of the experimental site before *kharif* 2016 was strongly acidic in reaction, sandy clay in texture, low in CEC, high in organic carbon, low in available N, high in available P, medium in available K, sufficient in available, S, Fe, Mn, Cu, Zn and exchangeable Ca and deficient in available B and exchangeable Mg.

Substitution of up to 25 to 50 per cent RDN either with FYM, crop residues or green manure gave yield either higher or on par with 100 per cent inorganic treatment. Substitution of 25 per cent RDN with FYM (T_7) gave the highest grain system productivity which was significantly higher than 100 per cent inorganic treatment. The number of productive tillers per hill and number of grains per panicle for the INM treatments were on par with 100 per cent inorganic treatment for both seasons. T_6 recorded the highest per cent filled grains during both *kharif* and *rabi*.

The application of recommended doses of fertilizers alone (T_5) resulted in lower uptake of N, P and K when compared to conjunctive use of 25 to 50 per cent RDN substituted either with FYM, crop residues or green manure. Integrated use of organics and inorganics also resulted in higher uptake of Ca, Mg and micronutrients (Fe, Mn, Cu, Zn and B) by grain and straw during both seasons over the purely inorganic treatments and the absolute control.

Long term INM treatments also improved the physical properties of the soil by decreasing the bulk density and improving the WHC significantly over the other treatments.

Soil pH showed a significant decrease after *kharif* in treatments where organic manures were applied compared to the inorganic treatments. EC of the soil was not influenced significantly due to different treatments during both the crop seasons. Organic carbon content and CEC of the soil were highest in treatment T_6 receiving 50% RDN through inorganic fertilizers and 50% N through FYM during *kharif* followed by 100% RDN during *rabi.*

Available N and K in soil did not show any significant difference between INM and 100% inorganic treatment. Soil available P was generally higher for all the treatments with significantly higher values for the 25 per cent FYM substituted treatment. Higher values for available B was observed for the treatments receiving 50 per cent substitution of fertilizers through organic manures compared to the other treatments. However, integrated treatments failed to show any consistent variation in exchangeable Ca and Mg, available S, Fe, Mn, Cu and Zn in soil over the other treatments.

Studies on microbial population and enzyme activities revealed the positive influence of integrated nutrient management on soil biological properties over inorganic treatments. Population of bacteria, fungi, actinomycetes and *Azospirillum* were found to be higher for treatments involving substitution of fertilizers with organics either at 25 or 50 per cent. Urease and acid phosphatase activity were generally improved due to the substitution of inorganics by organics to the extent of 50 per cent.

Economic analysis revealed the superiority of integrated nutrient management over purely inorganic treatments and significantly higher B:C ratio was exhibited by the treatment receiving 25 per cent substitution of RDN with FYM during *kharif* and 75 per cent RDN through fertilizers during *rabi* compared to T_5. All INM treatments gave B:C ratio on par with T_5.

From the experiment, it was found that substitution of RDN up to 25 to 50 per cent gave grain yield either on par or significantly higher than the 100 per cent inorganic treatment. To achieve the maximum returns and highest productivity, 25 per cent nitrogen must be substituted as FYM during *kharif* and 75 per cent nutrients applied as fertilizers during *rabi*. Substitution of organic manures for inorganics has beneficial effect on soil health by improving physicochemical and biological properties and nutrient availability and resulting in enhanced grain and straw yield. Thus judicious substitution of organic manures for fertilizers can improve the yield in a rice-rice cropping system. It can also save 25 per cent of fertilizers during both seasons or 50 per cent fertilizers during *kharif* without any reduction in yield.

സംഗ്രഹം

മണ്ണിന്റെ ആരോഗ്യത്തിലും നെല്ലിന്റെ ഉൽപാദനക്ഷമതയിലും ദീർഘകാല സംയോജിത പോഷക നിയന്ത്രണ പദ്ധതിയുടെ സ്വാധീനം എന്ന വിഷയത്തെ സംബന്ധിച്ച ഒരു പഠനം കേരള കാർഷിക സർവകലാശാലയുടെ അധീനതയിൽ തിരുവനന്തപുരം കരമനയിൽ സ്ഥിതി ചെയ്യുന്ന സംയോജിത കൃഷി സമ്പ്രദായ ഗവേഷണ കേന്ദ്രത്തിൽ നടത്തുകയുണ്ടായി. രാസവളങ്ങളെ വിവിധയിനം ജൈവവളങ്ങളാൽ പ്രതിനിധാനം ചെയ്യുകവഴി മണ്ണിന്റെ ഭൗതിക രാസ ജൈവഗുണങ്ങളിലും നെല്ലിന്റെ ഉല്പാദനക്ഷമതയിലുമുള്ള സ്വാധീനം കണ്ടെത്തുക എന്നതായിരുന്നു പഠനത്തിന്റെ മുഖ്യ ലക്ഷ്യം.

രണ്ടായിരത്തി പതിനാറു- പതിനേഴ് വിരിപ്പ്, തുടർന്നുള്ള മുണ്ടകൻ കാലത്തുമായി നടത്തിയ പഠനത്തിൽ പന്ത്രണ്ട് വ്യത്യസ്ത ട്രീറ്റ്മെന്റ്കൾ ആണ് ഉൾപ്പെടുത്തിയിരുന്നത്. പ്രസ്തുത പരീക്ഷണത്തിന് റാൻഡമൈസ്ഡ് ബ്ലോക്ക് ഡിസൈൻ എന്ന പരീക്ഷണരീതിയാണ് അവലംബിച്ചത്. ഉമ എന്ന നെല്ലിനമാണ് പഠനവിധേയമാക്കിയത്. ശുപാർശചെയ്ത പോഷകങ്ങളുടെ (പാക്യജനകം : ഭാവകം: ക്ഷാരം – 90 : 45 : 45 കിലോഗ്രാം ഒരു ഹെക്ടറിനു) 50 ,75 അല്ലെങ്കിൽ 100 ശതമാനം പോഷകങ്ങൾ രാസവളങ്ങളാൽ മാത്രം പ്രയോഗിക്കുകയും, ശുപാർശചെയ്ത പോഷകങ്ങളുടെ 25 ശതമാനം അല്ലെങ്കിൽ 50 ശതമാനം (പാക്യജനകം അടിസ്ഥാനത്തിൽ) വിവിധതരം ജൈവവളങ്ങളാൽ (ചാണകം, വിള അവശിഷ്ടങ്ങൾ, പച്ചിലവളം) പ്രതിനിധാനം ചെയ്തും പ്രയോഗിച്ചു. ഇതിനു പുറമേ ഒരു പരിപൂർണ്ണ പോഷകരഹിത കൺട്രോൾ പ്ലോട്ടും കർഷകർ പിന്തുടരുന്ന വളപ്രയോഗ നിരക്കും പഠന വിധേയമാക്കി.

സംയോജിത പോഷക നിയന്ത്രണ പദ്ധതി പ്രയോഗിക്കപ്പെട്ട ചെടികളിലാണ് ഏറ്റവും കൂടുതൽ കതിരുകളുടെ എണ്ണം, ആയിരം നെന്മണികളുടെ തൂക്കം, കതിരിലെ നിറഞ്ഞ നെന്മണികളുടെ ശതമാനം, വിളവ് എന്നിവ കാണപ്പെട്ടത്. മണ്ണിന്റെ ഭൗതിക ഗുണങ്ങളായ ബൾക്ക് ഡെൻസിറ്റിയും ജല ആഗിരണ ക്ഷമതയും ഗുണീകരിച്ചു. മണ്ണിലെ മുഖ്യ സൂക്ഷ്മ മൂലകങ്ങളുടെ ലഭ്യതയും ഗണ്യമായി വർദ്ധിക്കുകയുണ്ടായി. ധാന്യ- വൈക്കോൽ പോഷക ആഗിരണത്തിലും ഇവ മുന്നിട്ടു നിന്നു. മണ്ണിന്റെ ജൈവഗുണങ്ങളായ ദീപനരസപ്രവർത്തനവും സൂക്ഷ്മജീവികളുടെ എണ്ണവും കൂടുതലായി കണ്ടെത്തിയതും ഈ പ്ലോട്ടുകളിലാണ്. പൂർണ്ണമായി രാസവളപ്രയോഗത്തെ അപേക്ഷിച്ച് ഏറ്റവും കൂടുതൽ ഉല്പാദനക്ഷമതയും ഉയർന്ന അറ്റാദായവും വരവ് ചെലവു അനുപാതവും ലഭ്യമായത് 25 ശതമാനം ശുപാർശ ചെയ്ത

പോഷകങ്ങളെ (പാക്യജനകം അടിസ്ഥാനത്തിൽ) ചാണകം വഴി പ്രതിനിധാനം ചെയ്ത പ്രയോഗത്തിലാണ്.

നെല്ല്-നെല്ല് വിള സമ്പ്രദായത്തിൽ ദീർഘകാല സംയോജിത പോഷക നിയന്ത്രണ പദ്ധതിയിലൂടെ രണ്ടു കാലങ്ങളായി 25 ശതമാനം രാസവളങ്ങളെ അല്ലെങ്കിൽ വിരിപ്പ് കാലത്ത് 50 ശതമാനം രാസവളങ്ങളെ ലാഭിക്കാമെന്ന് ഈ പഠനത്തിൽ നിന്നും കണ്ടെത്തി. രാസവളങ്ങളെ വിവിധ ജൈവവളങ്ങളാൽ പ്രതിനിധാനം ചെയ്യുക വഴി മണ്ണിന്റെ ഭൗതിക രാസ ജൈവഗുണങ്ങൾ മെച്ചപ്പെടുകയും അതുവഴി പോഷകലഭ്യതയും നെല്ലിന്റെ ഉല്പാദനക്ഷമതയും കൂടുകയും ചെയ്യുന്നതായി കണ്ടെത്തി.

Appendices

Appendix 1

Weather data during *kharif* (May - October 2016)

Standard week	Temperature (^{0}C)		Relative humidity (%)	Rainfall (mm)
	Maximum	Minimum		
22	31.32	24.79	86.73	7.11
23	30.07	24.58	97.53	167.13
24	30.38	23.97	89.38	128.52
25	29.79	23.49	84.32	68.33
26	30.45	24.21	83.48	25.91
27	31.71	24.57	80.07	35.00
28	29.86	23.86	83.00	60.40
29	30.64	25.21	80.64	0
30	29.93	24.57	83.00	36.80
31	30.21	25.29	82.50	8.00
32	30.93	25.21	77.86	0
33	30.57	25.07	83.21	11.30
34	30.29	25.14	82.79	17.60
35	30.36	24.71	81.57	2.00
36	29.79	24.07	84.36	3.00
37	30.5	25.07	81.57	0
38	30.43	25.00	83.36	0
39	30.79	25.00	81.93	0.60
40	30.36	24.12	94.88	0
41	30.68	23.94	94.12	1.27

Appendix 2

Weather data during *rabi* (October 2016 - February 2017)

Standard week	Temperature (^0C)		Relative humidity (%)	Rainfall (mm)
	Maximum	Minimum		
42	30.33	24.62	96.56	33.27
43	29.91	23.80	95.29	0.00
44	30.40	23.84	96.78	32.26
45	30.83	23.70	94.19	0.25
46	31.32	24.34	97.33	9.14
47	30.54	24.13	99.09	1.27
48	30.83	23.36	92.43	3.81
49	30.85	23.20	96.57	11.94
50	30.14	22.69	94.08	0.51
51	31.27	23.50	95.75	0.00
52	31.35	23.05	95.65	3.30
1	30.67	22.29	92.52	0.00
2	30.27	22.18	89.86	0.00
3	30.82	21.96	87.38	0.00
4	31.38	23.79	92.68	20.07
5	30.37	22.30	95.96	0.00
6	30.83	21.27	91.04	0.00
7	31.97	21.29	85.70	0.00
8	31.34	22.98	94.68	0.00

Appendix 3

Nutrient composition of organic manures used

	FYM	Crop residue	Green manure
Total N (%)	0.8	1.2	2.3
Total P (%)	0.4	0.352	0.278
Total K (%)	1.18	1.425	2.45
Total Ca (mg kg^{-1})	4214	460.5	766.5
Total Mg (mg kg^{-1})	391.4	131.25	184
Total Fe (mg kg^{-1})	1063.5	908	355.7
Total Mn (mg kg^{-1})	3437.5	2073	46.25
Total Cu (mg kg^{-1})	189.5	ND*	ND
Total Zn (mg kg^{-1})	251	79	33.25
Total B (mg kg^{-1})	9.167	7.35	5.85

*ND : Not detected

Appendix 4

Composition of media used for the isolation of micro organisms

1. Bacteria - Nutrient Agar

Beef extract	-	3g
Peptone	-	5g
NaCl	-	5g
Agar	-	20g
Distilled water	-	1000 ml

2. Fungi - Martins Rose Bengal Agar

Dextrose	-	10g
Peptone	-	5g
KH_2PO_4	-	1g
$MgSO_4.2H_2O$	-	0.5g

3. Actinomycetes - Kenknight's Medium

Glucose	-	1g
K_2HPO_4	-	0.1g
$NaNO_3$	-	0.1g
KCl	-	0.1g
$MgSO_4.7H_2O$	-	0.1g
Agar	-	15g

4. ***Azospirillum*** **- N Free Bromothymol blue (NFB) Medium**

NH_4Cl	-	0.1%
Malic acid	-	5g
K_2HPO_4	-	0.5g
$MgSO_4.7H_2O$	-	0.2g
NaCl	-	0.1g
$CaCl_2$	-	0.02g
Trace Element solution	-	2 ml
Bromothymol blue	-	2 ml
Fe EDTA	-	4 ml
FeSO4	-	0.05g
Vitamin solution	-	4 ml
KOH	-	4 g
Agar	-	20 g
Distilled water	-	1000ml

Appendix 5

Cost of inputs and produce

Cost of inputs

Labour	-	Rs. 612 per man day
Seeds	-	Rs.39 per kg
FYM	-	Rs. 1 per kg
Urea	-	Rs. 7 per kg
Rajphos	-	Rs. 10 per kg
MOP	-	Rs. 17 per kg

Cost of outputs

Rice grain	-	Rs. 22 per kg
Rice straw	-	Rs. 5 per kg