EFFECT OF TILLAGE, GREEN MANURING, RICE ESTABLISHMENT METHODS AND CROP RESIDUE MANAGEMENT PRACTICES ON MICRONUTRIENT UPTAKE AND TRANSFORMATION UNDER RICE-WHEAT CROPPING SYSTEM

Dissertation

Submitted to the Punjab Agricultural University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY
in
SOIL SCIENCE
(Minor Subject: Chemistry)

By

Mandeep Kaur
(L-2014-A-64-D)

Department of Soil Science
College of Agriculture
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LUDHIANA-141004

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CERTIFICATE I

This is to certify that the dissertation entitled, **"Effect of tillage, green manuring, rice establishment methods and crop residue management practices on micronutrient uptake and transformation under rice-wheat cropping system"** submitted for the degree of **Ph.D.**, in the subject of **Soil Science** (Minor subject: **Chemistry**) of the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Ms. Mandeep Kaur (L-2014-A-64-D)** under my supervision and that no part of this dissertation has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

Major Advisor
Dr S S Dhaliwal
Senior Soil Chemist
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CERTIFICATE II

This is to certify that the dissertation entitled, **"Effect of tillage, green manuring, rice establishment methods and crop residue management practices on micronutrient uptake and transformation under rice-wheat cropping system"** submitted by **Ms. Mandeep Kaur (L-2014-A-64-D)** to the Punjab Agricultural University, Ludhiana, in partial fulfillment of the requirements for the degree of **Ph.D.**, in the subject of **Soil Science** (Minor subject: **Chemistry**) has been approved by the student's Advisory Committee after an oral examination on the same.

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Place:

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ABSTRACT

The present study was carried out under two on-going field experiments at research farm, Department of Soil Science, Punjab Agricultural University, Ludhiana in split plot design with three replications. The soil of both experimental fields was loamy sand in texture, taxonomically classified as Typic Ustrochrept. The first experiment comprised of twelve treatment combinations among which the main plots consisted of four rice establishment methods viz. direct seeded rice under zero tillage (DSR-ZT), conventional tillage (DSR-CT), reduced tillage (DSR-RT) and puddled transplanted rice (PTR) and three subplots in wheat viz. conventional tillage (CTW-R), zero tillage without rice straw (ZTW-R) and zero till with rice straw (ZTW+R). In this study, soil samples were analyzed for basic chemical indices of soil quality. The DTPA-extractable micronutrient cations (Zn, Fe, Mn and Cu) and their different chemical fractions were analyzed using atomic absorption spectrophotometer (Varion AAS-FS Model). The ZTW+R showed marked increase in concentration of DTPA-extractable Zn, Fe, Mn and Cu and their transformation from occluded fractions towards bio-available forms. Residual fraction of all the micronutrient cations was found to be the most dominant fraction and water soluble + exchangeable fraction was found to be least dominant in soil. Organically bound fraction of all the micronutrient cations studied was found to be most important fraction contributing towards micronutrient uptake by both rice and wheat crops. The ZTW+R produced significantly higher wheat grain yield than ZTW-R. Moreover, rice grain yield under PTR and DSR-RT was comparable but significantly higher than DSR-CT and DSR-ZT. The second experiment consisted of twelve treatment combinations among which the four main plots comprised of puddled transplanted rice with no wheat straw retained (PTR_{W0}), puddled transplanted rice with 25% anchored wheat straw retained (PTR_{W25}), PTR_{W0} + GM and PTR_{W25} + GM. Similarly, three subplot treatments included conventional tillage wheat without rice residue (CTW_{R0}) zero tillage wheat without rice residue (ZTW_{R0}) and ZTW with 100% rice residue retained as mulch (ZTW_{R100}) in subsequent wheat crop. The results of the study revealed that soil pH decreased however, SOC and availability of DTPA-extractable micronutrients increased with crop residue retention and GM incorporation in soil. The DTPA-extractable Zn, Cu, Fe and Mn showed sharp decrease from 0-7.5 cm to 7.5-15 cm soil depth and afterwards the decrease was gradual with further increase in soil depth. The transformation of Zn, Cu, Fe and Mn was found higher under PTR_{W25} + GM treatment from occluded (AFeOx and CFeOx) fractions to mobile (WSEX) ones. Highest productivity and Zn, Cu, Fe and Mn uptake by grain and straw of rice and wheat were also recorded under PTR_{W25} + GM treatment. In nutshell, green manure incorporation and crop residue retention over the soil surface substantially increased the crop productivity and availability of Zn, Fe, Mn and Cu in soil.

Keywords: Tillage, rice establishment methods, straw management, green manure, micronutrients, rice-wheat

Signature of Major Advisor **Signature of the Student**

ਖੋਜ ਗ੍ਰੰਥ ਦਾ ਸਿਰਲੇਖ	:	ਕਣਕ-ਝੋਨਾ ਫ਼ਸਲੀ ਚੱਕਰ ਵਿੱਚ ਵਹਾਈ, ਹਰੀ ਖਾਦ, ਝੋਨੇ ਦੀ ਬਿਜਾਈ ਦੇ ਤਰੀਕੇ ਅਤੇ ਫ਼ਸਲ ਦੀ ਰਹਿੰਦ-ਖੂੰਦ ਦੀ ਸੰਭਾਲ ਦਾ ਲੱਘੂ ਤੱਤਾਂ ਦੀ ਮਾਤਰਾ ਅਤੇ ਤਬਦੀਲੀ ਉੱਪਰ ਅਸਰ
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ਸਾਰ-ਅੰਸ਼

ਮੌਜੂਦਾ ਖੋਜ ਅਧਿਐਨ ਪੰਜਾਬ ਖੇਤੀਬਾੜੀ ਯੂਨੀਵਰਸਿਟੀ ਲੁਧਿਆਣਾ ਦੇ ਭੂਮੀ ਵਿਗਿਆਨ ਵਿਭਾਗ ਵਿਖੇ (2010 ਤੋਂ ਚਲਦੇ ਆ ਰਹੇ ਤਜ਼ਰਬੇ ਉੱਪਰ) ਕੀਤਾ ਗਿਆ। ਇਸ ਅਧਿਐਨ ਦੇ ਉਪਚਾਰ ਸਪਲਿੱਟ ਪਲਾਟ ਡਿਜ਼ਾਇਨ ਵਿਧੀ ਤਹਿਤ ਤਿੰਨ ਵਾਰ ਦੁਹਰਾਏ ਗਏ। ਤਜ਼ਰਬੇ ਵਾਲੇ ਖੇਤਾਂ ਦੀ ਮਿੱਟੀ ਟਿਪਿੱਕ ਓਸਟ੍ਰੋਕ੍ਰੈਪਟ ਸ਼੍ਰੇਣੀ ਨਾਲ ਸੰਬੰਧਤ ਮੈਰਾ ਰੇਤਲੀ ਸੀ। ਪਹਿਲੇ ਤਜ਼ਰਬੇ ਦੌਰਾਨ 12 ਉਪਚਾਰਾਂ ਦੀ ਵਰਤੋਂ ਕੀਤੀ ਗਈ ਜਿਸ ਵਿੱਚ ਚਾਰ ਮੁੱਖ ਪਲਾਟਾਂ ਵਿੱਚ ਝੋਨੇ ਦੀ ਬਿਜਾਈ (ਝੋਨੇ ਦੀ ਸਿੱਧੀ ਬਿਜਾਈ- ਕੰਨਵੈਨਸ਼ਨਲ ਟਿਲੇਜ, ਸਿੱਧੀ ਬਿਜਾਈ- ਰਿਡਊਜ਼ ਟਿਲੇਜ਼, ਸਿੱਧੀ ਬਿਜਾਈ- ਜ਼ੀਰੋ ਟਿਲੇਜ਼ ਅਤੇ ਕੱਦੂ ਤੋਂ ਬਾਅਦ ਪਨੀਰੀ ਦੀ ਲਵਾਈ ਅਤੇ ਤਿੰਨ ਉਪ ਪਲਾਟਾਂ ਵਿੱਚ ਕਣਕ ਦੀ ਫ਼ਸਲ ਦੀ ਕਾਸ਼ਤ (ਪ੍ਰੰਪਰਾਗਤ ਬਿਜਾਈ, ਪਰਾਲੀ ਤੋਂ ਬਗੈਰ ਬਿਨਾਂ ਵਹਾਈ ਅਤੇ ਪਰਾਲੀ ਸਹਿਤ ਬਿਨ੍ਹਾਂ ਵਹਾਈ) ਕੀਤੀ ਗਈ। ਮਿੱਟੀ ਦੀ ਗੁਣਵਤਾ ਦੇ ਵੱਖੋ-ਵੱਖਰੇ ਰਸਾਇਣਿਕ ਸੂਚਕਾਂ ਦਾ ਮੁਲਾਂਕਣ ਕੀਤਾ ਗਿਆ ਅਤੇ ਨਾਲ ਵੱਖੋ-ਵੱਖਰੇ ਲਘੂ ਤੱਤਾਂ (ਜ਼ਿੰਕ, ਕਾਪਰ, ਆਇਰਨ ਅਤੇ ਮੈਂਗਨੀਜ਼) ਅਤੇ ਇਹਨਾਂ ਅੰਸ਼ਾਂ ਦੀ ਗਤੀਸ਼ੀਲਤਾ ਦਾ ਪਤਾ ਅਟਾਮਿਕ ਅਬਸੌਰਪਸ਼ਨ ਸਪੈਕਟ੍ਰੋਫੋਟੋਮੀਟਰ ਨਾਲ ਲਗਾਇਆ ਗਿਆ। ਪਰਾਲੀ ਸਹਿਤ ਬਿਨ੍ਹਾਂ ਵਹਾਈ ਵਾਲੇ ਪਲਾਟਾਂ ਵਿੱਚ ਡੀ ਟੀ ਪੀ ਏ- ਨਿਸ਼ਕਰਸ਼ਤ ਲਘੂ ਤੱਤਾਂ ਦੀ ਮਿਕਦਾਰ ਵਿੱਚ ਵਾਧਾ ਹੋਣ ਦੇ ਨਾਲ-ਨਾਲ ਇਹ ਲਘੂ ਤੱਤ ਜੈਵਿਕ ਤੌਰ ਤੇ ਉਪਲਬਧ ਰੂਪਾਂ ਵਿੱਚ ਤਬਦੀਲ ਹੋਏ। ਮਿੱਟੀ ਵਿੱਚ ਸਾਰੇ ਲਘੂ ਤੱਤਾਂ ਦੇ ਰੈਜ਼ੀਡਿਊਲ ਅੰਸ਼ਾਂ ਦੀ ਮਿਕਦਾਰ ਸਭ ਤੋਂ ਵਧੇਰੇ ਸੀ ਅਤੇ ਪਾਣੀ ਵਿੱਚ ਘੁਲਣਸ਼ੀਲ+ਸਥਾਨਾਂ ਤਰਤ ਅੰਸ਼ਾਂ ਦੀ ਮਿਕਦਾਰ ਸਭ ਤੋਂ ਘੱਟ ਦਰਜ ਕੀਤੀ ਗਈ। ਅਧਿਐਨ ਦੇ ਨਤੀਜਿਆਂ ਤੋਂ ਇਹ ਤੱਥ ਸਾਹਮਣੇ ਆਇਆ ਕਿ ਕਣਕ ਅਤੇ ਝੋਨਾ ਦੋਨਾਂ ਫ਼ਸਲਾਂ ਵਿੱਚ ਹੀ ਲਘੂ ਤੱਤ ਗ੍ਰਹਿਣ ਦੇ ਲਿਹਾਜ ਨਾਲ ਸਾਰੇ ਲਘੂ ਤੱਤਾਂ ਦੇ ਜੈਵਿਕ ਤੌਰ ਤੇ ਸੀਮਾਬੱਧ ਅੰਸ਼ ਸਭ ਤੋਂ ਵਧੇਰੇ ਅਹਿਮ ਅੰਸ਼ ਸਨ। ਝੋਨੇ ਦੇ ਦਾਣਿਆਂ ਦਾ ਝਾੜ ਕੱਦੂ ਤੋਂ ਬਾਅਦ ਪਨੀਰੀ ਦੀ ਲਵਾਈ ਵਾਲੇ ਪਲਾਟਾਂ ਵਿੱਚ ਅਤੇ ਝੋਨੇ ਦੀ ਸਿੱਧੀ ਬਿਜਾਈ- ਰਿਡਊਜ਼ ਟਿਲੇਜ ਵਿੱਚ ਲਗਭਗ ਬਰਾਬਰ ਪਾਇਆ ਗਿਆ ਪਰੰਤੂ ਇਹਨਾਂ ਪਲਾਟਾਂ ਵਿੱਚ ਝੋਨੇ ਦਾ ਝਾੜ ਸਿੱਧੀ ਬਿਜਾਈ-ਜ਼ੀਰੋ ਟਿਲੇਜ ਅਤੇ ਕੰਨਵੈਨਸ਼ਨਲ ਟਿਲੇਜ ਨਾਲੋਂ ਅਰਥਪੂਰਨ ਤੌਰ ਤੇ ਵਧੇਰੇ ਸੀ। ਇਸ ਦੇ ਨਾਲ ਹੀ ਨਤੀਜਿਆਂ ਤੋਂ ਇਹ ਤੱਥ ਸਾਹਮਣੇ ਆਏ ਹਨ ਬਿਨ੍ਹਾਂ ਵਹਾਈ ਵਿਧੀ ਅਧੀਨ ਝੋਨੇ ਦੀ ਨਾੜ ਵਾਲੇ ਖੇਤਾਂ ਵਿੱਚ ਹੈਪੀ ਸੀਡਰ ਦੀ ਵਰਤੋਂ ਨਾਲ ਬੀਜੀ ਗਈ ਕਣਕ ਨੇ ਅਰਥਪੂਰਨ ਤੌਰ ਤੇ ਸਭ ਤੋਂ ਵਧੇਰੇ ਦਾਣਿਆਂ ਅਤੇ ਪਰਾਲੀ ਦਾ ਝਾੜ ਦਿੱਤਾ। ਦੂਜੇ ਤਜਰਬੇ ਦੇ 12 ਉਪਚਾਰਾਂ ਵਿੱਚੋਂ 4 ਮੁੱਖ ਪਲਾਟਾਂ ਵਿੱਚ ਝੋਨੇ ਦੀ ਬਿਜਾਈ (ਕੱਦੂ ਕੀਤਾ ਝੋਨਾ ਬਿਨਾਂ ਕਣਕ ਦੇ ਨਾੜ ਤੋਂ, ਕੱਦੂ ਕੀਤਾ ਝੋਨਾ ਕਣਕ ਦੇ 25% ਨਾੜ ਨਾਲ, ਕੱਦੂ ਕੀਤਾ ਝੋਨਾ ਬਿਨਾਂ ਕਣਕ ਦੇ ਨਾੜ ਤੋਂ+ਹਰੀ ਖਾਦ ਅਤੇ ਕੱਦੂ ਕੀਤਾ ਝੋਨਾ ਕਣਕ ਦੇ 25% ਨਾੜ ਨਾਲ + ਹਰੀ ਖਾਦ) ਅਤੇ ਉਪ ਪਲਾਟਾਂ ਵਿੱਚ ਕਣਕ ਦੀ ਫ਼ਸਲ ਦੀ ਕਾਸ਼ਤ (ਪ੍ਰੰਪਰਾਗਤ ਬਿਜਾਈ, ਪਰਾਲੀ ਤੋਂ ਬਗੈਰ ਬਿਨਾਂ ਵਹਾਈ ਅਤੇ ਪਰਾਲੀ ਸਹਿਤ ਬਿਨਾਂ ਵਹਾਈ) ਕੀਤੀ ਗਈ। ਤਜ਼ਰਬੇ ਦੇ ਨਤੀਜਿਆਂ ਤੋਂ ਇਹ ਪਤਾ ਚੱਲਿਆ ਹੈ ਕਿ ਮਿੱਟੀ ਵਿੱਚ ਪੀ ਐਚ ਦੇ ਘਟਣ ਨਾਲ ਅਤੇ ਜੈਵਿਕ ਕਾਰਬਨ ਦੀ ਮਿਕਦਾਰ ਦੇ ਵਧਣ ਨਾਲ ਲਘੂ ਤੱਤਾਂ ਦੀ ਉਪਲਬਧਤਾ ਵਿੱਚ ਵਾਧਾ ਹੋਇਆ। ਕੱਦੂ ਕੀਤਾ ਝੋਨਾ ਕਣਕ ਦੇ 25% ਨਾੜ ਨਾਲ+ਹਰੀ ਖਾਦ ਵਿੱਚ ਲਘੂ ਤੱਤਾਂ ਵਿੱਚ ਹੋਈਆਂ ਨਿਯਮਤ ਤਬਦੀਲੀਆਂ ਤੋਂ ਇਹ ਤੱਥ ਸਾਹਮਣੇ ਆਏ ਕਿ ਇਹ ਲਘੂ ਅੰਸ਼ ਅਕਲਿਊਡਿਡ ਰੂਪ ਤੋਂ ਉਪਲਬਧ ਰੂਪਾਂ ਵਿੱਚ ਤਬਦੀਲ ਹੋਏ। ਕੱਦੂ ਕੀਤੇ ਝੋਨੇ ਵਿੱਚ 25% ਕਣਕ ਦੇ ਨਾੜ ਅਤੇ ਹਰੀ ਖਾਦ ਦੀ ਸਾਂਝੀ ਵਰਤੋਂ ਵਾਲੇ ਉਪਚਾਰ ਅਧੀਨ, ਕਣਕ ਅਤੇ ਝੋਨੇ ਦੇ ਦਾਣੇ ਅਤੇ ਪਰਾਲੀ ਵਿੱਚ ਪੌਸ਼ਟਿਕ ਤੱਤਾਂ ਦਾ ਗ੍ਰਹਿਣ ਅਤੇ ਉਤਪਾਦਕਤਾ ਸਭ ਤੋਂ ਵਧੇਰੇ ਦਰਜ ਕੀਤੀ ਗਈ। ਦੋਵਾਂ ਖੋਜ਼ ਅਧਿਐਨਾਂ ਦੁਆਰਾ ਦਰਸਾਏ ਗਏ ਨਤੀਜਿਆਂ ਤੋਂ ਇਹ ਸਾਬਤ ਹੋਇਆ ਕਿ ਕਣਕ ਦਾ ਨਾੜ, ਝੋਨੇ ਦੀ ਪਰਾਲੀ ਅਤੇ ਹਰੀ ਖਾਦ ਵੱਖੋ-ਵੱਖਰੇ ਜਾਂ ਮਿਸ਼ਰਤ ਹਾਲਤ ਵਿੱਚ ਪਾਉਣ ਨਾਲ ਜ਼ਮੀਨ ਦੀ ਪੀ ਐਚ ਘਟਦੀ ਹੈ ਅਤੇ ਜੀਵਿਕ ਮਾਦਾ ਅਤੇ ਲਘੂ ਤੱਤਾਂ ਦੀ ਬਹੁਤਾਤ ਹੁੰਦੀ ਹੈ।

ਮੁੱਖ ਸ਼ਬਦ: ਟਿਲੇਜ਼, ਝੋਨਾ ਲਾਉਣ ਦੇ ਵੱਖੋ ਵੱਖਰੇ ਤਰੀਕੇ, ਰਹਿੰਦ-ਖੂੰਦ ਦੀ ਸੰਭਾਲ, ਹਰੀ ਖਾਦ, ਲਘੂ ਤੱਤ, ਕਣਕ ਝੋਨਾ

ਮੁੱਖ ਸਲਾਹਕਾਰ ਦੇ ਹਸਤਾਖਰ

ਵਿੱਦਿਆਰਥੀ ਦੇ ਹਸਤਾਖਰ

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CHAPTER I

INTRODUCTION

Rice-wheat (RW) is a dominant cropping system responsible for food security (Chauhan *et al* 2012) and livelihood of millions of people in South Asian countries (Singh *et al* 2014). Rice-wheat system (RWS) has been practicised on around 13.5 million hectares (M ha) of the Indo-Gangetic plains (IGP) (Gupta and Seth 2007), of which 10 M ha in India account for one-third of the total cereals production. Punjab and Haryana, termed as "food bowl of India", contributes to 69% of the national food production which account for 84% of the total wheat and 54% of the total rice. However, RWS has arised many soil, water and environmental issues which are threat to sustainability of the system. Appearance of multiple nutrient deficiencies, decreasing soil organic matter (SOM), buring of residues and deteriorating water quality are some of the major reasons for declining RW productivity (Ladha *et al* 2000). Further, poor management of crop residues and excessive use of conventional production technologies deteriorates soil and environemental health. High input costs of water application, fertilizers, machinery and labour have dwindled farm profitability (Jat *et al* 2009). Moreover, excessive explotation and unsustainable use of ground water has declined and deteriorated water table in some key RW areas of South Asia (Kataki *et al* 2001). Therefore, proper planning and executing strategic initiatives are highly crucial for management of gradually deteriorating natural resources and sustaibable crop production, soil health and production environment in the RW growing areas (Balasubramanian *et al* 2012).

Resource conservation technologies (RCTs) based on conservation agriculture (CA) are gaining momentum as an substitute to conventional practices for addressing the problems of energy, labour, water scarcity, environment degradation, climate change (Gathala *et al* 2013, Jat *et al* 2015) and enhancing the productivity of RWS in South Aisa (Zhang *et al* 2014, Dikgwatlhe *et al* 2014). Some of the CA based RCTs include zero tillage, direct seeded rice (DSR) and insitu incorporation of crop residue and green manure in soil (Ladha *et al* 2003, Kumar and Ladha 2011). Hence, increasing productivity and keeping pace with the escalating food demand with minimum environmental disturbance has become a challenge to farmers and scientists.

Rice straw has poor nutritive value for animals because of high silica content (Mandal *et al* 2004). Despite higher ecological concerns, open buring of rice straw is an easy alternative for timely residue management. In Punjab, nearly 16 million tonnes of rice straw is burnt annually (Yadvinder-Singh *et al* 2008) leading environmental pollution and losing SOM and nutrients (Bijay-Singh *et al* 2008). In-situ soil incorporation of rice residue or leaving on soil surface as mulch improves physical, chemical and biological properties of soil by improving SOM, soil structure and conserving soil moisture. Beside, it helps in suppression of weeds and reduces environmental degradation. The development of zero tillage machine and Turbo Happy Seeder enables wheat sowing directly into rice residues that are retained over the surface soil (Sidhu *et al* 2007, Kumar *et al* 2013, Yadvinder-Singh *et al* 2014, Kaur *et al* 2014) which ultimately results in higher wheat yield in various on-farm trials.

Tillage systems affect the soil properties and growth and development of crops. Tillage system affects soil compaction and water availability which modify the distribution pattern of macro- and micro-nutrients in surface soil (Hangrove 1985, Carter and Gupta 1997) and their uptake by plants (Shierlaw and Alston 1984, Lavado *et al* 1999, Arvidsson 1999). With the advent of minimum tillage (MT) techniques, larger amount of organic matter accumulate on the topsoil which ultimately results in alteration of status of micronutrient cations (Shuman and Hangrove 1985). Iron (Fe) and manganese (Mn) concentration increases in the exchangeable and organic fractions under no-tillage as compared to conventional tillage practices due to conversion from occluded forms to more plant available forms. The effects of no-till were greater for Mn and Fe as compared to zinc (Zn) and copper (Cu). Further, Mn, Cu, Fe and Zn move into the exchangeable and organic fractions at low pH and Eh (reducing conditions) than at high pH and Eh (oxidizing conditions) (Sims and Patrick 1978). Thus, under reduced conditions and with an addition of organic matter in soil, microelements will become more available and move into the organic fraction.

Furthermore, tillage techniques influence SOM and soil pH which eventually affected the availability as was as the distribution of micronutrient cations. Mahler *et al* (1985) specified that tillage system can affect DTPA-extractable Fe and Mn level in soil. He showed that the surface soil under conventional tillage (CT) and MT contained greater amounts of Fe and Mn than NT plots. Conversely, Santiago *et al* (2008) observed that Mn, Cu, and Zn concentration in plants were higher with NT system than CT and MT systems. The difference was associated with an increase in SOM in the NT systems. In CT and conservation tillage systems, nitrogen fertilization is also a factor that can alter soil quality and fertility thereby affecting the uptake of Zn, Cu, Fe and Mn by the crop and weeds.

Direct seeded rice (DSR) offers various benefits like more efficient water use, high tolerance to water dearth, less methane (CH_4) gas emissions, decreased the cultivation cost, preventing the formation of compact layer in sub-soil and minimizing the labour input (Balasubramanian and Hill 2002). Direct seeding of rice permits early wheat planting and increasing wheat productivity (Ladha *et al* 2000). The yields of DSR and puddled transplanted rice (PTR) were significantly same provided there is no weed competition (Yadvinder-Singh *et al* 2010).

Leguminous green manure (GM) is a standard management tool in cropping systems, due to the reason that it highly affects the soil productivity and N dynamics in the soil-plant system and provides N to subsequent crops (Chauhan *et al* 2012, Singh *et al* 2014). The incorporation of green manure crop before rice under RWS is considered to be highly advantageous than a simple rice-wheat sequence (Gathala *et al* 2013). Organic amendments such as green manure (GM), farm yard manure (FYM), and crop residue (CR) etc. have obvious effect on the solubility as well as availability of different fractions of zinc due to their bio-degradation in soil (Singh *et al* 2006, Mishra *et al* 2009, Dhaliwal *et al* 2012). An addition of GM having lower C:N ratio to lowland rice brings about numerous changes in soil chemical properties and various nutrient transformations which can improve the sustainability of soil N fertility in lowland rice. Increase in rice yield was observed when whole of the wheat straw was retained over soil surface along with incorporation of *Sesbania* green manure (Aulakh *et al* 2001, Yadvinder-Singh *et al* 2004) in RW system. The soil compaction due to puddling in rice adversely effects the soil structure and root growth of succeeding wheat crop which ultimately results in inefficient use of both water and nutrients (Kirchhof and So 1996, Gathala *et al* 2011a).

The amount of SOM has a great impact on various soil properties. Addition of fresh organic matter (OM) causes a flush of microbial activity and adds complexing agents to the soil, which affects the redox potential of the soil. Surface placed residues reduce rapid leaching of soil nutrients, which is more likely when residues are incorporated into the soil. Formation of higher number of continuous pores between the surface and the subsurface soil layers under NT (Kay 1990) may lead to more rapid passage of soluble nutrients deeper into the soil profile as compared tilled soil.

Various research studies revealed the effect of different tillage systems, rice establishment methods and crop residue management practices on the chemical as well as physical properties of the soil. The information on surface and depth wise distribution of DTPA-extractable micronutrient cations (Zn, Cu, Fe and Mn) with different tillage systems, rice establishment methods, green manure incorporation and crop residue management practices is meager in rice-wheat system. Also the information on transformation of different micronutrient actions related to different tillage systems and rice establishment methods in the system is lacking and needs to be investigated. Hence, there is need to study the effect of tillage, different rice establishment systems on wheat yield, green manuring and crop residue on micronutrients (Zn, Cu, Fe and Mn) availability and their transformation under rice-wheat system. Taking these points into consideration the research has been conducted with the following objectives;

1. Effect of tillage, green manure, rice establishment methods and crop residue management practices on yield and uptake of micronutrients in grain and straw
2. Effect of tillage, green manure, rice establishment methods and crop residue management practices on soil pH, EC and SOC

3. Effect of tillage, green manure, rice establishment methods and crop residue management practices on surface and profile distribution of DTPA-extractable micronutrients (Zn, Cu, Fe and Mn) in soil
4. Effect of tillage, green manure, rice establishment methods and crop residue management practices on chemical fractions of micronutrients (Zn, Cu, Fe and Mn) in surface soil

CHAPTER II

REVIEW OF LITERATURE

Literature on yield, nutrient uptake in rice and wheat crops, micronutrients distribution and their transformation in soil as influenced by tillage, rice establishment methods, green manuring and crop residue management practices under rice-wheat system has been reviewed under following heads:

2.1 Yield and yield attributes of rice and wheat crops

2.2 Nutrient uptake by wheat and rice

2.3 Chemical properties of soil

2.4 DTPA-extractable micronutrients in soil

2.5 Chemical fractionation of micronutrients

2.1 Effect of tillage, green manuring, rice establishment methods and crop residue management practices on yield and yield attributes of rice and wheat crops

The rice–wheat (RW) cropping system occupies 13.5 million hectares (m ha) in the Indo-Gangetic Plains (IGP) of India, Bangladesh, Nepal and Pakistan (Gupta and Seth 2007) and are important to income, employment and livelihood for millions of people in the region. In India only, RW rotation occupies approximately 10.5 m ha and it contributed nearly 40% of the country's total food grain basket (Saharawat *et al* 2010). In this rain dependent agro-ecology, the conventional system of rice planting intensively includes dry and wet tillage followed by transplanting of 25-40 days old seedlings. So, for most of the time, farmers are unable to transplant rice seedlings in time which eventually leads to lessening in rice yield. Moreover, the conventional rice planting system increases the cost of production and delays the sowing of succeeding wheat crop. Also the repetitive wet tillage operations in rice not only destroy soil structure which ultimately causes 8–9% reduction in wheat yield as compared to wheat grown after DSR but are also labour, time, energy, water and carbon inefficient (Kumar and Ladha 2011). There are numerous factors which enforced the farmers to admit sub-optimal and inadequate management practices to grow rice and wheat that end-up with low productivity and profitability. Therefore, the farmers of the IGP immediately need technologies that have twin benefits of dropping production costs while augmenting productivity on sustainable basis. To address the challenges of rice–wheat production system defined above, conservation agriculture (CA) based alternative tillage and crop establishment methods have been designed which plays vivacious role in RW production system (Malik *et al* 2014, Ladha *et al* 2009, Jat *et al* 2013).

The conservation agriculture (CA) is systems based management optimization comprising a paradigm shift from intensive tillage to reduced tillage, founding of permanent organic soil cover with economically feasible crop rotation that complement reduced tillage as well as residue retention over the soil surface (FAO 2013). Experimental indication from various production environments guides that CA based management practices can have both instant, e.g. reduced production costs, stabilized crop yield, improvement in water productivity, adaptation to climatic erraticism (Hobbs 2007, Bhushan *et al* 2007, Jat *et al* 2009, Malik *et al* 2014) and long-term benefits, e.g. higher soil organic matter (SOM) contents and improved soil quality (Gathala *et al* 2011b, Kienzler *et al* 2012). However, the extent of benefits of CA based technologies tends to be site and situation specific and cannot be overly generalized across farming systems (Hobbs 2007). Based on evidences primarily from Africa, Giller *et al* (2009) cautioned that CA should be judged on merits in different agro-ecological conditions and not be interpreted as a "silver bullet" towards attaining the economical, ecological and social dimensions of sustainable agriculture production. There is no universal template for CA based management and production practices, so the actual practices employed for CA always need a process of refinement and localization to boost system performance in different environments (Kienzler *et al* 2012). CA based cropping system ought to be designed for and tested in specific location in order to have significant adoption (Ladha *et al* 2009).

Continued puddling for rice cultivation over decades has led to deterioration of soil physical properties through structural breakdown of soil aggregates and capillary pores and clay dispersion thereby restricting germination and rooting of succeeding crops (Tomar *et al* 2006). Therefore, it is imperative that alternate method of growing crops that are more water efficient and less labour intensive to be developed to enable farmers to produce more with less cost of production. Huge labours are needed to accomplish transplanting of rice seedlings and mostly it is delayed to a greater extent due to unavailability of adequate labours during transplanting peak. Thus, late planted rice takes more time to reach the maturity, which not only reduces the rice yield but also delays sowing of succeeding crop particularly wheat but direct seeding of rice can reduce the labour and water requirement, shorten the duration of crop by 7-10 days and provide comparable yield with transplanted rice (Mishra *et al* 2010). A shift in rice production system from transplanted rice to direct seeding is testimony of the resource conservation technologies (Gupta *et al* 2006). In plains of Eastern India, sowing of wheat gets delayed due to wet condition after rice harvesting which takes much time to come in working condition. On the other hand, ZT minimizes loss on account of delayed sowing as it advances the wheat sowing by 10-15 days and also saves the time and cost involved in field preparation. CT wheat sowing, which requires excessive tillage delays the sowing and reduce the yield, but the same can be accomplished efficiently with use of improved machines, viz. zero, strip and rotavator till drill etc. to save the time, fuel, energy and cost (Jha *et al* 2007).

A no-till system is a soil management technique that reduces soil disturbance, increases soil organic matter accumulation and can also increase crop yield (Santos *et al*

2012). No-till and minimum tillage systems can produce rice grain yield similar to those produced with conventional puddling (Mabbbayad and Buencosa 1967, Mittra and Pieris 1968, De *et al* 1979, Rodriguez and Lal 1979). It has also been reported that in clay soil, minimum tillage produced the similar grain yield as through puddling (Sharma *et al* 1988). Another study recorded that the direct seeded zero tillage gave at par yield as compared with transplanted rice (Singh *et al* 2008). ZT rice after spray of glyphosate @ 0.5 kg a.i/ha gave significantly higher yield over the other methods of establishment. The rice yield was statistically at par in case of zero tillage when compared with the conventional tillage system in direct seeding of rice (Bhatacharaya *et al* 2006). It was further reported that zero tillage may be adopted as resource conservation technology and producing good crop yield. Another study reported that direct seeded rice with conventional seeding (in the prepared field) or rotavator seeding was better than zero till seeding. However, soil quality parameters (viz. soil organic carbon concentration, bulk density and moisture content) were significantly better under conservation tillage (zero and rotavator) than conventional tillage (Bazaya *et al* 2009). The establishment of rice under different tillage systems proved that rice can be successfully grown under zero till transplant and proved to be more suitable alternative of conventional method of puddled transplant. The grain yield of rice under zero tillage (6.74 t/ha) was significantly higher than puddled transplant (6.19 t/ha). Similar results were also reported by Reddy (2004). Reddy *et al* (2005) conducted an experiment on farmer's field and observed that grain yield of rice under zero tillage (6.36 and 6.74 t/ha) was similar to the puddled transplant (6.33 and 6.72 t/ha) in 2002 and 2003, respectively.

Saharawat *et al* (2010) reported that number of effective tillers was numerically (9 per cent) higher in direct seeded rice as compared to the conventional tillage rice. However, Kumar *et al* (2005) studied the effect of different planting methods on the productivity of rice at farmer's field. They were observed that number of effective tillers, spike length and 1000-grain weight was maximum under zero tillage which was at par with the unpuddled transplant. Thus as a result, the rice yield was statistically at par in zero tillage when compared with the unpuddled transplant and puddled transplant. The highest pooled yield (8.5 t/ha) of rice was recorded with drum seeding (wet bed) followed by direct seeding under dry bed and mechanical transplanting-puddled compared to manual transplanting-puddled and mechanical transplanting in unpudddled conditions (Gangwar *et al* 2006).

Ranwa and Singh (1999) in two a year study at Hisar (Haryana) reported that organic manures improved the yield attributing characters of wheat *i.e* effective tillers m^{-1} row length, number of grains $spike^{-1}$, grain weight $spike^{-1}$ and test weight. The valuable effect of organic sources on yield attributes could be attributed to the fact that after proper decomposition and mineralization of organic manures, the manures supplied available plant nutrients to the plants and also had solubilizing effects on fixed form of nutrients in soil. In a similar study Nehra *et* *al* (1999) stated that organic manure application or green manure incorporation increased dry matter accumulation, number of effective tiller, grains per ear of wheat. Ebaid and Refaee (2007) found that 20 ton ha^{-1} organic manure was adequate for the highest values for panicle length, number of panicles m^{-2} and no of grains/panicle of rice. Bassal and Zahran (2002) found that addition of FYM significantly increased flag leaf area, plant height, number of panicles per m^2, panicle length, panicle weight, number of filled grains/ panicle, 1000-grain weight, grain yield and straw yield in rice.

In North-West India, burning of rice residues is very common which leads to easy tillage and seeding operations, control of weeds and it also reduces impediment to the newly growing crops (Yadvinder-Singh *et al* 2005). To solve the issue of rice straw burning and late sowing of wheat, a new machine called Happy Seeder (HS) has been developed for in-situ management of straw in the field (Sidhu *et al* 2007). The mulching of rice straw also has a noteworthy effect on conserving initial soil moisture and reducing weed growth. Residue retention alongwith conservation tillage systems mends SOM and availability of nutrients in the surface soil layer, which ultimately buffers the soil against raindrop impact, suppresses evaporation (salinization) and erosion, and thus improves conservation of water in soil (Lal 2009). The cultivation of wheat crop in zero till soil of a post rice harvest field utilizes residual soil moisture and reduces the time period from rice harvest to wheat seeding in intensive rice-wheat cropping system (Rahman *et al* 2005).

Yadvinder-Singh *et al* (2005) stated that data regarding the chemical composition of crop residues is essential to know about the quantity of nutrients released in the soil upon the crop residue decomposition. The crop residues played a fundamental role in the maintenance of the soil quality at acceptable levels which are the key sources of carbon inputs. Cereal straws are poor with respect to nitrogen and phosphorus content thus, wheat sown immediately after the incorporation of rice residues or straw suffer due to unavailability of plant available N (Mary *et al* 1996). Fertilizer nitrogen is more effective in no-tillage when the straw is retained rather than removed or incorporated (Malhi and Nyborg 1990). Availability of nitrogen from rice residues to subsequent wheat is highly dependent on rate of decomposition of crop residues, the quality of the residue and environmental conditions (Fox *et al* 1990).

In rice-wheat system, the crop residues incorporation by disc plough or by mould-board plough is a better option for effective disposal of residues which may produce higher yield and net farm returns compared to their removal or in-situ burning. Yadvinder-Singh *et al* (2010) informed that rice straw incorporation has higher wheat grain yields and builds up of soil fertility as compared to no-rice straw incorporation. Qamar *et al* (2012) reported that zero tillage (ZT) recorded higher grain yield of wheat under deep tillage as compared with conventional tillage (CT). Saharawat *et al* (2013) reported that ZT wheat produced significantly higher yield followed by reduced tillage (RT) and CT. Lowest yield in CT wheat was due to significantly lower number of effective tillers and low 1000 grain weight with respect to the ZT. Gathala *et al* (2011a) conveyed that direct drilling of wheat in the presence of rice residues using the Happy Seeder produced significantly higher grain yield with respect to ZT without rice residue and CT. Higher wheat yield was also obtained under ZT over CT (Yadav *et al* 2005). Naresh *et al* (2013) conducted a field experiment for 3 years to examine the effect of rice residues and its management on different properties of soil and on the crop productivity. The results indicated that before planting of the wheat crop, the incorporation of residues of both crops in rice-wheat system (RWS) augmented the available form of nitrogen, phosphorus and potassium contents in soil over removal and burning. The surface retention of crop residues increased the uptake of micronutrients as well as macronutrients like nitrogen, phosphorus and potassium by 14.7, 28.4 and 17.8%, respectively. The total productivity of the system increased by 10.8-15.9% in residue retention plots with permanent wide beds planting, Happy Seeder sown and NT planting system over CT. Rahman *et al* (2005) reported that the rice straw mulching had a significant effect on conserving initial soil moisture and reducing weed growth. They further reported that rice straw mulching with 120 kg N ha^{-1} had significantly grain yield of wheat under ZT as compared to without rice straw mulch due to higher plant density, spike density and 1000-grain weight. Khalid *et al* (2013) indicated that under irrigated conditions in a hot arid climate when crop residues were left on the soil surface, the final biomass and grain yield of wheat under ZT were similar to those obtained under RT and CT. Wasaya *et al* (2017) conducted a 2 year study in a maize crop comprising of 3 tillage permutations viz. conventional tillage (using cultivator), deep tillage with mould board plough and deep tillage with chisel plough. They found that maize crop under chisel plough exhibited under higher leaf area index and crop growth rate, which finally resulted 23% and 8% higher grain and dry matter yield, respectively as compared with mould board tilled plots.

The incorporation of green manure in combination with wheat residue can be advantageous in alleviating the adverse effects of wheat residue on rice due to nitrogen immobilization and can increase yield (Yadvinder-Singh *et al* 2004). Sharma *et al* (1995) informed that *Sesbania* GM and mungbean residue incorporation in rice augmented the grain yield of succeeding wheat by 0.3-0.8 t ha^{-1}. Sharma and Prasad (1999) indicated that both *Sesbania aculeata* and *Sesbania rostrata* increased the yield of succeeding wheat by 0.2-0.3 t ha^{-1}. Saha and Mandal (2000) observed that dry matted production of wheat was significantly affected by preceding GM crops. Kumar and Sharma (2000) observed that *Dhaincha* and blackgram had significantly positive impact on the growth and yield attributes of wheat which eventually resulted in significantly higher wheat grain yield as compared to the control plots (no green manure application). According to Voisin *et al* (2014), growing of leguminous crop

(*Asragalus sinicus* L.) prior to rice crop leads to maximum utilization of natural resources (light, water and heat) which ultimately leads to increase of rice yield at a maximum economic as well as environmental cost. Jat *et al* (2015) reported that the residual effects of incorporation of mungbean (*Vigna radiata* L.) residue resulted in significantly higher grain yield of succeeding wheat crop.

Hossain *et al* (2016) observed that incorporation of legumes in the wheat rice cropping sequence resulted in higher wheat equivalent yield than wheat-fallow-rice cropping sequence. The total system productivity increased by 65%, 49% and 5% in 2009-2010, and by wheat-soyabean-rice, wheat-dhaincha-rice, respectively, as compared to in wheat-fallow- rice, indicating that the recycling of the legume residues could partly substitute N for rice and had a considerably positive impact on the ensuing wheat crop. Lampurlanes *et al* (2016) reported higher yield of wheat, barley, canola and wheat crop in a long term tillage experiment under NT followed by sub soiling up to 50 cm soil depth and lowest yield was found under mould board plough. Singh *et al* (2016) observed that the grain yield of puddled transplanted rice (PTR) was higher than CT-DSR and ZT-DSR in a 5 year study on rice-maize system in NW India. They further observed maize yield was 4% and 14.2% higher than ZT-DSR/zero tilled maize as compared with conventionally tilled maize preceded by CT-DSR and TPR. Banjara *et al* (2017) observed significantly higher seed and stover yield, pods per plant, dry biomass, no. of branches and plant height of chick pea under minimum tillage and line sowing of seed at third day after harvesting rice as compared with zero tillage and conventional tillage practices. Mu *et al* (2016) examined the effect of different tillage practices on crop yield in a wheat-maize system in north China. They observed that deep mould board ploughing at depth of 30 cm and chisel ploughing significantly increased wheat yield by 6% and 7.3% and maize yield by 8.7% and 9% respectively, as compared with mould board ploughing to a depth of 15 cm.

2.2 Effect of tillage, green manuring, rice establishment methods and crop residue management practices on nutrient uptake by wheat and rice crops

Micronutrients availability in soil is directly related with their uptake by plants and content in staple foods, which not only directly affect food quality but also are closely linked to the health of humans. Earlier studies have shown that incorporation of organic materials or green manure, which contain considerable amount of iron, significantly increase crop uptake and soil availability of Fe (Mann *et al* 2006, Walia *et al* 2010). Long-term application of crop residues or green manure incorporation increases the SOM content which increase the Zn availability (Rehman *et al* 2012). Further, Behera *et al* (2011) observed that, Zn forms labile organic mineral complexes during the organic matter decomposition, which increase the available Zn concentration in soil. Duhan and Singh (2002) showed that the crop residue application increases the Mn uptake by plants. Earlier studies have observed that the balanced fertilization increases grain yield, accelerates rice nutrient uptake and maintains soil nutrient balance (Mann *et al* 2006, Li *et al* 2007, Xue *et al* 2014). Use of the nitrogenous fertilizers, reduce soil pH which augments mobility of Fe, Zn, Cu and Mn in soil (Uprety *et al* 2009). Chhibba (2010) concluded that the nutrients taken up by the cereal crops, on an average, 25% of N and P, 50% of S, 75-80% of K and 50-80% of Zn, Cu and Mn are retained in crop residues making them valuable nutrient sources. Prasad *et al* (2010) observed increased the uptake of micronutrients (Fe, Mn, Cu and Zn) with retention of paddy straw and wheat straw. Walia and Kler (2010) found that application of FYM along with soil incorporation of crop residue and green manuring significantly increased the micronutrients (Fe, Mn, Cu and Zn) uptake by maize than inorganic fertilization alone in maize-wheat due to the increased DTPA-extractable Fe, Mn, Cu and Zn in soil.

The uptake of Zn, Cu, Fe and Mn is influenced by soil conditions and cropping system. In alkaline soils, uptake of Zn, Fe, Cu and Mn was higher in rice than wheat under rice-wheat system (Gupta and Mehla 1993). Tiwana and Narang (1997) observed Zn, Cu, Fe and Mn uptake by wheat, in rice-wheat cropping system under heavy fertilization, corresponding to 445,68,1218 and 212 g ha^{-1} at 180-60-30 and 414, 40, 1043 and 158 g ha^{-1} at 120-60-30 NPK levels respectively. The uptake of Zn, Cu, Fe and Mn in straw and grain showed that much of the Zn, Cu, Fe and Mn were ranged from 67-69, 73-76, 81-85 and 79-81 per cent respectively in rice and 71-72, 66-68, 77-78 and 56-64 per cent respectively in wheat. Sakal (2000) observed that the increasing doses of N, P and K progressively increased the Zn, Cu, Fe and Mn uptake by rice, wheat and sorghum crops. The removal of Zn is more in rice followed by wheat and sorghum. The total uptake of Zn by these 3 crops was 2.53-6.53 (average 4.92) kg ha^{-1}. The mean Cu uptake by rice, wheat and sorghum were 0.82, 0.74 and 0.71 kg ha^{-1} respectively. Whereas, the Fe and Mn uptake by rice crop was more with respect to wheat and sorghum as these elements in rice soil were present in readily available form. In rice and sorghum the uptake pattern were Fe > Mn > Zn > Cu and in wheat it was Fe > Zn > Mn > Cu.

Ali and Mishra (2000) observed the uptake of micronutrients (Zn, Cu, Fe and Mn) under pulses based cropping system. They reported that in the leguminous crop (chickpea), application of 25 kg ha^{-1} improved nodulation, root growth and yield and also increased uptake of Zn and Fe. The effect of fertilizers and organic materials on uptake of micronutrients by rice and wheat crops under rice-wheat cropping system was observed by Prasad and Sinha (2000) on long term experiment in Bihar. They reported that the uptake of micronutrients (Zn, Cu, Fe and Mn) was increased upto 100 per cent N, P and K and beyond this level, their uptake slightly dropped. The uptake of Zn, Cu, Fe and Mn by wheat and rice in plots treated with organic manure and crop residues was in the order of FYM + crop residue > FYM > crop residue > no organic manure or crop residue. The higher uptake of Cu, Fe and Mn were 63, 510 and 250 g ha^{-1} in rice crop except Zn. The Zn uptake was higher in wheat crop (139 g ha^{-1}) in control plot.

Ghosh *et al* (2001) reported that the biomass produced by soybean was higher than wheat under soybean-wheat cropping system and average uptake of Zn, Cu, Fe and Mn by soybean was more as compared to the wheat. The crops also differ significantly in their requirements to remove Zn, Cu, Fe and Mn from the soil. The uptake of Fe and Mn was much higher than that of Zn and Cu because of their higher initial concentration in soils. Li *et al* (2007) stated that the maize stalks contained higher concentration of Zn, Cu, Fe and Mn (12.1, 8.6, 679 and 35.4 mg kg^{-1} respectively) than wheat straw (6.31, 2.43, 348 and 31.5 mg kg^{-1}respectively) whereas, wheat grain had higher Zn, Cu, Fe and Mn than corn grain. The effect of organic manure application and fertilizer on Zn, Cu, Fe and Mn uptake by rice under rice-wheat cropping system was observed by Walia *et al* (2008). They reported significantly highest uptake of Zn, Cu, Fe and Mn recorded in treatments of 75 per cent recommended N + 25% N through GM application than 50 percent recommended N + 50% N through GM application and 100 per cent recommended N + 50% N through farm yard manure application, respectively. The uptake of Zn, Cu, Fe and Mn in rice (grain + straw) ranged from 389.4-864.8, 41.9-153.9, 533-1319.1 and 730.6-1679.3 g ha^{-1} respectively. Khan *et al* (2002) reported that, the uptake of micronutrients were higher in case of N, P, K, S and Zn treatments under rice-wheat cropping system on different fertilizer treatments. Uptake of micronutrients cations was higher when all common fertilizer (N, P and K) and additionally S and Zn were applied which indicated that balanced fertilization can greatly influence the uptake of micronutrient cations. Lu *et al* (2004) reported that the Mn uptake by rice increased significantly under flooding. It appears that the increased Mn uptake by rice was another cause of Mn spatial distribution in soil profile. The uptake of Mn by rice was the main pathway of Mn spatial distribution on the clay textured and low pH soil. Chandi and Takker (1982) found the uptake of Zn by different cropping systems viz. rice-wheat, maize-wheat, groundnut-wheat, bajra-gram, guara-potato and mash-raya. They reported that the uptake of Zn increased with increase in rates of Zn irrespective of crop and rotation because of increase in available Zn and dry matter yield of crops. The mean uptake of Zn was higher in rice followed by potato, bajra, wheat, groundnut, maize, raya, guara and gram crop and rice-wheat followed by guara-potato, maize-wheat, groundnut-wheat, bajra-gram, mash-raya rotation. Bharadwaj *et al* (1994) reported that the Zn, Cu, Fe and Mn uptake were lowest in the plots receiving no fertilizer or manure treatment since the initiation of the experiment. This clearly indicated that continuous cropping without fertilization caused the lowest uptake of Zn, Cu, Fe and Mn as compared to fertilized plots.

2.3 Effect of tillage, green manuring, rice establishment methods and crop residue management practices on chemical properties of soil

Soil properties viz. pH, SOM and available macronutrients are significantly affected by mineral fertilizers and crop residues or organic manures which determine the availability of micronutrients to plants (Rutkowska *et al* 2014). Change in frequency and intensity of tillage practices changes the soil properties, distribution of macronutrients and micronutrients, and SOM content in surface as well as in soil profile. These changes turn out to be sustainable and could affect the availability of plant nutrients for crop growth, crop production, and soil productivity. Long-term no-tillage (NT) systems store nutrients in the soil surface, while moldboard plowing (MP) distributes them uniformly throughout the tillage depth. Stratification of nutrients has been noted in long-term tillage practicies under NT, whereas soil mixing promotes uniform distribution of nutrients in MP and chisel plow (CP) (Ismail *et al* 1994). In contrast, Franzluebbers and Hons (1996) also observed similar changes in distribution of plant nutrients due to tillage practicies.

The decrease in surface soil pH under NT was observed with application of N (Blevins *et al* 1983), soil acidity (Dick 1983), and more OM (Franzluebbers and Hons 1996). Ismail *et al* (1994) found a high soil pH in the surface soil of NT than MP due to slow mixing of lime applied on the surface. SOM plays significant role in nutrient availability and soil aggregate stability. The soil productivity reduces when SOM decreases (Bauer and Black 1994). High residue producing crops along with NT increase SOM (Havlin *et al* 1990) and low residue producing crops in combination with MP decreases SOM (Edwards *et al* 1992). Crop residues have a residual effect on crop growth, OC, and N availability (Maskina *et al* 1993). An accumulation and distribution of OC in soil is affected by different tillage practices. Ismail *et al* (1994) observed a decrease in OC in the 0 to 30 cm layer in silt loam soil during the first 5 year, no change in the next 5 year, and an increase in the last 10 year in both NT and MP. Higher water-stable aggregates (>250 um) were found in a silt loam soil after continuous wheat crop (*Triticum aestivum* L.) than wheat-fallow rotation system due to continuous addition of crop residue (Monreal *et al* 2005). Franzluebbers and Hons (1996) evaluated the effect of different tillage (zero and conventional tillage) systems with sorghum stalk shredded on soil pH in soil profile in wheat crop (initial soil pH 8.2) and they observed that soil pH under zero tillage was 0.1-0.2 units lower than under conventional tillage at a depth of 0-5 cm, but there was no difference at lower soil depths.

Martinez *et al* (2013) studied the effect of different tillage systems (zero till with maize residue as mulch and conventional tillage with maize residue buried into the soil) on pH and electrical conductivity (EC) of soil in maize-wheat system. The acidity increased under ZT in the top 15 cm of soil layer as compared to CT. They also revealed the significant decrease in pH upto 2 cm soil depth under ZT than CT due to decomposition of crop residues, which releases H^+ ions in soil. They further observed that higher EC was observed in top 2 cm soil depth under ZT might be due to the greater biological activity. The soils under NT are normally more acidic in the surface layers but less acidic in deeper layers than under CT due to an increase in the soil organic matter and associated organic acids and changes in the proportions of cations and anions in soil under ZT (Logan *et al* 1991, Prasad and Power 1991). Yadvinder-Singh *et al* (2005) revealed that improved hydraulic conductivity and reduced evaporation under NT can increase soil acidification at surface with leaching of soluble salts and replacement of base-forming cations on the exchange complex by H and Al ions through decomposition of OM and disintegration of minerals, respectively. On the contrary, Mishra *et al* 2010 reported that soil pH and EC was not influenced by either ZT with rice straw or CT.

Gangwar *et al* (2006) studied the effect of different tillage systems on soil organic carbon content after three years of RWS. They observed that SOC was significantly increased under ZT as compare to CT. They further observed that rice straw incorporation into the soil significantly increased organic carbon in the soil as compared to rice straw removal. Mishra *et al* (2010) also found significantly higher SOC under ZT with rice straw as mulch than CT. Bhattacharya *et al* (2008) also found similar results that SOC was significantly higher under ZT as compare to CT in 0-15 cm soil layer after 4 years of RWS. However, SOC content in 15-30 cm soil depth remained almost unaffected in both ZT and CT. Martinez *et al* (2013) concluded that SOC was significantly more under ZT as compared to CT due to slower decomposition of crop residues in more compacted soil surface, which acts as a physical barricade for organic matter decomposition.

Mamta *et al* (2011) found that SOC content was significantly higher in ZT wheat following ZT transplanted rice than ZT wheat following puddled transplanted rice (PTR) and CT wheat following PTR at 0-5 cm soil depth. However, soil organic content at 5-10 cm soil depth was similar under all the treatments. Santiago *et al* (2008) stated that SOC content was significantly higher in ZT than CT in 0-5 cm soil depth. Wang *et al* (2008) also reported that soil organic carbon was significantly higher in ZT with wheat straw as mulch than CT at 0-5 cm and 5-10 cm soil depths but significantly lower at lower soil depths i.e. 10-20 cm and 20-30 cm. Dalal *et al* (2011) reported that conservation practices, predominantly ZT and crop residue retention, improved soil OC and N in the surface soil which was due to an accumulation of crop residues near the soil surface and a minimal or lack of soil disturbance which results in slow decomposition of crop residue.

Yadvinder-Singh *et al* (2005) reported that the effect of crop residues on soil pH may be insignificant, but management strategies may noticeably influence soil pH. Long-term studies (over 10 years) revealed that burning of straw increases soil pH as opposed to surface-managed residues. Yaduvanshi and Sharma (2008) considered the effect of tillage and rice straw management on soil pH after wheat harvest in RWS (initial soil pH 9.1) and observed that tillage and straw management did not affect the soil pH after 3 years of RWS in the 0-15 cm soil layer but soil pH remained slightly lower in ZT under rice straw retained plots as compared to the conventionally tilled plots. Kumar *et al* (2004) also studied the influence of tillage and rice straw management on soil pH and EC and found that tillage and rice straw (either removed or mulch) did not affect soil pH and EC. In contrast, Malhi *et al* (2011) reported that no significant effect of tillage (ZT and CT) and straw management (retained or removed) on soil pH in 0-15 cm soil layer in barley-wheat-canola rotation (initial soil pH 6.6).

Long term field study of thirty years was initiated on two different soil types by Yadvinder-Singh *et al* (2010) who reported that SOC content increased by 29.6% on sandy loam soil and 11.6% on silt laom soil with the retention of straw (mean of incorporation and surface mulch) compared with straw burning in sandy loam, respectively in RWS. The per cent increase in SOC content was more on sandy loam soil with lower initial organic carbon content than on silt loam. Ram *et al* (2013) observed that SOC was significantly increased with rice straw mulch as compared to without mulch in 0-15 cm soil depth. Choudhary *et al* (2014) observed that soil organic carbon was significantly greater in ZT wheat with rice straw retention than ZT and CT wheat in 0-15 cm soil layer.

2.4 Effect of tillage, green manuring, rice establishment methods and crop residue management practices on micronutrients availability in soil

Rice-wheat cropping (RWC) system has played fundamental role South Asia's food security as it contributes food grains for the region. High yielding varieties and higher application of inputs and improved crop management practices, the productivity of RWC system was increased which leads to Green Revolution primarily in North-Western India (Nawaz *et al* 2017). However, the success was accompanied by deteriorating soil health and resource degradation, which pose a serious threat to the sustained ability of the region to meet the food demand of increasing population. Hence, for restoration of soil health and productivity, there is an urgent need to look forward to other options like, crop residues incorporation for supplying plant nutrients especially micronutrients.

Changes in micronutrient distribution within the soil profile have been reported for different tillage systems. NT enhances Zn concentration in the first few cm of soil compared to CT (Edwards *et al* 1992, Hargrove 1985). Likewise, extractable Mn found to be greater in the surface soil layers with NT (Edwards *et al* 1992, Blevins *et al* 1983). However, no differences have been reported for extractable Cu, regardless of tillage system (Edwards *et al* 1992, Hargrove 1985). In an experiment, after 21 years of different tillage farming, it was concluded that more Cu, Mn and Zn appeared in surface layer (0-5 cm) horizon of soil under NT faming (Santiago *et al* 2008). Lavado *et al* (2001) stated that after 18 years of ZT, the topmost layer of soil (0-5 cm) contained more DTPA-Zn than an analogous soil layer under

CT. However, in the deeper soil horizon, CT soil was more abundant in this micronutrient. Carter (2005) observed that after 18 years of NT farming, the surface layer of soil (0-10 cm) contained more Mn than CT. Franzluebbers and Hons (1996), who carried out an 8-year study on loamy soil, demonstrated that the most extensive changes caused by NT occurred in the 0-5 cm soil layer, where Zn and Mn were more abundant, whereas the content of Cu was depressed (DTPA+EDTA extraction) compared to CT. At the same time, they observed that the 0-30 cm soil horizon was richer in all the three elements. According to Wright *et al* (2007), after just 5 years of ZT on loamy soil, the Zn content in the topmost layer of 0-15 cm was elevated in comparison to conventional tillage. Moreover, independently from the tillage method, the content of Zn tended to decline at deeper soil layers more profoundly than that of Mn or Cu. Another report (Martin-Rueda *et al* 2007) concludes that 4 year ZT farming has led to increased concentrations of Mn, Zn and Cu in soil (0-15 cm) versus ploughed soil. Nevertheless, changes in the concentration of micronutrients caused by extensive tillage appear more promptly in heavier soils and are observable in the topmost soil horizons as well as in deeper layers (down to 30 cm depth).

Continuous use of chemical fertilizers in the intensive cropping system, with low use of OM, resulted in quick depletion of micronutrients from soils (Santiago *et al* 2008). The accumulation of Zn in surface soil layers is caused by: (i) the addition through plant residues left over by the soils which have also been reported by Katyal and Sharma (1991), Setia and Sharma (2004), Verma *et al* (2005). Similar results were acquired by Khan *et al* (2002) and Wright *et al* (2007), where available micronutrient contents decreased with time. Balanced use of fertilizers, based on yield estimation, soil testing and plant analysis is recommended. Otherwise, continuous depletion of nutrients from the soil will continue, leading to yield decreases and low soil fertility. Soil OM content and its mineralization rate can influence levels of K, P and micronutrients in soil. Residue accumulation at the soil surface produces higher K and P concentration under conservation tillage than under CT (Thompson and Whitney 2000). Conventional tillage also accelerates organic P mineralization and nutrient accumulation in deeper soil layers (Varsa and Ebelhar 1999). Organic matter plays vital role in availability of micronutrients which tend to be in higher concentration in soils under NT, especially Zn and Mn, because of higher OM concentration (Franzluebbers and Hons 1996); although these micronutrients could be leached through complexation with humic acids. Westermann and Sojka (1996) did not find differences in micronutrient concentration among tillage systems, however, Rhoton (2000) observed higher levels of Mn and Zn concentrations and lower levels of Fe and Cu concentration under NT than under CT.

Singh *et al* (1999) observed noteworthy differences in DTPA extractable micronutrients cations after 10 years of continuous rice-wheat cropping under various fertilizers and manure treatments. Chaudhary and Narwal (2005) found that application of organic manures or crop residue significantly increased the DTPA extractable and total content of micronutrients in all soil depths, the increase was higher in the surface layer than in the lower depths. Application of appropriate rates of N, P and K fertilizers can increase soil Cu, Zn and Mn availabilities (Zhang *et al* 2004). Herencia *et al* (2008) observed that addition of compost resulted in an increase in micronutrients (Fe, Cu, Zn, Mn) as compared to soil with mineral nutrition. Concentration of all the DTPA extractable micronutrients in green manure plot increased compared to non green manure plots after rice as well as wheat harvest (Nayyar and Chhibba 2000). Khan *et al* (2002) concluded in a long-term fertilizer experiment that an application of organic manures resulted in redistribution of micronutrients from non available forms to readily available and potentially available forms in soil.

Herencia *et al* (2008) found that DTPA-extractable Cu was significantly correlated with soil organic matter content. Singh *et al* (2006) found that DTPA extractable micronutrient cations (Zn, Cu, Fe, Mn) in acid soils increased significantly in N, NP and NPK treated plots over the years. Maqueda *et al* (2011) had shown that an application of plant compost and the elimination of synthetic fertilizers resulted in an increase of Fe, Zn, Mn and Cu extractability as compared to soil treated with inorganic fertilization. Fan *et al* (2012) found that application of organic residues significantly increased DTPA Fe, Mn, and Cu concentrations in bulk soil as compared to control plots. Soil OM exerts a substantial and direct impact on the availability of Zn, Fe and Mn but has little influence on the availability of soil Cu (Zhang *et al* 2001). In addition, the interaction of other soil macronutrients and micronutrients also affected micronutrients uptake by crops (Aulakh and Malhi 2005). Kaushik *et al* (1993) reported that different fertilization treatments of a long-term field experiment can cause soil macronutrients and their available concentrations to change, which in turn affects soil micronutrient levels.

The relationship between metals and OM can either increase the solubility of the metals or contributing to their immobilization. Two of the most important soil properties that determine metal availability and leachability are pH and OM content, both soluble and particulate. The solid organic components added to soils provide new exchange sites for cations and binding sites for other molecules. Metals are retained in either readily or difficultly recoverable forms (Diaz-Barrientos *et al* 2003). However, mobilization of metals by organic substances that have been added to soils has also been observed. Organic compounds with functional groups that are capable to form stable complexes with metals can increase their concentration in the soil solution. Carlson-Ekvall and Morrison (1995) found that metal availability is strongly favoured in the presence of organic substances that have been identified in sewage sludge. Madrid (1999) indicated that organic amendments can increase the solubility of metals by producing ligands that chelate the metals, thereby blocking their sorption and promoting their release through the development of soluble metal complexes. Furthermore, SOM can modify the pH, which influences the nature and extent of metal retention by both solid and soluble organic compounds. Strobel *et al* (2005) showed that dissolved organic carbon (DOC) enhanced the release of Cu of soil from less than 8% (without) to more than 20% (with) of extractable Cu. Del Castilho *et al* (1993) found a substantial increase of Zn in the soil solution of organically amended soil. The availability of Fe was also affected by the formation of Fe and DOC complexes (Raulund-Rasmussen *et al* 1998). From the agricultural point of view, the availability of micronutrients is more important than the total metal concentration. According to Rupa and Shuka (1999), DTPA-triethanolamine and 0.1N hydrochloride (HCl) were the best extracting solutions for Zn and Cu, respectively, based upon the correlation between the concentration and uptake of both metals by rice plants. Other relevant studies have also shown that extractants, such as ethylene diamine tetraacetic acid (EDTA) and DTPA may give results that correlated well with plant uptake of micronutrients (Alvarez *et al* 2006). Adiloglu and Kursum (2003) indicated that these two chelating extractants were the most suitable for the determination of micronutrient availability. The application of organic compost to the soil can alter the distribution of metals with respect to that of the control soil. Different forms of metals have different mobility and phytoavailability (Shuman *et al* 2001).

2.5 Effect of tillage, green manuring, rice establishment methods and crop residue management practices on chemical fractions of micronutrients (Zn, Cu, Fe and Mn)

Zinc is one of the essential micronutrient and is required by the crop plants in very small amounts. It plays a fundamental role in various metabolic processes in plants. The deficiency of zinc in soil adversely affects the growth and development of crop plants. It was estimated that about 30 per cent of the agricultural soils of the world may be zinc deficient to the extent that normal growth and development of wide range of agriculturally important crops are affected (Sillanappa 1982). Takkar (1996) indicated that zinc deficiency is wide spread in Indian soils i.e. nearly 50 per cent of the Indian soils found to be deficient. Hence, Zn deficiency has become a major micronutrient constraint after N and P deficiency. In the soil environment, continues shifting of these nutrients from one form to other was reported by (Sharma *et al* 2004).

No tillage is being used more and more in an effort, not only to conserve soil, but to conserve energy and reduce production costs. No-tillage also conserves soil moisture making dryland cropping more profitable. Blevins *et al* (1983) showed that for the surface 0 to 15 cm soil layer there has a twofold increase in organic matter under NT versus CT after 10 yr. Stinner *et al* (1983) found that extractable ions were higher under CT in the 1st yr after plowing soil that had been in fallow for 12 yr. However, in the 2nd yr, the NT plots contained higher amounts of exchangeable ions. The immobile fertilizer elements also accumulate on the surface with NT. Chandi and Takkar (1982) found that added Zn accumulated in the top 0 to 5 cm layer under NT. Hargrove *et al* (1982) showed that Ca, Mg, P, Mn, and Zn accumulated on the surface with NT but K was lower on the surface in an acid Ultisol in the humid southeastern United States.

Besides tillage, cropping systems can influence soil properties, particularly soil organic matter and pH (Chandi and Takkar 1982). Thus, both no-tillage and cropping systems can influence soil properties, especially pH, organic matter and the availability of many plant micronutrients. Such changes in soil properties may cause the availability of micronutrients to change by shifting their various chemical forms. Zn is especially sensitive to soil pH. Exchangeable forms increase with decline in soil pH, but SpAd-Zn and MnOx-Zn increase with increases in pH (lyengar *et al* 1981). Miller and McFee (1983) fractionated a soil contaminated with Zn in the top 2.5 cm. Metals (Cd, Zn, Cu, and Pb) were higher in the exchangeable and organic fractions than for other fractions but relatively low in the CFeOx, MnOx, and RES fractions. Sims and Patrick (1978) found that Fe, Mn, Zn, and Cu were higher in the WSEX and OM-bound frcation at low pH and Eh than at high pH and Eh. The Fe, Zn, and Cu were higher in the WSEX, MnOx, and AFeOx fractions at high pH and Eh. Shuman (1979) found that Zn and Cu were mostly in the clay (residual) fraction for fine-textured soils, whereas Mn was found mostly in the WSEX and OM bound fraction.

Shuman (1985) found that Mn was primarily in the organic and Mn oxide fractions for finer-textured soils. There were high correlations between CEC, organic matter, and clay content vs. metals removed from the various fractions. Results demonstrate that accumulated organic matter near the soil surface can increase plant availability of Mn and Fe and possibly decrease the availability of Zn by causing redistribution of elements between soil fractions. Shuman (1988a) reported that the increasing SOM content caused Mn and Fe to move from the less soluble forms to more plant available forms (exchangeable and organic). Oxidation-reduced effects are the possible mechanism of this movement. Copper was not affected significantly. Increasing soil organic matter caused Zn to increase in the Mn and Fe oxide fractions at the expense of the Zn in the other fractions.

The incorporation of green manure, FYM and crop residue plays vital role in availability and transformation of various chemical fractions of micronutrient cations. Total Zn content in soil is not a good indicator of its bioavailability to the growing plants. Zinc may fix with various organic and inorganic soil components ($CaCO_3$, Fe, Mn and Al oxides, organic matter etc.). Plant roots directly absorb nutrients which are present in soil solution. Due to uptake of Zn^{2+} by plant roots, natural equilibrium among these different pools is disturbed. In order to attain the equilibrium, Zn bound to different soil solid phases releases to replenish the soil solution Zn. Hence, these different chemical pools of Zn control its bioavailability and transport to plant roots. An application of organic manures resulted in increase and redistribution of Zn from non-available forms to readily available (water-soluble plus exchangeable) and potentially available forms in soil (Sekhon *et al* 2006). Miller *et al* (1985) reported that the increase of OM-bound Fe may be due to chelating effects promoted by the decomposition of organic matter added in treatments amended with composted urban wastes. The higher values of DTPA-extractable Fe in organic residues treated plots could be ascribed to alteration of less soluble fractions of Fe to more plant available fractions resulting from the addition of organic matter in the form of organic manure (Shuman 1988b).

Sekhon *et al* (2006) observed that the organic manures in the absence of inorganically applied Zn increased the WSEX, organic fraction and the MnOx and AFeOx fractions of Zn. Hellal (2007) report increased MnOX-Zn in soil with addition of composted mixtures as a result of increased Fe availability in calcareous soil by high acidulation effect of compost. Herencia *et al* (2008) showed that percentage of Zn in the specific fractions with respect to total content are Zn and addition of OM caused Zn to move from less soluble forms to more plant available fraction which was always favoured by organic amendment. Sekhon *et al* (2006) reported that incorporation of green manure to rice increased AFeOx form of Zn under rice-wheat rotation. Mandal *et al* (1988) observed that addition of 0.5% FYM caused a substantial increase in the contents of AFeOx bound fraction of native soil Zn with simultaneous decline in that of CFeOx bound and Al oxides Zn fraction. Hellal (2007) reported that addition of composted mixtures increased AFeOx but occluded fractions did not differ significantly due to application of composted mixtures. Pal (1974) reported that with application of GM, FYM and wheat cut straw, the higher supply of Zn in WSEX fractions were strongly correlated with grain uptake.

Agbenin and Henningsen (2004) reported the increased AFeOx-Fe fractions in soil when fertilized with NPK, FYM and FYM+NPK. Sekhon *et al* (2006) observed that OM bound fraction of Zn increased with application of FYM in rice-wheat system. Katyal and Rattan (2003), Sharma *et al* (2004) showed that the decreased total fraction with GM after the harvest of wheat due to an increase in the WSEX fractions held on inorganic sites. Dhaliwal and Manchanda (2008) reported that addition of GM in rice-wheat system increased WSEX-Fe fractions. Dhaliwal and Walia (2008) reported that when FYM, GM and WCS are applied along with chemical fertilizers, they release different fractions of Fe in the soil. Continuous use of NPK fertilizers with or without organic manures substantially changes the available and total Zn and Fe supply to crops. Submergence conditions during rice growth release higher Fe in the presence of GM (Dhaliwal and Manchanda 2008). Rupa *et al* (2003) reported transformation of DTPA-Fe fraction with addition of FYM. According to Herencia *et al* (2008), addition of organic and mineral fertilization increases OM-bound fractions of Zn and Fe and their availability in the soil. Hellal (2007) from his pot experiment showed that the addition of composted mixtures increased WSEX-Fe in the soil. An increased availability of

Fe in soil with the addition of FYM and green manure was observed in rice-wheat cropping system (Yadvinder-Singh *et al* 1992, Yadav and Kumar 2000).

Singh and Abrol (1986) studied the Zn transformation as a result of Zn and gypsum addition, in which they reported that WSEX and AFeOx-Zn fractions contributed significantly more to Zn uptake by rice than the other fractions. DTPA extracted Zn more readily from WSEX and complexed fractions than from sesquioxides. The Zn present in WSEX and complexed forms significantly contributed to the Zn nutrition of rice plants whereas that associated with AFeOx and CFeOx fractions was relatively unavailable (Mandal and Mandal 1986). OM-bound Zn was the chief source of plant available Zn for wheat and OM-bound and occluded Zn were the important sources of Zn for rice crop in calcareous soil treated with organic materials (Prasad *et al* 2002). Rupa *et al* (2003) studied the effect of addition of zinc with and without FYM and P on Zn transformations in a laboratory pot experiment. Addition of FYM was more pronounced on the oxide bound Zn fraction and the percentage utilization of Zn by wheat was highest with addition of FYM alone at the rate of 10 t ha^{-1} as compared to other treatments with no added FYM. Application of 7.5 mg Zn kg^{-1} soil increases different fractions of soil Zn and its utilization by wheat (0.87-1.17%) than other Zn levels (0.8-0.88%). About 85 per cent of the added Zn was recovered in different fractions in Zn treatments with highest recovery percent at Zn level of 7.5 (95%) mg kg^{-1} soil than at 3.75 (87%) and 15 (73%) mg Zn kg^{-1} soil levels. Phosphorus additions up to 40 mg kg^{-1} soil increased the plants available Zn in soils than higher P levels. The distribution of Zn fractions and their contribution towards availability and plant uptake indicated residual zinc as the leading portion of total Zn under long-term maize-wheat cropping sequence (Behera *et al* 2008).

Tillage and crop rotation practices affect soil properties such as SOM (Havlin *et al* 1990) and pH (Blevins *et al* 1977), and ultimately influence micronutrients availability. Surface soils under NT generally have higher organic C and N concentrations (Havlin *et al* 1990) and potential mineralization (Doran 1980) than CT. Greater surface soil extractable Ca, Mg, P, Mn, and Zn contents under NT than CT systems have also been reported (Follett and Peterson 1988). No-till moved Fe and Mn from oxide and mineral forms to exchangeable and organic forms when compared with CT, while fractional distributions of Zn and Cu were remained unaffected by tillage system (Shuman and Hargrove 1985). Increased surface organic matter and extractable nutrients under NT, compared with CT, have been attributed to accretion of crop residues on the soil surface, resulting in a wetter, cooler, less oxidative soil environment (Doran 1980). Soil quality can be strongly affected by soil management, and maintaining or improving soil quality which can be accomplished by using long term CT systems (Havlin *et al* 1999, Reeves 1997). A key to improving soil quality is increasing SOC which greatly influences soil physical, chemical, and biological properties (Reeves 1997).

Increasing SOC with no-tillage is generally associated with an accumulation near the soil surface (Hunt *et al* 1996, Motta *et al* 1999). Therefore, SOC with no-tillage is characterized by stratification while SOC in conventional tillage systems is more evenly distributed within the plow layer (Edwards *et al* 1992, Motta *et al* 1999).

Conventional agriculture resulted in a loss of OM, yield degradation of cultivated soils. Soil OM is a key soil resource that needs to be maintained and managed for agricultural sustainability (Whitbread *et al* 2003). Soil OM, also, is an important source of nutrients for plant growth and maintains favorable soil structural properties. In addition, the supply of OM to soil increases its microbial activity, which adds complexing agents and affects the soil redox status (Shuman 1988a). Therefore, organic amendments as well as the tillage practices can have a profound influence on metal solubility in soil. It is very important to know how organic amendments as well as tillage practices influence metal behavior in soil in respect of plant availability.

CHAPTER III

MATERIALS AND METHODS

The present study entitled, **"Effect of tillage, green manuring, rice establishment methods and crop residue management practices on micronutrient uptake and transformation under rice-wheat cropping system"** was carried out at Soil Science Department, Research Farm, Punjab Agricultural University, Ludhiana. This chapter provides the experimental details of materials used, techniques employed and observations recorded during the course of investigation.

3.1 Experiment No.1: Effect of rice establishment methods, tillage and rice straw management practices on micronutrient uptake and transformation in rice-wheat system

3.1.1 Location

The experimental site is located in the Ludhiana district of Punjab at an elevation of 247m above mean sea level and lie at $30^0$54' latitude and $75^0$40' longitude, which represents the central agro-climatic zone of Punjab under Trans-Gangetic agro-climatic zone of India.

3.1.2 Climate

The geographical location of Punjab is in the North-West Indian sub-continent with Western Himalaya in North and Thar Desert in South. The periodic circulation of moist air masses from South-West and North-West decides the occurrence of two wet periods each followed by a dry period. The South - Western current of summer monsoon coming over Bay of Bengal brings rain from July to September. During the months of October to June generally dry conditions prevail except light showers received from North-Western depressions during winter months. On an average, annual rainfall of Ludhiana is nearly 650 mm, about three-fourth of this rainfall is contributed by the south-west monsoon during July to September. Winter rains received in the months of December, January and February are mostly scanty. In general, it represents sub-tropical and semi-arid climate with hot and dry summers during April to June, hot and humid conditions during the months July to September, cold winters from November to January and mild climate during February and March. The mean maximum and minimum temperatures show considerable variations during different months of the year. May and June are the hottest months with intensive evapotranspiration losses, whereas December and January are the coldest months. Frost is not so common in this region.

3.2 Soil characteristics of experimental site

The chemical properties of soil of experiment no. 1 (Effect of rice establishment methods, tillge and rice straw management practices on micronutrient uptake and transformation in rice-wheat system) were determined and are given in Table 3.1.

Table 3.1: Basic soil chemical properties of the experimental field

Soil properties	Value	Method employed
Order	Inceptisols	
Taxonomic classification	Typic Ustochrepts	
Texture	Loamy sand	International pipette method (Day 1965)
pH	7.26	Jackson (1973)
Electrical conductivity (dS m^{-1})	0.35	Soil:Water (1:2) (Richard 1954)
Organic Carbon (%)	0.45	Chromic acid titration (Walkley and Black 1934)
Available P (kg ha^{-1})	18.3	0.5 M $NaHCO_3$ extractable P method (Olsen *et al* 1954)
Available K (kg ha^{-1})	114	Ammonium acetate extractable K using Flame Photometer (Merwin and Peech (1950)
Available Zn (mg kg^{-1})	1.76	Lindsay and Norvell (1978)
Available Cu (mg kg^{-1})	0.68	
Available Fe (mg kg^{-1})	5.86	
Available Mn (mg kg^{-1})	4.15	

Experimental details

The field experiment was laid out in a split plot design under three replications. The details of the treatments are given below:

Treatments:

a) **Main plots-**Rice establishment methods (4)

- Direct seeded rice under zero tillage (DSR-ZT)
- Direct seeded rice under conventional tillage (DSR-CT)
- Direct seeded rice under reduced tillage (DSR-RT)
- Puddled transplanted rice (PTR)

b) **Sub plots-**Tillage and rice straw management in wheat (3)

- Conventional tillage without rice straw (CTW-R)
- Zero tillage without rice straw (ZTW-R)
- Zero tillage with straw as mulch using Happy Seeder (ZTW+R)

Plot size: 5.4 x 20.0 m = 108 m^2

Variety: Wheat (WH 1105) and Rice (PR 124)

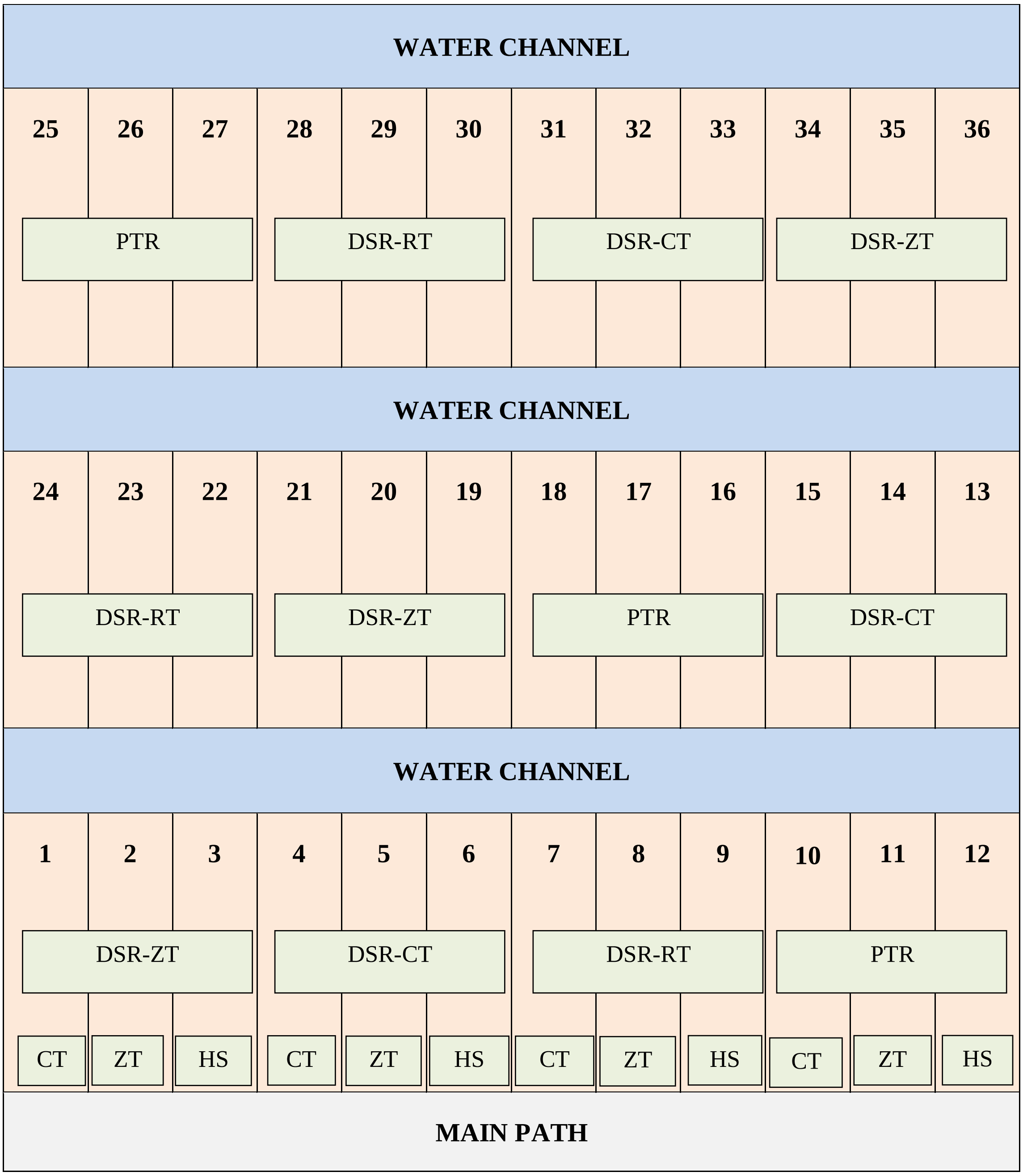
Row spacing: 20 cm

Rows harvested/plot: 10

Length of row harvested: 6m

Harvested area: 12.0 m^2

Fig. 3.1: Layout of experiment no.1



3.3 Crop management

3.3.1 Seed bed preparation

After harvest of rice, subplots represented three different sowing methods of wheat: (i) conventional till, (ii) zero till without rice straw and (iii) zero till with rice straw (Happy Seeder). Rice straw was removed from conventional and zero till without residue wheat plots. However, after harvesting of wheat, main plots represented four different rice establishment methods: (i) Direct seeded rice-zero tillage (DSR-ZT) (ii) Direct seeded rice-conventional tillage (DSR-CT) (iii) Direct seeded rice-reduced tillage (DSR-RT) (iv) Puddled transplanted rice (PTR).

3.3.2 Sowing

The wheat was sown by tractor driven seed drill at 20 cm row spacing in the conventional till wheat plots. Wheat was sown in zero till plots with row spacing of 20 cm using zero till seed cum fertilizer drill. Wheat was sown in Happy Seeder plots using the zero-till Happy Seeder into standing rice residue. The seed rate of 40 kg acre^{-1} was used in wheat. In case of rice crop under PTR, seedlings were transplanted in lines at 20 x 15 cm spacing, whereas for sowing of DSR, zero till seed-cum-fertilizer drill was used. DSR-RT involved seeding of rice in un-puddled and un-ponded field and it implies only one pass of rotavator. But DSR-CT involved minimum three passes of rotavator and cultivator. The seed rate of 8 kg acre^{-1} was used in rice crop.

3.3.3 Fertilizer application

In wheat crop, N was applied in the form of urea @ 110 kg acre^{-1} in the three split doses at sowing and before first and second irrigation. Phosphorus (P_2O_5) @ 55 kg acre^{-1} in the form of di-ammonium phosphate and potassium (K_2O) @ 20 kg acre^{-1} in the form of muriate of potash fertilizer were applied at the time of sowing. On the other hand, in puddled transplanted rice, nitrogen was applied in the form of urea @ 90 kg acre^{-1} in three split doses, one third nitrogen was applied before the last puddling and remaining nitrogen in two splits, second dose three weeks after transplanting and the other three weeks afterwards. However, in case of DSR plots, the N was applied as urea @ 130 kg acre^{-1} in three equal splits at four, six and nine weeks after sowing. Phosphorus (P_2O_5) was applied as di-ammonium phosphate @ 27 kg acre^{-1} and potassium (K_2O) in the form of muriate of potash @ 20 kg acre^{-1}. The whole of phosphorus and potassium were applied before the last puddling.

3.3.4 Irrigation

The field was irrigated before sowing in wheat crop. First irrigation was relatively light and given three weeks after sowing of wheat crop. The subsequent irrigations were applied at 4-5 weeks intervals. On the other hand, in case of puddled transplanting rice, water was kept standing continuously for two weeks after transplanting. Afterwards, irrigation was applied two days after the ponded water has been infiltrated into soil.

3.3.5 Harvesting and threshing

At maturity, wheat crop was harvested manually with the help of sickle. After sun drying in open for three days then threshing was done. On the other hand, the rice crop was also harvested with sickle manually and after sun drying, the crop was threshed manually as well.

3.4 Experiment No. 2: Effect of tillage, green manuring and wheat straw management practices on micronutrients uptake and transformation in rice-wheat system

3.4.1 Location

The present study was carried out at the experimental area of Department of Soil Science, PAU, Ludhiana, Punjab in the IGP in the north-western India. A field experiment on irrigated rice-wheat system was established in 2011 which was started with rice on a Typic Ustochrept soil. Before imposing treatments in rice in 2011, the experiment was laid out before sowing of previous wheat crop (2010-2011) which was raised by applying recommended dose of fertilizers to the whole field.

3.4.2 Climate

The region has a sub-tropical climate alongwith hot, wet summers and cool dry winters. The weather conditions at the experimental site during rice and wheat growing seasons were quite variable in all the years of experimentation. This showed that the weather conditions were not similar and hence there is a need to adopt the climate resilient management practices for sustainable production of crops.

3.5 Soil characteristics of experimental site

The chemical properties of soil of the experiment no. 2 (Effect of tillage, green manuring and straw management practices on micronutrient uptake and transformation in rice-wheat system) were determined and are given in Table 3.2.

Table 3.2: Basic soil chemical properties of the experimental field

Soil properties	Value	Method employed
Order	Inceptisols	
Taxonomic classification	Typic Ustochrepts	
Texture	Loamy sand	International pipette method (Day 1965)
pH	7.28	Jackson (1973)
Electrical conductivity (dS m^{-1})	0.36	Soil:Water (1:2) (Richard 1954)
Organic Carbon (%)	0.47	Chromic acid titration (Walkley and Black 1934)
Available P (kg ha^{-1})	18.6	0.5 M $NaHCO_3$ extractable P method (Olsen *et al* 1954)
Available K (kg ha^{-1})	117	Ammonium acetate extractable K using Flame Photometer (Merwin and Peech (1950)
Available Zn (mg kg^{-1})	1.69	Lindsay and Norvell (1978)
Available Cu (mg kg^{-1})	0.61	
Available Fe (mg kg^{-1})	5.39	
Available Mn (mg kg^{-1})	4.03	

Experimental details

The experiment was set out in a split plot design with three replications. Treatments were comprised of four combinations of wheat straw and *Sesbania* green manure (GM) management ($PTRw_0$, puddled transplanted rice with no wheat straw retained; $PTRw_{25}$, puddled transplanted rice with 25% anchored wheat straw (12-15 cm high stubbles) retained; $PTRw_0$ + GM, puddled transplanted rice with no wheat straw retained plus green manure and $PTRw_{25}$ + GM, puddled transplanted rice with 25% anchored wheat straw retained plus green manure) in main plots and three combinations of tillage and rice residue management in sub plots in subsequent wheat (CTW_{R0}, conventional till wheat with rice residue removed; ZTW_{R0}, zero till wheat with rice residue removed and ZTW_{R100}, zero till wheat with 100% rice residue retained as mulch). The treatments were allocated to the same experimental plots in all the years of study. The details of the treatments are given below:

Treatments:

a) **Main plots-** Wheat straw and green manure practices in rice (4)

- Wheat straw removed ($PTRw_0$)
- Wheat straw retained ($PTRw_{25}$)
- Wheat straw removed + green manure ($PTRw_0$ + GM)
- Wheat straw retained + green manure ($PTRw_{25}$ + GM)

b) **Sub plots-** Tillage and rice straw management practices in wheat (3)

- Conventional tillage without rice straw (CTW_{R0})
- Zero tillage without rice straw (ZTW_{R0})
- Zero tillage with rice straw as mulch using Turbo Happy Seeder (ZTW_{R100})

Location: PAU, Soil Science research farm

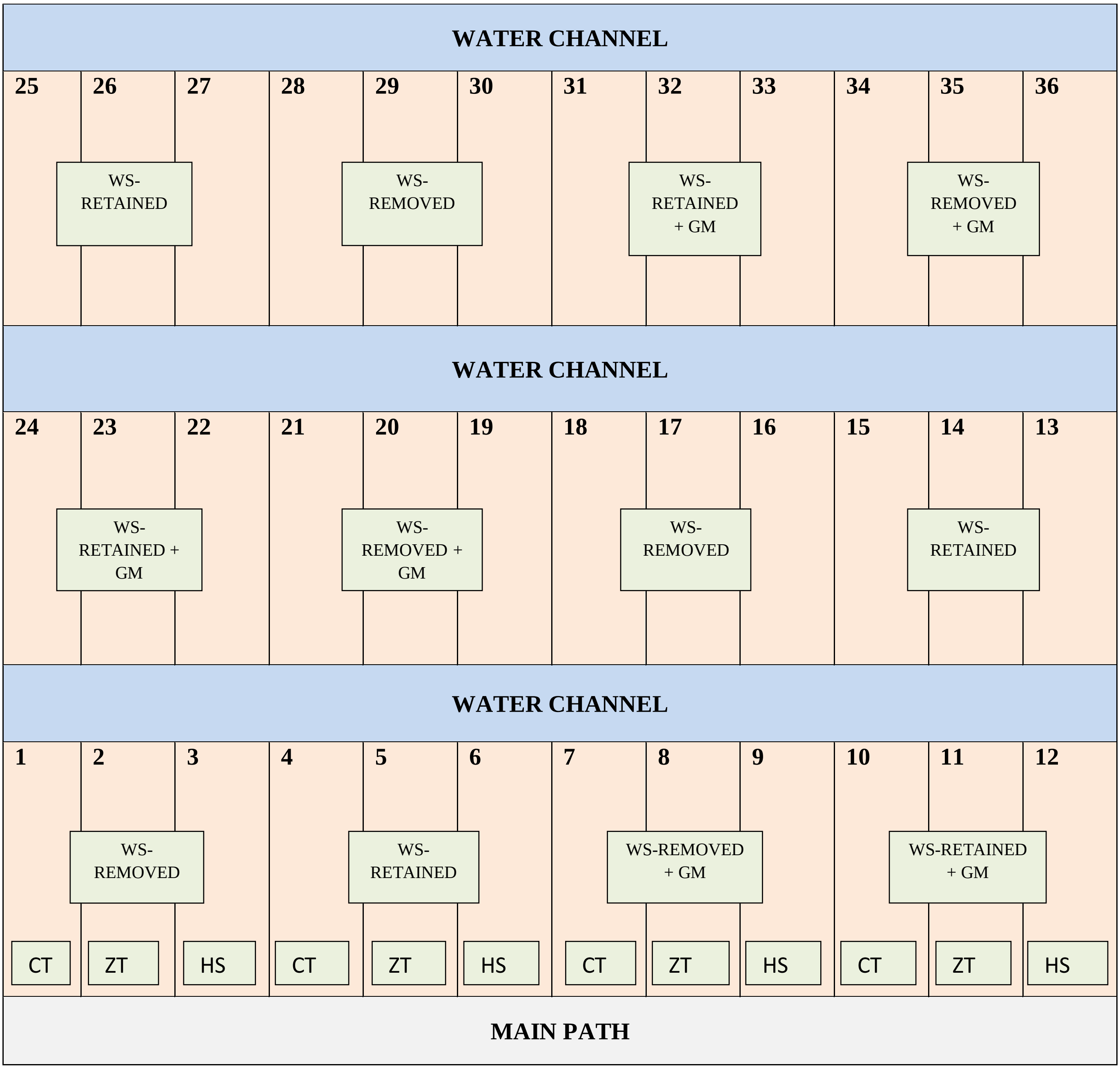
Plot size: 3.6 m x 19.0 m

Variety: wheat (WH 1105) and rice (PR 124)

Row spacing: 20 cm

Harvested area: 12 m^2

Fig. 3.2: Layout of experiment no.2



3.6 Soil and crop management

3.6.1 Green manure, tillage and crop establishment in rice

All the plots after harvesting of wheat were irrigated and GM (*Sesbania aculeata*) was sown with zero till using seed rate of 20 kg acre^{-1} in designated plots. Green manure was sown in third week of April and incorporated in the second week of June. In other treatments soil was tilled using two diskings followed by planking to keep the plots weed free. GM crop was raised without applying any chemical fertilizers but required 4-5 irrigations depending upon the climatic conditions. At the age of 6-7 weeks GM was incorporated into the soil 1-2 days before transplanting of rice by two diskings followed by two harrowing and planking. All the treatment plots were puddled (wet tillage) following different tillage operations. Rice seedlings of 30 days old (variety PR 124) were transplanted manually in the second week of June each year.

3.6.2 Tillage and rice residue management in wheat

Rice crop was harvested manually at ground level in no residue (R_0) treatments and whole of the straw was removed from the plots. In the R_{100} plots, combine harvester fitted with straw spreader was used and entire amount of the rice straw was retained. Wheat variety WH 1105 was sown at row spacing of 20 cm apart using a seed rate of 100 kg ha^{-1} with ZT seed cum fertilizer drill in both ZTW_{R0} and CTW_{R0} in the first fortnight of November in different years of experimentation. Turbo Happy Seeder (Sidhu *et al* 2015) was used for direct planting wheat in ZTW_{R100} plots in rows 20 cm apart using the same seed rate and row spacing. Wheat was harvested nearby ground manually with the help of sickles and all harvested biomass was removed from the plots where no residue was retained i.e.W_0 plots. In W_{25} treatments, wheat was harvested at 12-15 cm above the ground level to simulate combine harvesting.

3.6.3 Fertilizer management

Rice received only 75 kg N ha^{-1} in GM treatments (PTR_{W0} + GM and PTR_{W25} + GM) and 150 kg N ha^{-1} in no-GM treatments. Urea was the source of N after compensating N applied through diammonium phosphate at the time of sowing. At planting whole amounts of P, K and Zn were applied on all the plots. Fertilizer N was divided in three split doses and applied at the time of transplanting of rice and at 3 and 6 weeks after transplanting.

In wheat crop, nitrogen was applied in the form of urea in the three split doses, first dose at the time of sowing and the remaining two-third dose was applied in two equal split doses immediately before 1st irrigation i.e. at 3 weeks (crown root initiation) and immediately before second irrigation i.e. at 8 weeks (maximum tillering) after sowing. Phosphorus (P_2O_5) was applied @ 60 kg ha^{-1} in the form of di-ammonium phosphate and potassium (K_2O) @ 30 kg ha^{-1} in the form of muriate of potash fertilizer was applied at the time of sowing.

3.6.4 Irrigation water management

Rice plots were flooded for the first 2 weeks, followed by irrigation two days after the disappearance of standing water from the previous irrigation till physiological maturity. Wheat was irrigated (about 75 mm each) at critical growth stages i.e. crown root initiation (CRI), maximum tillering (MT), panicle initiation (PI) and dough stages as recommended for the crop in the region. At maturity, wheat crop was harvested manually with the help of sickle. After sun drying in open for three days threshing was done.

3.7 Collection and preparation of soil and plant samples

Soil samples were collected from the surface (0-7.5 cm) as well as subsurface (7.5-15, 15-30, 30-45 and 45-60 cm) soil layers before sowing of wheat crop (October 2015-16) and at after harvesting of rice crop (October 2017). The soil samples were collected by auger randomly from four places in each treatment plots. The samples were air dried, ground in wooden pestle and mortar and then passed through 2 mm sieve and preserved in polythene bags for the subsequent analysis of different chemical properties. Plant samples were collected at maximum tillering stage of both rice and wheat crops from both the experimental fields. Data regarding different agronomical parameters like number of effective tillers per m^2, spike length, height of the plant and 1000 grain weight were collected at maturity. The grain and straw samples were also collected at harvesting of rice and wheat crops and dried to a constant weight at 65^oC for 48h and grounded to pass through a sieve of 0.5 mm and then stored in paper bags.

3.8 Yield and yield attributing characters (rice and wheat)

(i) Effective tillers

The number of spike bearing tillers were counted from middle rows from two positions of one meter row length in each plot at harvest and were expressed as effective tillers m^{-1}.

(ii) Plant height

Plant height was recorded from each plot at 10 different selected plants. It was taken from ground level to the tip of the spike. It was expressed as an average of 10 plants in cm.

(iii) Spike length

Spike length was recorded from each plot of 10 different plants. It was expressed as an average of 10 spikes in cm.

(iv) Grain yield

Bundle weights of harvest from a net plot area of 12 m^2 were taken after sun drying. Grain yield was recorded after hand threshing.

(v) Straw yield

Straw yield was determined as difference between bundle weight and grain yield.

(vi) 1000 grain weight

1000 grains were counted from produce of each treatment. Their weight was recorded using electronic balance and expressed in grams.

3.9 Methods used for soil and plant analysis

3.9.1 Soil texture

Soil texture was determined by standard international pipette method. The USDA size fractions for separation of sand (0.02-2.0 mm) by gravity sedimentation method of Day (1965) were followed. Sand was separated by using 70-mesh sieve. The clay (<0.002 mm) was separated from silt using 0.1N solution of sodium hexametaphosphate as dispersing agent.

3.9.2 Soil pH

A soil suspension was prepared with distilled water keeping 1:2 soil to water ratio and the concentration of hydrogen ions in soil (pH) of suspension was measured by potentiometric method (Jackson 1973). The pH of the solution being directly proportional to the potential developed on the glass membrane was measured in conjunction with saturated calomel electrode as reference electrode.

3.9.3 Electrical conductivity (EC)

The soil suspension used for pH determination was used to measure soluble salts after keeping them overnight to obtain a clear supernatant solution. The soluble salts in the soil were measured with a conductivity meter, also known as salt bridge. The conductivity of electric current through soil suspension is proportional to the concentration of soluble salts present in it (Richard 1954). The electrical conductivity was expressed as deci siemens per meter (dS m^{-1}).

3.9.4 Soil organic carbon (SOC)

Rapid titration method (wet digestion method) was used for organic carbon determination (Walkley and Black 1934). In this determination 2 gm of dried soil was treated with 10 ml of 1N $K_2Cr_2O_7$ solution in a 250 ml conical flask. 20 ml of concentrated H_2SO_4 was slowly added to the flask. After 30 minutes, about 0.5 gm of NaF, 100 ml of distilled water and 10 drops of diphenylamine indicator were added to the flask. These contents were titrated against 0.5 N ferrous amonium sulphate (FAS) solution. The change from violent to bright green through blue colour was the end point. The value of FAS used for titration was adopted for calculating organic carbon and was expressed as percentage. 10 ml of 1N $K_2Cr_2O_7$ solution in another flask was titrated without soil against 0.5N FAS solution to determine blank. The organic carbon in the soil was calculated as:

Organic carbon (%) = [(X-Y) * 0.003 * 100 * N]/W

Where X = volume of 0.5 N FAS used for blank titration

Y = volume of 0.5 N FAS used for soil sample

N = Normality of FAS used

W = Weight of soil sample taken = 2 gm

1 ml of 1N $K_2Cr_2O_7$ = 0.003 gm carbon.

3.9.5 Available phosphorus

Available phosphorus in soil samples was determined by the method described by Olsen *et al* (1954). One gm soil sample was extracted with 20 ml of 0.5 N $NaHCO_3$ solution (pH = 8.5). The soil sample was shaken for 30 minutes on an end-to-end shaker. Five ml of filtrate was taken in 25 ml volumetric flask and ammonium molybdate and stannous chloride was added in it and volume was made. Blue colour was developed by virtue of ammonium molybdate and stannous chloride that formed heteropolycomplexes with soluble phosphate ions. The intensity of blue colour that was proportional to the concentration of phosphate ions, was read on spectrophotometer at wave length of 660 nm using a red filter. The concentration of available phosphorus in soil was expressed as kg ha^{-1}.

Av. P (kg ha^{-1}) = ppm of P calculated from standard curve * dilution factor * 2.24

3.9.6 Available potassium

Available potassium content of soil was determined by the method described by Merwin and Peech (1950). Five gram soil was taken in a 150 ml conical flask and extracted with 25 ml of neutral 1 M CH_3COONH_4 solution. The filtrate was aspirated into the automizer of the calibrated flame photometer and reading was noted. The concentration of potassium in the solution was proportional to the galvanometer reading. The concentration of available potassium in the soil was expressed as kg ha^{-1} and calculated as

Av. K (kg ha^{-1}) = ppm of K in sample * dilution factor * 2.24

3.9.7 DTPA-extractable micronutrient cations

Availability of DTPA-extractable micronutrient cations (Zn, Cu, Fe and Mn) was assessed by extracting 10 gm of soil sample with 20 ml of diethylene triamine penta acetic acid (DTPA) extractant (0.005 M DTPA + 0.01 M $CaCl_2$ + 0.1 M TEA buffer adjusted to pH 7.3) as described by Lindsay and Norvell (1978). The determination of these four (Zn, Cu, Fe and Mn) micronutrient cations was done by the same extract with the instrument named atomic absorption spectrophotometer (Varian Model AAS FS 240).

3.9.8 Total micronutrients

The total elemental analysis of micronutrient cations was done by taking 0.5 gm sample of soil which was digested with 5 ml of hydrofluoric acid (HF), 1 ml of perchloric acid ($HClO_4$) and 5-6 drops of nitric acid (HNO_3) in platinum crucibles of 30 ml capacity (Page *et al* 1982). When the soil became completely dry in the crucible then the residue in the crucible was completely dissolved by using 6 N HCl. The contents of the crucible were shifted to 100 ml capacity volumetric flask then the final volume was made using double distilled water. The digests were then analysed with atomic absorption spectrophotometer for total micronutrient cations after appropriate dilutions. The results were reported on an oven-dry weight basis.

3.9.9 Analysis of soil samples for Zn, Cu, Fe and Mn fractions

The sequential extraction procedure was used to determine different chemical fractions of Zn, Cu, Fe and Mn in surface soil samples. The processed surface (0-15 cm) soil samples were used to fractionate Zn, Cu, Fe and Mn into following chemical forms as per sequential procedure described below:

1. Water soluble plus exchangeable fraction (WSEX)

Five gram of soil was shaken with 20 ml of 0.005 M Pb $(NO_3)_2$ in 100 ml centrifuge tubes for fifteen minutes at 25˚C in orbital shaker and then the sample was centrifuged for ten minutes at 6000 rpm. Afterwards, the supernatant filtered, separated and stored for analysis. (Manchanda *et al* 2006). The Reagent 0.005 M $Pb(NO_3)_2$ was prepared by dissolving 1.65gm of lead nitrate in one liter adjusting the pH of solution to 6.8 by 0.5M ammonium acetate (NH_4OAC) which is prepared by dissolving 38.5 gm of ammonium acetate in 1 litre.

2. Specifically adsorbed (SpAd)

The soil residue from water soluble plus exchangeable fraction was shaken with 20 ml of 0.05M $Pb(NO_3)_2$ for 2 hours at 25˚C in orbital shaker and ; the sample was, thereafter, centrifuged for ten minutes at 6000 rpm and then the supernatant filtered (Iwaski *et al* 1993). The Reagent 0.05 M $Pb(NO_3)_2$ was prepared by dissolving 16.56 gm lead nitrate in one litre adjusting the pH of solution to 6.0 by 0.5M ammonium acetate (NH_4OAC).

3. Mn-Oxide bound fraction (MnOx)

To the left over soil sample, 20.0 ml of $NH_2OH.HCl$ (hydroxylamine hydrochloride) 0.1 mol l^{-1} was added. The pH was set at 6.2, and the mixture was then shaken for half an hour, centrifuged and filtered; then the separated supernatant was stored for analysis (Chao 1972). The Reagent 0.1 M $NH_2OH.HCl$ in 0.01M HNO_3 was prepared by dissolving 6.95 gm of (hydroxylamine hydrochloride) $NH_2OH.HCl$ and 0.625 ml Nitric acid ($HNO_{3)}$ in water and made the volume to one litre.

4. Amorphous Fe-Oxides bound (AFeOx)

To the left over soil sample after Mn-Oxide bound fraction analysis, 20.0 ml of $NH_2OH.HCl$ (hydroxylamine hydrochloride) 0.1 mol l^{-1} plus HCl 0.25 mol l^{-1}, at pH 1.3 were added, and the mixture was shaken for 30 min at 25˚C in orbital shaker, centrifuged and filtered; the separated supernatant was stored for analysis (Chao and Zhau 1983). The Reagent 0.25 M $NH_2OH.HCl$+0.25 M HCl was prepared by dissolving 17.37 gm of Hydroxyl amino chloride($NH_2OH.HCl$) in water and pour 21 ml of Hydrochloric acid (HCl) in it and make the volume of solution to one litre.

5. Crystalline Fe-Oxides bound (CFeOx)

To the remaining soil sample after AFeOx fraction, 20.0 ml of 0.25 M $NH_2OH.HCl$ +0.25 M HCl + ascorbic acid 0.01 mol l^{-1}, at pH 1.21 were added, then the sample was heated in boiling water (100˚C) in a beaker placed on hot plate for 30 minutes, shaking from time to time; there after centrifuged and filtered; the separated supernatant was stored for analysis (Manchanda *et al* 2006). The sequential extraction continued in the remaining of the soil sample The Reagent 0.25 M $NH_2OH.HCl$ +0.25 M HCl +0.1 M ascorbic acid was prepared by dissolving 17.37 gm of Hydroxyl amino chloride ($NH_2OH.HCl$) in water, pour 21 ml of Hydrochloric acid (HCl) and 17.61gm of ascorbic acid in it and make the volume of solution to one litre.

6. Organically bound fraction (OM)

To the remaining soil samples after CFeOX fraction, 20 ml of 1% $Na_4P_2O_7$ was added and then the sample was shaken for one hour at 25˚C in orbital shaker and then it was centrifuged for ten minutes at 6000 rpm. Afterwards, the supernatant filtered, separated and stored for analysis (Raja and Iyengar 1986). The reagent was prepared by dissolving 4.46 gm of sodium-pyrophosphate in one litre of distilled water.

7. Residual fraction (RES)

Residual fraction (cation) = Total content (cation) - sum of all fractions (cation). The amount of Zn, Cu, Mn and Fe in different fractions was estimated using atomic absorption spectrophotometer.

3.9.9 Plant analysis

The plant samples (rice and wheat crops) were collected at maximum tillering stage and the grain and straw samples were collected during *Kharif* and *Rabi* seasons from each plot at maturity and dried in oven at 65˚C for 3 days. Dried samples of grain and straw were digested in a diacid mixture of HNO_3 and $HClO_4$ (3:1) for the analysis of total Zn, Cu, Fe and Mn. The samples were determined with atomic absorption spectrophotometre (Isaac and Kerber 1971).

3.9.10 Statistical analysis

The data was analyzed by using analysis of variance for split plot design. Least significant difference was used to compare the treatment effects at $P<0.05$.

CHAPTER IV

RESULTS AND DISCUSSION

Results of the field experiment conducted to study the “Effect of tillage, green manuring, rice establishment methods and crop residue management practices on micronutrient uptake and transformation under rice-wheat cropping system” are describes in this chapter. The results of this experiment are presented under the headings listed below:

Experiment No.1: Effect of rice establishment methods, tillage and rice straw management on micronutrient uptake and transformation in rice-wheat system

4.1 Effect of rice establishment methods, tillage and rice straw management practices on yield parameters of wheat and rice

4.1.1 Grain and straw yield of wheat

4.1.2 Yield attributes of wheat

4.1.3 Grain and straw yield of rice

4.1.4 Yield attributes of rice

4.2 Effect of rice establishment methods, tillage and rice straw management practices on concentration of micronutrients at maximum tillering of wheat and rice

4.2.1 Micronutrients (Zn, Cu, Fe and Mn) concentration at maximum tillering of wheat

4.2.2 Micronutrients (Zn, Cu, Fe and Mn) concentration at maximum tillering of rice

4.3 Effect of rice establishment methods, tillage and rice straw management practices on concentration of micronutrients in wheat and rice

4.3.1 Micronutrients (Zn, Cu, Fe and Mn) concentration in wheat grains

4.3.2 Micronutrients (Zn, Cu, Fe and Mn) concentration in wheat straw

4.3.3 Micronutrients (Zn, Cu, Fe and Mn) concentration in rice grains

4.3.4 Micronutrients (Zn, Cu, Fe and Mn) concentration in rice straw

4.4 Effect of rice establishment methods, tillage and rice straw management practices on uptake of micronutrients in wheat and rice

4.4.1 Micronutrients (Zn, Cu, Fe and Mn) uptake in wheat grains

4.4.2 Micronutrients (Zn, Cu, Fe and Mn) uptake in wheat straw

4.4.3 Micronutrients (Zn, Cu, Fe and Mn) uptake in rice grains

4.4.4 Micronutrients (Zn, Cu, Fe and Mn) uptake in rice straw

4.5 Effect of rice establishment methods, tillage and rice straw management practices on soil chemical properties

4.5.1 Distribution of pH in profile

4.5.2 Distribution of electrical conductivity in profile

4.5.3 Distribution of soil organic carbon in profile

4.6 Effect of rice establishment methods, tillage and rice straw management practices on DTPA-extractable micronutrients (Zn, Cu, Fe and Mn)

4.6.1 Distribution of DTPA-extractable Zn in profile

4.6.2 Distribution of DTPA-extractable Cu in profile

4.6.3 Distribution of DTPA-extractable Fe in profile

4.6.4 Distribution of DTPA-extractable Mn in profile

4.7 Effect of rice establishment methods, tillage and rice straw management practices on chemical fractions of micronutrients (Zn, Cu, Fe and Mn) in surface soil

4.7.1 Water soluble plus exchangeable fraction (WSEX)

4.7.2 Specifically adsorbed fraction (SpAd)

4.7.3 Mn-oxide bound fraction (MnOx)

4.7.4 Amorphous Fe-oxide bound fraction (AFeOx)

4.7.5 Crystalline Fe-oxide bound fraction (CFeOx)

4.7.6 Organically bound fraction (OM)

4.7.7 Residual fraction (RES)

4.7.8 Total fraction

4.1 Effect of rice establishment methods, tillage and rice straw management practices on yield parameters of wheat and rice

4.1.1 Grain and straw yield of wheat

The grain yield of a crop is the net resultant of interaction of various factors and is principle criterion for comparing the efficiency of different treatments because ultimate effects of experimental variables reflect the final yield. Tillage and rice straw management practices in wheat, irrespective of rice establishment methods, significantly affected wheat grain yield in year 2016-17, but it failed to show significant effect on the wheat grain yield in year 2015-16. However, the different rice establishment methods, irrespective of tillage and rice straw management practices in wheat, failed to show significant effect on grain yield of subsequent wheat (2015-16) as well as on next year sown wheat (2016-17) (Table 4.1). Wheat sown with happy seeder (HS) or zero tilled wheat with residues (ZTW+R) produced significantly (5 and 8 percent) higher grain yield than CTW-R and ZTW-R wheat, respectively. Even CTW-R wheat produced significantly higher (3 percent) grain yield than ZTW-R. The interaction between rice establishment methods, and tillage and rice straw management practices on wheat grain yield was not significant. The grain yield expression is basically a function of absolute infrastructure and seed development activity of plant (Pandey *et al* 2014). Similarly Singh *et al* (2013) reported that ZT wheat sown with HS significantly produced higher yield of wheat grains with respect to farmer’s practice. Sidhu *et al* (2007) observed that grain yield of wheat sown with HS was comparable with or higher than CT wheat sown after straw removal or burning. The grain yield increases with HS due to higher spike density and number of grains per spike. Ram *et al* (2013) found that grain yield of ZT wheat was significantly higher under rice straw mulch than ZT without mulch due to better hydrothermal regime and root growth, which increased nutrient uptake and crop growth. Rahman *et al* (2005) found that ZT+R produced significantly higher yield of wheat grains in relation to ZT-R. They observed that higher yield was attributed to significantly higher plant density, spike density, grains spike^{-1} and 1000 grain weight. Crop residue management practices also influenced the wheat yield significantly in 1998–1999 and 2000– 2001. The highest mean yield was recorded under rice straw incorporation followed by burning and the conventional practice of straw removal. This was because of increase in water stable aggregates and porosity and reduction in bulk density thereby facilitating crop establishment and better crop growth contributing towards the higher yield of wheat (Verma and Bhagat 1992). Ghuman and Sur (2001) observed in sub-humid sub-tropical climate that minimum tillage in conjunction with crop residue management practices improved and sustained the higher wheat yield.

Table 4.1: Effect of rice establishment methods, tillage and straw management practices on wheat yield

Treatment	Grain yield (t ha^{-1})		Straw yield (t ha^{-1})		Harvest index (%)		1000 grain weight (gram)	
	2015-16	**2016-17**	**2015-16**	**2016-17**	**2015-16**	**2016-17**	**2015-16**	**2016-17**
Rice establishment methods								
DSR-ZT	4.94	5.14	5.80	5.96	46.1	47.1	42.8	44.2
DSR-CT	4.98	5.17	5.89	6.07	45.8	46.8	42.9	43.1
DSR-RT	5.12	5.29	6.03	6.20	45.9	46.8	42.9	43.2
PTR	4.92	5.15	5.84	5.99	45.6	46.9	43.0	43.7
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Tillage and rice straw management practices								
CTW-R	4.93	5.15	5.85	6.03	45.7	46.9	42.6	43.2
ZTW-R	4.79	5.00	5.53	5.68	46.6	47.7	42.0	42.3
ZTW+R	5.23	5.42	6.30	6.45	45.2	46.2	44.1	45.1
LSD (0.05)	NS	0.31	0.55	0.49	NS	NS	NS	1.69
Interaction								
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

The straw yield of wheat (2015-16) and (2016-17) ranged from 5.53 to 6.30 t ha^{-1} and 5.68 to 6.45 t ha^{-1} respectively, in all the treatments (Table 4.1). Tillage and rice straw management practices in wheat, irrespective of rice establishment methods, significantly affected straw yield of wheat in both years (2015-16 and 2016-17). However, different rice establishment methods, irrespective of tillage and rice straw management practices failed to cause significant effect on straw yield of subsequent wheat. Zero tilled wheat with residues (ZTW+R) produced significantly (7 and 12 per cent, respectively) higher straw yield than ZTW-R and CTW-R wheat. CTW-R wheat produced significantly higher (3 percent) straw yield than ZTW-R. The interaction between rice establishment systems and tillage and rice straw management practices in wheat on straw yield of wheat was non-significant at $P<0.05$. Sidhu *et al* (2007) reported that straw yield of wheat sown with HS retaining rice straw as surface mulch was higher than ZT-R wheat. Singh *et al* (2005) found that rice establishment methods did not affect straw yield of subsequent wheat sown either under CT and ZT. Arora *et al* (2011) reported that poor root growth and lower N use efficiency were responsible for lower wheat yields in ZT-R compared with CT-R.

The harvest index is the ratio of economical yield (grain yield) to the total biological yield (grain yield + straw yield) and increase the harvest index means better productivity. Tillage and rice straw management practices in wheat irrespective of rice establishment methods, showed non-significant effect on harvest index of wheat in both wheat sown years (2015-16 and 2016-17). Similarly, different rice establishment methods, irrespective of tillage and rice straw management practices, failed to cause significant impact on straw yield of following wheat crop (Table 4.1). Harvest index was found higher in ZTW wheat than CTW. The interaction between rice establishment systems, and tillage and rice straw management practices in wheat on harvest index of wheat was non-significant at $P<0.05$.

Thousand grain weight is a function of production factors that gives indication of grain development and filling patterns as influenced by crop management practices. Tillage and rice straw management practices in wheat, irrespective of rice establishment methods, significantly affected thousand grain weight of wheat in 2016-17. However, the effect of different rice establishment methods irrespective of tillage and rice straw management practices in wheat, failed to cause significant effect on 1000 grain weight of subsequent wheat (Table 4.1). The interaction between rice establishment systems, and tillage and rice straw management practices in wheat on thousand grain weight of wheat was not significant. He *et al* (2009) found that 1000 grain weight of ZT wheat with maize residue was significantly higher as compared to ZT-R and CT. Rahman *et al* (2005) reported that 1000 grain weight of wheat was significantly higher in ZT+R than ZT-R.

4.1.2 Yield attributes of wheat

Tillage and rice straw management practices in wheat irrespective of rice establishment methods, significantly affected the number of effective tillers (Table 4.2). However, the effect of different rice establishment methods, irrespective of tillage and rice straw management practices in wheat, failed to cause significant effect on number of effective tillers of subsequent wheat. Zero tilled wheat with residues (ZTW+R) produced significantly higher number of effective tillers than ZTW-R and CTW-R. ZTW+R wheat produced significantly higher (5 percent) number of effective tillers than CTW-R. The interaction between rice establishment methods and tillage and rice straw management practices on number of effective tillers of wheat was not significant.

Table 4.2: Effect of rice establishment methods, tillage and straw management practices onwheat yield attributes

Treatment	Plant height (cm)		Effective tillers (m^{-2})		Spike length (cm)	
	2015-16	**2016-17**	**2015-16**	**2016-17**	**2015-16**	**2016-17**
Rice establishment methods						
DSR-ZT	95.1	96.5	347.9	353.8	11.8	12.2
DSR-CT	97.2	97.1	354.4	358.1	12.3	12.9
DSR-RT	96.9	97.5	361.8	364.8	12.7	13.3
PTR	96.7	97.3	348.9	351.7	12.3	12.6
LSD (0.05)	NS	NS	NS	3.94	NS	NS
Tillage and rice straw management practices						
CTW-R	96.5	97.4	353.9	357.5	12.3	12.8
ZTW-R	95.3	96.9	350.8	353.6	12.0	12.3
ZTW+R	97.6	97.7	355.1	360.2	12.5	13.1
LSD (0.05)	NS	NS	NS	4.61	NS	0.59
Interaction						
LSD (0.05)	NS	NS	NS	NS	NS	NS

Tillage and rice straw management practices in wheat, irrespective of rice establishment methods, significantly affected spike length of wheat in 2016-17. However, the effect of different rice establishment methods irrespective of tillage and rice straw management practices in wheat, failed to cause significant effect on spike length of subsequent wheat (Table 4.2). The interaction between rice establishment methods, and tillage and rice straw management practices on spike length of wheat was not significant. Spike length under ZT wheat with residues was significantly higher compared with ZT-R wheat. Gangwar *et al* (2006) also reported significantly higher spike length under ZT with rice straw incorporation than ZT-R.

Gangwar *et al* (2006) concluded in his study that reduced tillage by strip till drilling and crop residue incorporation at 5 Mg ha^{-1} along with 150 kg N ha^{-1} was the best combination for maximizing the wheat yield due to better land preparation, good aeration, better germination, more water penetration, less weed infestation and increased nutrition as compared to zero tillage. It appears that wheat crop in zero tillage suffered due to soil compaction, which might have restricted oxygen supply to root zone; decreased water percolation into sub-soil (low infiltration rate) and increased bulk density which restricted vigorous plant growth and resulted in low yield. Moreover, reduced tillage modified soil physical environment so as to favor root proliferation and increased the ability of wheat crop to utilize sub-soil water and nutrients and contributed to the higher yield. Furthermore, considerable saving in time, fuel, labour, cost and energy were obtained by the use of strip and zero till drilling as compared to conventional sowing. The economic efficacy and energy efficiency directed these drills as a suitable alternative to conventional sowing of wheat after puddled rice in sandy loam soils of IGP of India.

4.1.3 Grain and straw yield of rice

In our study, different rice establishment methods viz. DSR-ZT, DSR-CT, DSR-RT and PTR irrespective of the tillage and rice straw management practices in wheat significantly affected rice grain yield during both the years of experimentation (2016 and 2017). In case of puddled transplanted rice (PTR), grain yield was observed higher in relation to DSR-RT, DSR-CT and DSR-ZT but the grain yield was found to have non-significant difference with DSR-RT (Table 4.3). Grain yield varied from 4.73 to 5.90 t ha^{-1} in first year rice (2016) and 4.99 to 6.16 t ha^{-1} in second year rice (2017). In the first year, PTR showed 20 percent and 9 percent higher grain yield as compared to DSR-ZT and DSR-CT. The interaction between rice establishment methods and tillage and rice straw management practices in wheat on rice grain yield was non-significant. Similarly, in second year rice (2017), grain yield was observed to be higher under PTR (6.16 t ha^{-1}) as compared to DSR-RT (5.97 t ha^{-1}), DSR-CT (5.80 t ha^{-1}) and DSR-ZT (4.99 t ha^{-1}) treatments. Among the rice establishment methods, DSR-RT found to have non-significant difference with PTR. On contrary, PTR have significantly higher grain yield i.e. 19 percent and 6 percent as compared to the DSR-ZT and DSR-CT. Even the grain yield was observed as significantly higher in case of DSR-RT as compared to the DSR-ZT among the different rice establishment methods in both the years (2016 and 2017). However, the effect of tillage and rice straw management practices in wheat failed to show significant differences on rice grain yield during both the years, but the grain yield was found higher in the treatments where residue was retained (ZTW+R) as compared to the treatments where no residue was retained (ZTW-R) as well as CTW-R. The interaction between rice establishment methods, and tillage and rice straw management practices in wheat on rice grain yield was not significant. Jat *et al* (2014) recorded higher rice grain yield during the initial three years of experimentation in conventional tillage based rice systems (i.e. CTR-CTW and CTR-ZTW) than in conservation agriculture based systems (i.e. ZTDSR-ZTW, UpTPR-ZTW). During the fourth and fifth years, the rice yields under conventional tillage (CT) and conservation agriculture (CA) were comparable whereas sixth year onwards, higher yields were recorded under CA based system than in CT based systems. Reduced tillage produced 10.9 and 22.9% higher overall mean yield than conventional and zero tillage. This was because of low soil moisture; lack of seed cover, seed damage by birds and compactness of the soil in zero tillage causing lower values of yield contributing characters (grains, length and weight of ear-head and 1000 grain weight) and lower grain yield.

Table 4.3: Effect of rice establishment methods, tillage and straw management practiceson rice yield

Treatment	Grain yield ($t\ ha^{-1}$)		Straw yield ($t\ ha^{-1}$)		Harvest index (%)		1000 grain weight (gram)	
	2016	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**
Rice establishment methods								
DSR-ZT	4.73	4.99	6.58	6.65	41.8	43.0	21.9	22.2
DSR-CT	5.33	5.80	7.61	7.42	41.2	43.9	23.2	23.4
DSR-RT	5.82	5.97	7.60	7.43	43.6	44.7	24.2	24.4
PTR	5.90	6.16	8.33	8.25	41.5	40.1	24.6	25.0
LSD (0.05)	0.45	0.32	0.63	1.17	NS	NS	1.02	1.25
Tillage and rice straw management practices								
CTW-R	5.35	5.73	7.54	7.76	42.2	42.6	23.7	23.9
ZTW-R	5.28	5.52	7.33	7.52	41.3	42.5	22.9	23.2
ZTW+R	5.72	5.94	7.72	7.77	42.6	43.7	23.8	24.2
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Interaction								
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

The straw yield ranged from 6.58 to 8.33 $t\ ha^{-1}$ and 6.65 to 8.25 $t\ ha^{-1}$ in the first and second year i.e. 2016 and 2017, in the treatments under different rice establishment methods and tillage and rice straw management practices in wheat (Table 4.3). From our results, it was observed that PTR showed significant increase in straw yield as compared to DSR-ZT, DSR-CT and DSR-RT. Straw yield was found lowest in case of DSR-ZT (6.58 and 6.65 $t\ ha^{-1}$ in 2016 and 2017, respectively) among different rice establishment methods. Tillage and rice straw management practices in wheat, irrespective of rice establishment methods, failed to cause significant effect on straw yield of rice during both the years (2016 and 2017). Similarly, the straw yield was also found significantly higher in case of PTR as compared to the DSR-ZT, DSR-CT and DSR-RT during the second year (2017). In case of tillage and rice straw management practices in wheat, ZTW+R showed higher residual effect on straw yield of rice followed by ZTW-R and CTW-R, but the effect was non-significant during both the years. The interaction between rice establishment methods, and tillage and rice straw management practices in wheat on straw yield of rice crop was non-significant.

A glance at the data regarding the harvest index of rice crop indicated that it varied from 41.2 to 43.6 percent and from 40.1 to 44.7 percent in 2016 and 2017, respectively, among the tillage and rice straw management practices as well as the rice establishment systems, although no significant differences were observed (Table 4.3). However the harvest index was found higher in case of direct seeded rice i.e. DSR-RT, DSR-CT and DSR-ZT treatments as compared to puddled rice among the tillage and rice straw management practices. However, among the rice establishment systems irrespective of the tillage and the rice straw management practices, harvest index was found higher in ZTW+R (ZT wheat sown with happy seeder) as compared to the ZTW-R as well as CTW-R during both the years.

A close examination of the data among the tillage and rice straw management practices as well as the rice establishment systems indicated that 1000 grain weight ranged between 21.9 to 24.6 gram and from 22.2 to 25.0 gram in 2016 and 2017, respectively (Table 4.3). Among the rice establishment systems, 1000 grain weight was found higher in PTR as compared to DSR-RT, DSR-CT and DSR-ZT. It was observed that 1000 grain weight was significantly higher in PTR (24.6 g) as compared to the DSR-CT (23.2 g) and DSR-ZT (21.9 g) but not with respect to DSR-RT (21.2 g) in 2016. Similarly in 2017, 1000 grain weight was significantly higher in PTR (25.0 g) as compared to the DSR-CT (23.4 g) and DSR-ZT (22.2 g) but not with DSR-RT (24.4 g). On the other hand, tillage and rice straw management practices showed residual effect on 1000 grain weight among the rice establishment methods, it was found higher in ZTW+R as compared to the ZTW-R as well as CTW-R. However, the interaction between the tillage and rice straw management practices and rice establishment methods was non-significant.

4.1.4 Yield attributes of rice

Plant height is one of the important growth parameter of any crop plant which may vary due to agronomic practices and alter the soil and above ground conditions for the better growth for higher grain yield. Plant height is an index of growth and development representing the infrastructure builds up over a period of time and can be used to study the effect of different treatments on crop growth. In our study, the data related to plant height ranged between 98.4 to 103.2 cm and between 98.8 to 103.9 cm during 2016 and 2017, respectively (Table 4.4). The effect of rice establishment methods upon plant height was found significantly higher in puddled transplanted rice (PTR) as compared to the DSR-ZT only, but plant height in PTR was not significantly higher with respect to DSR-RT as well as DSR-CT during both the years i.e. 2016 and 2017. However, among the tillage and rice straw management practices irrespective of the rice establishment systems, it was found that the plant height was higher in ZTW+R treatment as compared to the ZTW-R and CTW-R. The trend was found same during both the years. The interaction amongst tillage and rice straw management practices and the rice establishment methods was non-significant.

Effective tillers m^{-2} is designated as most important yield component amongst the yield attributing characters. It is the decisive factor to obtain the higher crop yield. The data presented in Table 4.4 revealed that rice establishment methods significantly influenced the effective tillers m^{-2}. The ZTW+R registered higher effective tillers m^{-2} than other tillage systems. The maximum number of effective tillers m^{-2} in ZTW+R as compared to ZTW-R and CTW-R could be due to less weed population, which accounts for less competition for various growth factors such as water, nutrient, space and light as compared to other methods of tillage that ultimately affects yield. Wheat residue suppressed the weeds at early crop growth stages and hence reduces the crop weed competition at initial growth stages.

Panicle length is also important yield attribute of rice which contributes to the rice productivity. Panicle length helps in determining number of spikelets per panicle and number of grains per panicle which plays key role in increasing or decreasing yield. Data presented in Table 4.4 showed that the panicle length was not influenced by different tillage systems and showed almost similar panicle length. These results are in conformity with the findings of Kumar *et al* (2013).

Table 4.4: Effect of rice establishment methods, tillage and straw management practiceson rice yield attributes

Treatment	Plant height (cm)		Effective tillers (m^{-2})		Panicle length (cm)	
	2016	**2017**	**2016**	**2017**	**2016**	**2017**
Rice establishment methods						
DSR-ZT	98.4	98.8	336.2	339.4	23.1	23.1
DSR-CT	101.1	101.8	342.8	345.9	23.6	23.8
DSR-RT	102.8	103.5	348.8	351.9	24.9	25.1
PTR	103.2	103.9	356.3	359.4	25.2	25.2
LSD (0.05)	2.29	3.01	13.2	9.20	0.86	0.73
Tillage and rice straw management practices						
CTW-R	101.3	102.0	344.9	349.2	24.1	24.3
ZTW-R	100.8	101.4	342.6	346.2	23.7	23.8
ZTW+R	102.0	102.6	350.5	352.1	24.7	24.9
LSD (0.05)	NS	NS	3.49	NS	0.54	0.56
Interaction						
LSD (0.05)	NS	NS	NS	NS	NS	NS

4.2 Effect of rice establishment methods, tillage and rice straw management practices on concentration of micronutrients at maximum tillering of wheat and rice

4.2.1 Micronutrients (Zn, Cu, Fe and Mn) concentration at maximum tillering of wheat

A persual of the data in Table 4.5 indicated that the concentration of Zn at maximum tillering stage of wheat under rice establishment methods irrespective of the tillage and rice straw management practices in wheat showed significant effect among the treatments on subsequent wheat in 2016-17, but the effect was non-significant in 2015-16. Zn concentration in 2016-17 was significantly higher in DSR-RT (16.4 mg kg^{-1}) and DSR-CT (16.4 mg kg^{-1}) with respect to DSR-ZT (13.4 mg kg^{-1}) and it was at par with PTR (15.7 mg kg^{-1}). Whereas, amongst the tillage and rice straw management practices irrespective of the rice establishment methods, the Zn concentration at maximum tillering stage of wheat was found significantly higher in ZTW+R (12.1 and 16.2 mg kg^{-1}) with respect to ZTW-R (11.2 and 14.6 mg kg^{-1}) during both the years (2015-16 and 2016-17). However, the interaction between rice establishment methods and tillage and rice straw management practices in wheat was found non-significant.

Table 4.5: Effect of rice establishment methods, tillage and straw management practices on micronutrients concentration (mg kg^{-1}) at maximum tillering of wheat

Treatment	Zn		Cu		Fe		Mn	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
Rice establishment methods								
DSR-ZT	10.9	13.4	5.69	5.69	167.6	204.2	16.5	19.4
DSR-CT	11.2	16.4	5.74	6.09	207.7	243.7	17.0	22.1
DSR-RT	12.5	16.4	5.98	6.17	212.3	247.6	18.2	24.4
PTR	12.1	15.7	5.89	5.71	200.8	240.3	16.9	21.5
LSD (0.05)	NS	1.09	NS	NS	30.4	17.5	1.05	2.13
Tillage and rice straw management practices								
CTW-R	11.8	15.6	5.72	5.93	201.9	233.2	17.2	21.7
ZTW-R	11.2	14.6	5.69	5.76	175.9	220.4	15.8	20.7
ZTW+R	12.1	16.2	6.05	6.06	213.5	248.7	18.5	23.2
LSD (0.05)	0.85	0.82	NS	NS	20.4	14.5	1.24	1.21
Interaction								
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

The data in Table 4.5 revealed that rice establishment methods indicated non-significant effect on concentration of Cu at maximum tillering stage of wheat during both the years i.e. 2015-16 and 2016-17. Although the effect was found non-significant, but the concentration of Cu was found higher in DSR-RT (5.98 and 6.17 mg kg^{-1}) as compared to PTR (5.89 and 5.71 mg kg^{-1}) during both the years (2015-16 and 2016-17). However, among the tillage and rice straw management practices, Cu concentration again showed non-significant effect among the different treatments but the concentration was found higher in ZTW+R (6.05 and 6.06 mg kg^{-1}) followed by CTW-R (5.72 and 5.93 mg kg^{-1}) followed by ZTW-R (5.69 and 5.76 mg kg^{-1}) during both the years (2015-16 and 2016-17). The interaction was also found non-significant within the different treatments.

The Fe concentration at maximum tillering stage of wheat varied from 167.6 to 213.5 mg kg^{-1} in 2015-16, whereas it ranged from 204.2 to 248.7 mg kg^{-1} in 2016-17. The significant results were found among the treatments under rice establishment methods as well as tillage and rice straw management practices. The Fe concentration was significantly higher in DSR-RT i.e. 212.3 and 247.6 mg kg^{-1} as compared to DSR-ZT i.e. 167.6 and 204.2 mg kg^{-1} during 2015-16 and 2016-17 sown wheat. However, amongst the tillage and rice straw management practices, Fe concentration was found significantly higher in ZTW+R with respect to ZTW-R. The trend was similar during both the years. Even the Fe concentration was found higher in CTW-R as compared to ZTW-R.

A close examination of the data indicated that the Mn concentration at maximum tillering stage of wheat varied from 16.5 to 18.5 mg $kg^{-1}$and from 19.4 to 23.2 mg kg^{-1}during both the years of experimentation i.e. 2015-16 and 2016-17. The Mn concentration was found significantly higher in ZTW+R as compared to ZTW-R. Even the Mn concentration was higher in CTW-R as compared to ZTW-R. Among the rice establishment methods irrespective of the tillage and rice straw management practices in wheat, the Mn concentration was found significantly higher in DSR-RT with respect to DSR-ZT. However the interaction between rice establishment methods as well as tillage and rice straw management practices in wheat showed non-significant effect among the treatments.

4.2.2 Micronutrients (Zn, Cu, Fe and Mn) concentration at maximum tillering of rice

The Zn concentration at maximum tillering stage of rice varied from 37.91 to 48.37 mg kg^{-1} in 2016 and from 33.79 to 46.59 mg kg^{-1} in 2017 among the different treatment combinations (Table 4.6). Rice establishment methods found to have significant effect on Zn concentration in rice at maximum tillering stage, as the Zn concentration was found significantly higher in DSR-RT (48.37 and 46.59 mg kg^{-1}), DSR-CT (45.32 and 43.87 mg kg^{-1}) and DSR-ZT (44.51 and 43.28 mg kg^{-1}) as compared to PTR (37.91 and 33.79 mg kg^{-1}) during both the years of experimentation (2016 and 2017). The trend was found similar during both the years. However, in case of tillage and rice straw management practices irrespective of the rice establishment methods, rice straw management practices in wheat showed its residual impact on Zn concentration at maximum tillering stage of rice, as Zn concentration was found significantly higher under ZTW+R treatments as compared to ZTW-R. The interaction was found non-significant among the different treatments.

Rice establishment methods indicated non-significant effect on Cu concentration in rice at maximum tillering stage during both the years. Although the results revealed non-significant effect among the treatments, still the Cu concentration was found higher in PTR as compared to DSR treatments. On the other hand, in case of tillage and rice straw management practices irrespective of the rice establishment methods, Cu concentration was found higher in ZTW+R as compared to ZTW-R and CTW-R. The interaction between rice establishment methods and tillage and rice straw management practices in wheat was found non-significant.

Table 4.6: Effect of rice establishment methods, tillage and straw management practices on micronutrients concentration (mg kg^{-1}) at maximum tillering of rice

Treatment	Zn		Cu		Fe		Mn	
	2016	2017	2016	2017	2016	2017	2016	2017
Rice establishment methods								
DSR-ZT	44.51	43.28	5.4	5.2	149.9	145.0	154.0	142.8
DSR-CT	45.32	43.87	5.5	5.8	156.0	152.9	197.9	189.4
DSR-RT	48.37	46.59	5.4	5.4	159.1	153.6	197.2	185.4
PTR	37.91	33.79	5.6	5.9	174.5	173.0	205.8	198.6
LSD (0.05)	6.14	3.49	NS	NS	15.71	18.15	18.7	15.3
Tillage and rice straw management practices								
CTW-R	43.34	41.35	5.4	5.6	158.9	154.0	194.5	184.5
ZTW-R	41.90	40.83	5.2	5.1	156.5	152.6	178.7	167.2
ZTW+R	46.83	45.73	5.9	6.1	164.2	160.4	202.2	185.6
LSD (0.05)	3.76	3.61	NS	0.5	NS	NS	NS	14.2
Interaction (LSD)	NS	NS	NS	NS	NS	NS	NS	NS

A glance at the data showed that the Fe concentration in rice at maximum tillering stage ranged between 149.9 to 174.5 mg kg^{-1} and from 145.0 to 173.0 mg kg^{-1} during 2016 and 2017. Significantly higher concentration of Fe in rice was found under PTR (174.5 and 173.0 mg kg^{-1}) with respect to DSR-CT (156.0 and 152.9 mg kg^{-1}) and DSR-ZT (149.9 and 145.0mg kg^{-1}) during both the years (2016 and 2017) among rice establishment methods irrespective of the tillage and rice straw management practices. However, no significant effect was found to observe under tillage and rice straw management practices in wheat on succeeding rice for Fe concentration at maximum tillering stage. But the residual effect was found more under ZTW+R followed by CTW-R followed by ZTW-R for Fe concentration in rice. The interaction was found non-significant within the different treatment combinations.

The Mn concentration in rice at maximum tillering stage ranged from 154.0 to 205.9 mg kg^{-1} and 142.8 to 198.6 mg kg^{-1} during 2016 and 2017. Among the rice establishment methods, significant difference was observed within the treatments, as the Mn concentration was found significantly higher in PTR (205.9 and 198.6 mg kg^{-1}) as compared to DSR-ZT (154.0 and 142.8 mg kg^{-1}), but it was at par with respect to DSR-RT (197.2 and 185.4 mg kg^{-1}) as well as DSR-CT (197.9 and 189.4 mg kg^{-1}). However, the residual effect of tillage and rice straw management practices in wheat was found over the rice establishment methods. Amongst the tillage and rice straw management practices, the Mn concentration was found higher in ZTW+R treatment as compared to ZTW-R and CTW-R during both the years. The interaction between rice establishment methods and tillage and rice straw management practices in wheat found non-significant.

4.3 Effect of rice establishment methods, tillage and rice straw management practices on concentration of micronutrients in wheat and rice

4.3.1 Micronutrients (Zn, Cu, Fe and Mn) concentration in wheat grains

Zinc

In our study, tillage and rice straw management practices as well as rice establishment systems did not significantly affected the Zn concentration in wheat grain (Table 4.7). Zn content ranged from 23.8 to 24.99 mg kg^{-1} in first year sown wheat (2015-16) and from 24.23 to 24.83 mg kg^{-1} in the second year wheat (2016-17). The rice establishment methods were also unable to show significant differences among the treatments. Otherwise, Zn concentration was found higher in ZTW+R where wheat was sown with happy seeder, as compared to the treatments where no residue was retained i.e. ZTW-R and CTW-R. Among the tillage and rice straw management practices, ZTW+R showed 5 percent and 3 percent higher Zn concentration as compared to ZTW-R and CTW-R during the first year wheat crop (2015-16). Similarly, in the second year of an experiment, ZTW+R showed 6 percent and 3 percent higher Zn concentration as compared to ZTW-R and CTW-R. Rice establishment systems also found to have non-significant effect on Zn concentration in wheat grains during both the years. The interaction between tillage and rice straw management practices in wheat, and rice establishment methods found non-significant. Tillage and rice straw management practices as well as rice establishment methods was not significant, so the results revealed that most of the Zn content retained in the wheat straw.

Habiby *et al* (2014) observed that zinc concentration of wheat grain augmenteddue to the increase inSOM after the plant residues incorporation such as safflower and clover. The availability of micronutrients in the soil can strongly affect the production and quality of crops. Soil OM exerts a significant and direct impact on the availability of Zn, Fe and Mn but has little influence on the availability of soil Cu (Zhang *et al* 2001). In addition, the interaction of other soil macronutrients and micronutrients also affected micronutrients uptake by crops (Aulakh and Malhi 2005).

Organic matter is a reservoir of several nutrients, including copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn). It chelates micronutrientcations and thus the availability increased in plants through decrease in precipitation with phosphorus (Ndiaye and Krishna 2002) or oxides (Havlin *et al* 1999). Conversely, according to Ndiaye and Krishna (2002) and Wei *et al* (2006), SOM can behave as a sink for Cu due of its ability to strongly complex and bind this nutrient which can exacerbate Cu deficiency in soils. Nutrients tied up in crop residues and organic matter, released in the soil as plant available form during disintegration and mineralisation. However, decomposition of residuesarouses microbial activity as well as diversity, due to which, large proportions of these nutrients may be immobilised. Apart from stimulating microbial activity, decomposition of organic materials and nitrification of ammoniacal fertilizers cause a decline in soil pH, and plants may experience P deficiency and micronutrient toxicities. Straw burning causes considerable losses of some essential nutrients (Loke *et al* 2012) and a long-term negative effect on SOM and nutrient holding ability, it reduces microbial biomass and thus immobilization of P (Singh and Rengel 2007).

Copper

Tillage and rice straw management practices as well as rice establishment systems found to have non-significant effect on the Cu concentration in wheat grains (Table 4.7). Cu concentration varied from 4.13 to 4.81 mg kg^{-1} in first year sown wheat (2015-16) and from 4.15 to 4.83 mg kg^{-1} in the second year sown wheat (2016-17). However, the Cu concentration was found higher in ZTW+R or where wheat was sown with happy seeder, as compared to the treatments where no residue was retained i.e. ZTW-R and CTW-R. Among the tillage and rice straw management practices, ZTW+R showed 2 percent higher Cu concentration as compared to CTW-R during the first year wheat crop (2015-16). Rice establishment methods also found to have non-significant effect on Cu concentration in wheat grains during both the years. The interaction between tillage and rice straw management practices in wheat, and rice establishment methods found non-significant. Tillage and rice straw management practices as well as rice establishment systems was not significant, so the results revealed that most of the

Cu concentration retained in the wheat straw. On contrary, Wang *et al* (2016) reported that the application of crop residues increased the concentrations of Fe and Zn in wheat straw and grain, but the Cu concentrations tended to decrease with the compost treatments compared with the corresponding control.

Iron (Fe):

Tillage and rice straw management practices as well as rice establishment systems did not significantly affected Fe concentration in wheat grains (Table 4.7). Fe concentration varied from 28.04 to 29.68 mg kg^{-1} in first year sown wheat (2015-16) and from 28.41 to 30.22 mg kg^{-1} in the second year sown wheat (2016-17).

Table 4.7: Effect of rice establishment methods, tillage and straw management practices on concentration (mg kg^{-1}) of micronutrients in wheat grains

Treatment	Zn		Cu		Fe		Mn	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
Rice establishment methods								
DSR-ZT	24.69	25.63	4.13	4.15	28.04	28.41	12.33	12.37
DSR-CT	23.96	24.96	4.48	4.47	29.68	30.22	13.07	14.53
DSR-RT	23.93	24.23	4.29	4.40	28.88	29.45	12.83	12.98
PTR	24.97	26.51	4.50	4.53	29.20	29.48	12.47	12.91
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Tillage and rice straw management practices								
CTW-R	24.32	25.60	4.71	4.72	28.73	29.32	12.31	12.90
ZTW-R	23.84	24.83	4.28	4.37	28.65	28.76	12.68	13.19
ZTW+R	24.99	26.32	4.81	4.83	29.46	30.08	13.04	13.51
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Interaction								
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

However, Fe concentration was found higher in ZTW+R, as compared to the treatments where no residue was retained i.e. ZTW-R and CTW-R. Tillage and rice straw management practices showed that ZTW+R treatment is having 3 percent and 2 percent higher Fe concentration as compared to ZTW-R and CTW-R during the first year wheat crop (2015-16). Similarly, in the second year of an experiment, ZTW+R showed 4 percent and 3 percent higher Fe concentration as compared to ZTW-R and CTW-R. Even among the tillage and rice straw management practices, CTW-R is found to have more Fe concentration in wheat grains as compared to the ZTW-R treatment. Rice establishment systems also found to have non-significant effect on Fe concentration in wheat grains during both the years (2015-

16 and 2016-17). The interaction between tillage and rice straw management practices in wheat, and rice establishment methods found non-significant. Tillage and rice straw management practices as well as rice establishment systems was not significant, so the results revealed that most of the Fe content retained in the wheat straw. Wang *et al* (2016) reported that the application of crop residues increased the concentrations of Fe and Zn in wheat straw and grain, but the Cu concentrations tended to decrease with the compost treatments compared with the corresponding control.

Manganese

Tillage and rice straw management practices as well as rice establishment systems failed to show significant effect on Mn concentration in wheat grain (Table 4.7). Mn concentration ranged from 12.31 to 13.07 mg kg^{-1} and 12.37 to 14.53 mg kg^{-1} in wheat (2015-16) and (2016-17), respectively. However, Mn concentration was found higher in ZTW+R, as compared to the treatments where no residue was retained i.e. ZTW-R and CTW-R. Tillage and rice straw management practices showed that ZTW+R is having higher Mn concentration as compared to ZTW-R and CTW-R during both the years of wheat crop 2015-16 and 2016-17. Similarly, in the second year of an experiment, ZTW+R also showed higher Mn concentration as compared to ZTW-R and CTW-R. Even among the tillage and rice straw management practices, CTW-Ris found to have more Mn concentration in wheat grain as compared to the ZTW-R treatment. The interaction between tillage and rice straw management practices in wheat, and rice establishment methods found non-significant, so the results revealed that most of the Mn concentration was retained in the wheat straw.

4.2.2 Micronutrients (Zn, Cu, Fe and Mn) concentration in wheat straw

Zinc

Tillage and rice straw management practices as well as rice establishment systems did not significantly affected the Zn concentration in wheat straw (Table 4.8). Zn concentration in wheat straw varied from 17.16 to 18.73 mg kg^{-1} and 17.18 to 18.76 mg kg^{-1} in wheat (2015-16) and (2016-17). Zn concentration in wheat straw was found higher in ZTW+R same as in the case wheat grain, as compared to the treatments where no residue was retained i.e. ZTW-R and CTW-R. Zn concentration in wheat straw was found to be lowest in case of ZTW-R. Among the tillage and rice straw management practices, ZTW+R showed higher Zn concentration in wheat straw as compared to ZTW-R and CTW-R during both the years. Rice establishment systems also found to have non-significant effect on Zn content in wheat straw during both the years. The interaction between tillage and rice straw management practices in wheat, and rice establishment methods found non-significant.

Table 4.8: Effect of rice establishment methods, tillage and straw management practices on concentration (mg kg^{-1}) of micronutrients in wheat straw

Treatment	Zn		Cu		Fe		Mn	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
Rice establishment methods								
DSR-ZT	17.94	17.97	3.34	3.38	138.0	138.5	12.46	12.51
DSR-CT	17.16	17.18	3.13	3.14	134.9	135.2	11.73	11.81
DSR-RT	17.82	17.87	3.02	3.05	134.8	135.0	11.17	11.22
PTR	18.73	18.76	3.55	3.57	140.7	141.0	12.13	12.17
LSD (0.05)	NS	NS	NS	NS	2.05	3.12	NS	NS
Tillage and rice straw management practices								
CTW-R	17.73	17.76	3.24	3.26	137.3	137.7	11.65	11.69
ZTW-R	17.61	17.63	3.16	3.19	135.4	135.7	11.90	11.93
ZTW+R	18.40	18.45	3.37	3.40	138.6	138.9	12.07	12.16
LSD (0.05)	NS	NS	NS	NS	2.07	NS	NS	NS
Interaction								
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Copper

Cu concentrationin wheat straw ranged from 3.02 to 3.55 mg kg^{-1} in 2015-16 and 3.05 to 3.57 mg kg^{-1} in 2016-17. Tillage and rice straw management practices in wheat as well as the rice establishment systems did not show any significant differences among the treatments (Table 4.8). However, Cu concentration in wheat straw was found higher in ZTW+R i.e. 3.37 mg kg^{-1} in 2015-16 and 3.40 mg kg^{-1} in 2016-17 as compared to the treatments where no residue was retained i.e. ZTW-R (3.16 mg kg^{-1}) and CTW-R (3.24 mg kg^{-1}) in 2015-16 and ZTW-R (3.19 mg kg^{-1}) and CTW-R (3.26 mg kg^{-1}) in 2016-17. Rice establishment methods also found to have non-significant effect on Cu concentration in wheat straw during both the years. The interaction between tillage and rice straw management practices in wheat and rice establishment methods was found non-significant. Wang *et al* (2016) reported that the application of crop residues increased the concentrations of Fe and Zn in wheat straw and grain, but the Cu concentrations tended to decrease with the crop residue treatments compared with the corresponding control.

Iron

Fe concentration in wheat straw (Table 4.8) varied from 134.8 to 140.7 mg kg^{-1} in first year sown wheat (2015-16). Similarly, during the second year of the experiment (2016-17) it varied from135.0 to 141.0 mg kg^{-1}. However, among the tillage and rice straw management practices in wheat, Fe concentration was observed as significantly higher in ZTW+R with respect to the ZTW-R during first year wheat (2015-16). Whereas, no such significant difference was found during the second year sown wheat 2016-17. Even among the tillage and rice straw management practices, CTW-R is found to have more Fe concentration in wheat straw as compared to the ZTW-R treatment. Rice establishment methods also found to have significant effect on Fe concentration in wheat straw during both the years (2015-16 and 2016-17). The interaction between tillage and rice straw management practices in wheat, and rice establishment methods found non-significant.

Manganese

Tillage and rice straw management practices in wheat as well as rice establishment systems failed to show significant effect on Mn concentration in wheat straw (Table 4.8). Mn concentration ranged 11.17 to 12.46 mg kg^{-1} and 11.22 to 12.51 mg kg^{-1} in wheat (2015-16) and (2016-17), respectively. Tillage and rice straw management practices showed that ZTW+R is having higher Mn concentration in wheat straw as compared to ZTW-R and CTW-R during both the years. Even among the tillage and rice straw management practices, CTW-R is found to have more Mn concentration in wheat straw as compared to the ZTW-R treatment. The interaction between tillage and rice straw management practices in wheat, and rice establishment methods found non-significant.

4.2.3 Micronutrients (Zn, Cu, Fe and Mn) concentration in rice grains

Zinc

A close examination of the data regarding the effect of tillage and rice straw management practices as well as rice establishment systems failed to show significant effect on Zn concentration in rice grains (Table 4.9). It was observed that the Zn concentration in rice grains ranged between 18.12 to 19.50 mg kg^{-1} and 15.14 to 17.41 mg kg^{-1} in rice 2016 and 2017, respectively. Among the rice establishment systems irrespective of the tillage and rice straw management practices in wheat, Zn concentration in rice grains found higher in DSR-RT, DSR-CT, DSR-ZT than in PTR. The trend was found similar during both the years. Zn concentration in rice grains varied as 19.37 and 16.27 mg kg^{-1}, 19.15 and 15.94 mg kg^{-1}, 18.76 and 15.56 mg kg^{-1}, and 18.12 and 15.14 mg kg^{-1} in DSR-RT, DSR-CT, DSR-ZT and then in PTR during 2016 and 2017, respectively.

On the other hand, it was observed that different tillage and rice straw management practices in wheat irrespective the rice establishment systems showed non-significant effect on Zn concentration in rice grains 2016, but showed significant effect in 2017. The concentration for Zn in rice grains were found higher in ZTW+R treatments during both the years i.e. 2016 and 2017, as compared to the ZTW-R and CTW-R treatments. The Zn concentration in ZTW+R, CTW-R and ZTW-R treatments varied as 19.50 and 17.41 mg kg^{-1}, 18.82 and 15.65 mg kg^{-1} and 18.23 and 15.64 mg kg^{-1} in 2016 and 2017, respectively.

However, the interaction between tillage and rice straw management practices in wheat and rice establishment methods found non-significant. In majority of studies, there has been a significant positive correlationship (De *et al* 1979) in between organic matter and available Zn in soils and hence their uptake in plants.

Copper

The data showed that the effect of rice establishment methods on Cu concentration in rice grains found to have non-significant effect during both the years (Table 4.9). Cu concentration in rice grains ranged from 4.69 to 5.92 mg $kg^{-1}$and 3.21 to 3.40 mg kg^{-1} in first year (2016) as well as in second year rice (2017). The Cu concentration in rice grains was higher in PTR as compared to the DSR-RT, DSR-CT, DSR-ZT. In case of puddled transplanted rice (PTR), the Cu concentration was 5.92 and 3.40 mg kg^{-1}, in DSR-CT it was 5.55 and 3.34 mg kg^{-1}, in DSR-RT it was 5.43 and 3.30 mg kg^{-1} and in DSR-ZT mg kg^{-1} it was from 4.69 and 3.23 mg kg^{-1} in 2016 and 2017, respectively. However, Cu concentration in rice grains found higher in ZTW+R (5.70 mg kg^{-1}), as compared to the treatments where no residue was retained i.e. ZTW-R (5.37 mg kg^{-1}) and CTW-R (5.51 mg kg^{-1}) in 2015-16. Similarly, Cu concentration in ZTW+R (3.39 mg kg^{-1}) was higher as compared to ZTW-R (3.21 mg kg^{-1}) and CTW-R (3.36 mg kg^{-1}).

Table 4.9: Effect of rice establishment methods, tillage and straw management practices on concentration (mg kg^{-1}) of micronutrients in rice grains

Treatment	Zn		Cu		Fe		Mn	
	2016	2017	2016	2017	2016	2017	2016	2017
Rice establishment methods								
DSR-ZT	18.76	15.56	4.69	3.23	45.90	47.45	10.43	7.38
DSR-CT	19.15	15.94	5.55	3.34	47.01	49.54	11.35	7.61
DSR-RT	19.37	16.27	5.43	3.30	48.15	50.58	12.24	8.07
PTR	18.12	15.14	5.92	3.40	52.02	54.25	13.65	8.12
LSD (0.05)	NS	NS	NS	NS	3.50	3.93	1.53	NS
Tillage and rice straw management practices								
CTW-R	18.82	15.65	5.51	3.36	47.75	49.42	11.82	7.80
ZTW-R	18.23	15.64	5.37	3.21	46.94	49.39	11.32	7.42
ZTW+R	19.50	17.41	5.70	3.39	50.13	52.55	12.61	8.15
LSD (0.05)	NS	0.95	NS	NS	1.01	1.47	0.93	NS
Interaction								
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Das and Mandal (1986) reported that the uptake of Cu by the rice root, straw and grains wasfound to be more in the rice plants grown under waterlogged condition. The higher Cu uptake by the different plant parts of rice (root, straw and grain) under waterlogged condition may be explained due to favourable chemical environment of root medium leading to higher root proliferation and nutrient absorption by the rice due to the reducing conditions. The interaction between tillage and rice straw management practices in wheat, and rice establishment methods was found non-significant.

Iron

An examination of the data related to the effect of tillage and rice straw management practices as well as rice establishment methods on Fe concentration in rice grains (Table 4.9) found to have significant effect among the different treatments. Fe concentration in rice grains varied from 45.90 to 52.02 mg kg^{-1} in first year rice crop (2016) and from 47.45 to 54.25 mg kg^{-1} in 2017. Amongst the rice establishment methods irrespective of the tillage and rice straw management practices in wheat crop, the Fe concentration in rice grains was significantly higher in PTR (52.02 mg kg^{-1}) then direct seeded rice treatments viz. DSR-RT (48.15 mg kg^{-1}), DSR-CT (47.01 mg kg^{-1}) and DSR-ZT (45.90 mg kg^{-1}) in 2016. Similarly, in 2017, Fe concentration in rice grains was significantly higher in PTR (54.25 mg kg^{-1}) than DSR-CT (49.54 mg kg^{-1}) and DSR-ZT (47.45 mg kg^{-1}).

However, amongst the tillage and rice straw management practices, Fe concentration was found significantly higher in ZTW+R (50.13 and 52.55 mg kg^{-1}) as compared to the ZTW-R (46.94 and 49.39 mg kg^{-1}) and CTW-R (47.75 and 49.42 mg kg^{-1}) during both the years (2016 and 2017). Lowest Fe concentration in rice grains was found in case of ZTW-R treatment during both years. However, the interaction between tillage and rice straw management practices in wheat, and rice establishment methods found non-significant.

Manganese

Tillage and rice straw management practices as well as rice establishment systems showed significant effect on Mn concentration in rice grains (Table 4.9) in 2016. Mn concentration ranged from 10.43 to 13.65 mg kg^{-1} from 7.38 to 8.15 mg kg^{-1} in rice grains during 2016 and 2017, respectively. It was found that Fe concentration in rice grains was higher in PTR (13.65 mg kg^{-1}) followed by DSR-RT (12.24 mg kg^{-1}) followed by DSR-CT (11.35 mg kg^{-1}) and then DSR-ZT (10.43 mg kg^{-1}) in 2016. Likewise, Fe concentration in rice grains followed the same trend in 2017 as in 2016, where it was found higher in PTR (8.12 mg kg^{-1}) followed by DSR-RT (8.07 mg kg^{-1}) followed by DSR-CT (7.61 mg kg^{-1}) and then DSR-ZT (7.38 mg kg^{-1}). However, tillage and rice straw management practices in wheat irrespective of the rice establishment systems were found to show non-significant effect on Mn content in rice grains in 2017 but showed significant effect in 2016. Moreover, Mn concentration was found higher in ZTW+R, as compared to ZTW-R and CTW-R. In case of

ZTW+R, Mn concentration was 12.61 mg kg^{-1} which was significantly higher than ZTW-R (11.32 mg kg^{-1}) but not than CTW-R (11.82 mg kg^{-1}) treatment in 2016. Even ZTW+R found to have more Mn concentration in rice grains as compared to the ZTW-R treatment as well as CTW-R in 2017. The interaction between tillage and rice straw management practices in wheat, and rice establishment methods found non-significant.

4.2.4 Micronutrients (Zn, Cu, Fe and Mn) concentration in rice straw

Zinc

A persual of the data regarding the effect of tillage and rice straw management practices as well as rice establishment methods indicated that the Zn concentration in rice straw ranged between 54.62 to 62.92 mg $kg^{-1}$and 52.44 to 62.60 mg kg^{-1} in rice 2016 and 2017, respectively (Table 4.10). Among the rice establishment methods irrespective of the tillage and rice straw management practices in wheat, Zn concentration in rice straw found higher in DSR-RT, DSR-CT, DSR-ZT than in PTR. The trend was found similar during both the years. Zn concentration in rice straw varied as 62.92 and 60.59 mg kg^{-1}, 62.31 and 62.60 mg kg^{-1}, 61.35 and 59.15 mg kg^{-1}, and 54.62 and 52.44 mg kg^{-1} in DSR-RT, DSR-CT, DSR-ZT and then in PTR during 2016 and 2017, respectively. However, it was observed that different tillage and rice straw management practices in wheat irrespective of the rice establishment systems also showed significant effect on Zn concentration in rice straw in both year i.e.2016 and 2017. The concentration of Zn in rice straw was found significantly higher in ZTW+R as compared to the ZTW-R treatments. The Zn concentration in rice straw in treatments alike ZTW+R, CTW-R and ZTW-R varied as 62.53 and 62.34 mg kg^{-1}, 60.78 and 58.28 mg kg^{-1} and 57.58 and 55.47 mg kg^{-1} in 2016 and 2017, respectively. However, the interaction between tillage and rice straw management practices in wheat, and rice establishment methods found non-significant.

Copper

The data refer to the effect of tillage and rice straw management practices as well as rice establishment systems on Cu concentration in rice straw found to have non-significant effect on tillage and rice straw management practices during both the years (Table 4.10). Cu concentration in rice straw ranged from 2.92 to 3.54 mg kg^{-1} and from 2.81 to 3.52 mg kg^{-1}in first year (2016) as well as in second year rice (2017). On the other hand, amongst the rice establishment methods, the Cu concentration in rice straw showed significant differences among the treatments. It was observed that Cu concentration was higher in PTR as compared to the DSR-CT, DSR-ZT and DSR-RT. Tillage and rice straw management practices in wheat showed higher residual effect on Cu concentration under ZTW+R treatment in rice straw during both the years. Cu concentration in ZTW+R (3.32 mg kg^{-1}) was comparatively higher than the treatments where no residue was retained i.e. ZTW-R (3.11 mg kg^{-1}) and CTW-R (3.07 mg kg^{-1}) in 2016. Similarly in 2017, Cu concentration was higher in ZTW+R (3.24 mg kg^{-1}) was higher as compared to ZTW-R (3.01 mg kg^{-1}) and CTW-R (2.99 mg kg^{-1}). The interaction between tillage and rice straw management practices in wheat and rice establishment methods was found non-significant.

Table 4.10: Effect of rice establishment methods, tillage and straw management practices on concentration (mg kg^{-1}) of micronutrients in rice straw

Treatment	Zn		Cu		Fe		Mn	
	2016	2017	2016	2017	2016	2017	2016	2017
Rice establishment methods								
DSR-ZT	61.35	59.15	2.92	2.81	293.5	288.9	187.3	169.3
DSR-CT	62.31	62.60	3.22	3.09	317.2	311.8	218.4	205.9
DSR-RT	62.92	60.59	2.97	2.89	317.2	317.4	242.9	231.7
PTR	54.62	52.44	3.54	3.52	363.0	358.2	285.5	267.7
LSD (0.05)	NS	4.36	0.41	0.37	18.54	28.37	17.0	19.5
Tillage and rice straw management practices								
CTW-R	60.78	58.28	3.07	2.99	327.8	324.5	238.6	221.5
ZTW-R	57.58	55.47	3.11	3.01	299.4	294.6	219.1	204.0
ZTW+R	62.53	62.34	3.32	3.24	341.0	338.2	242.8	230.5
LSD (0.05)	3.34	4.49	NS	NS	21.20	21.31	18.0	13.1
Interaction								
LSD	NS	NS	NS	NS	NS	NS	NS	NS

Iron

Tillage and rice straw management practices as well as rice establishment systems significantly affected Fe concentration in rice straw (Table 4.10). The Fe concentration varied from 293.5 to 363.0 mg kg^{-1} in 2016 and from 288.9 to 358.2 mg kg^{-1} in 2017. Rice establishment methods showed that the Fe concentration was found significantly higher in PTR (363.0 mg kg^{-1}) as compared to the DSR-RT (317.2 mg kg^{-1}), DSR-CT (317.2 mg kg^{-1}) and DSR-ZT (293.5 mg kg^{-1}) in 2016. Similarly, the rice establishment systems also indicated significant results in 2017, as the Fe concentration was found higher in PTR (358.2 mg kg^{-1}) as compared to the DSR-RT (317.4 mg kg^{-1}), DSR-CT (311.8 mg kg^{-1}) and DSR-ZT (288.9 mg kg^{-1}). Moreover, the trend was found similar in both years. However, the tillage and rice straw management practices in wheat also showed significant differences among the treatments on Fe concentration in rice straw of subsequent rice, as the Fe was found significantly higher in ZTW+R treatment as compared to ZTW-R but was not showed significant difference w.r.t. CTW-R during both the years.

Manganese

The data revealed that the tillage and rice straw management practices as well as rice establishment methods expressed the significant effect on Mn concentration in rice straw (Table 4.10). Mn concentration ranged from 187.3 to 285.5 mg kg^{-1}and from 169.3 to 267.7 mg kg^{-1} in rice straw during 2016 and 2017, respectively. Rice establishment methods irrespective of the tillage and rice straw management practices showed significant results within the treatments during both the years, it was found that Mn concentration in rice straw was significantly higher in PTR (285.5 mg kg^{-1}) followed by DSR-RT (242.9 mg kg^{-1}) followed by DSR-CT (218.4 mg kg^{-1}) and then DSR-ZT (187.3 mg kg^{-1}) in 2016. Likewise, Fe concentration in rice straw followed the same trend in 2017, where it was found higher in PTR (267.7 mg kg^{-1}) followed by DSR-RT (231.7 mg kg^{-1}) followed by DSR-CT (205.9 mg kg^{-1}) and then DSR-ZT (169.3 mg kg^{-1}).

However, tillage and rice straw management practices in wheat irrespective of the rice establishment systems were found to show significant effect on Mn content in rice straw on subsequent rice crop in 2016 as well as in 2017. Mn concentration was found significantly higher in ZTW+R, as compared to CTW-R. In case of ZTW+R, Mn concentration was 242.8 mg kg^{-1} which was significantly higher than ZTW-R (219.1 mg kg^{-1}) but not significantly higher than CTW-R (238.6 mg kg^{-1}) treatment in 2016. Even in 2017, ZTW+R (230.5 mg kg^{-1}) found to have more Mn concentration in rice straw as compared to the ZTW-R (204.0 mg kg^{-1}) treatment. The interaction between tillage and rice straw management practices in wheat, and rice establishment methods found non-significant.

4.4 Effect of rice establishment methods, tillage and rice straw management practices on uptake of micronutrients in wheat and rice

4.4.1 Micronutrients (Zn, Cu, Fe and Mn) uptake in wheat grains

Zinc

Tillage and rice straw management practices as well as rice establishment systems did not significantly affected the Zn uptake in wheat grains (2015-16), but they exhibited significant effect on Zn uptake during the second year (2016-17) of experiment. Zn uptake ranged from 114.2 to 130.7 g ha^{-1} and from 124.2 to 142.6 g ha^{-1} in wheat grains of year 2015-16 and 2016-17 respectively, between tillage and rice straw management practices as well as rice establishment systems (Table 4.11). Among the tillage and rice straw management practices, ZTW+R is found to have 10.3 percent and 10.5 percent significantly higher Zn uptake in wheat grains as compared to the CTW-R and ZTW-R, respectively in 2016-17. Rice establishment systems indicated no significant difference among the treatments, but the uptake was higher in PTR than DSR-ZT, DSR-CT and DSR-RT under both years. The interaction between tillage and rice straw management practices in wheat, and rice establishment methods found non-significant. As tillage and rice straw management practices in wheat, and rice establishment methods did not affect Zn concentration in wheat grain and straw therefore, the effect on grain, straw and Zn uptake was solely attributed to the variability in wheat grain and straw yields. Chhibba (2010) reported that the nutrient taken up by the cereal crops, on an average, 50 – 80 percent of Zn was retained in crop residues. Prasad *et al* (2010) found that rice and wheat straw incorporation in soil significantly increased the Zn uptake as compared to the straw removal in RWS. Walia and Kler (2010) found that FYM with crop residue incorporation significantly higher Zn uptake as compared to inorganic fertilizer alone. The use of organic manures caused increase in uptake of micronutrients which may ultimately lead to increase in availability of Zn in soil. Habiby *et al* (2014) found that the concentration of Zn in wheat grain increased because of increase in SOM after the incorporation of safflower and clover residues. Even, Sinha and Prasad (1977) observed that addition of mobile organic chelating agents directly (e.g., fulvic and citric acids) increases the Zn diffusion into roots and consequently the uptake of Zn in wheat plants in case of calcareous soil.

Copper

Tillage and rice straw management practices as well as rice establishment systems did not significantly affected the Cu uptake in wheat grains during both the years of experimentation (2015-16) and (2016-17). Cu uptake ranged from 20.4 to 25.2 g ha^{-1} and from 21.3 to 26.2 g ha^{-1} in wheat grains during 2015-16 and 2016-17 respectively, between tillage and rice straw management practices as well as rice establishment systems (Table 4.11). Among the tillage and rice straw management practices, ZTW+R is found to have higher Cu uptake in wheat grains as compared to the CTW-R and ZTW-R, respectively. Rice establishment systems also directed no significant difference among the treatments. The interaction between tillage and rice straw management practices in wheat, and rice establishment methods found non-significant during both the years. As tillage and rice straw management practices in wheat, and rice establishment methods did not affect Cu content in wheat grain and straw therefore, the effect on grain, straw and Cu uptake was solely credited to the variability in wheat grain and straw yields. Chhibba (2010) reported that the nutrient taken up by the cereal crops, on an average, 50 - 80 percent of Cu was retained in crop residues. Prasad *et al* (2010) found that rice and wheat straw incorporation significantly increased the Zn uptake as compared to the straw removal in RWS. Walia and Kler (2010) found that the use of organic residues enhanced the uptake of micronutrients which might be due to increase in availability of Cu in soil.

Table 4.11: Effect of rice establishment methods, tillage and straw management practices on uptake (g ha^{-1}) of micronutrients in wheat grains

Treatment	Zn		Cu		Fe		Mn	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
Rice establishment methods								
DSR-ZT	122.0	131.7	20.4	21.3	138.5	146.0	60.9	63.6
DSR-CT	119.3	129.0	22.3	23.1	147.8	156.2	65.1	75.1
DSR-RT	122.5	128.2	21.9	23.3	147.9	155.8	65.7	68.7
PTR	122.8	136.5	22.2	23.3	143.7	151.9	61.4	66.5
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	5.27
Tillage and rice straw management practices								
CTW-R	119.9	131.8	23.2	24.3	141.6	151.0	61.0	66.4
ZTW-R	114.2	124.2	20.5	21.9	137.2	143.8	60.7	65.9
ZTW+R	130.7	142.6	25.2	26.2	153.9	163.0	68.2	73.2
LSD (0.05)	NS	10.29	NS	NS	NS	6.03	NS	4.45
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

Iron

Tillage and rice straw management practices as well as rice establishment systems showed significantly higher Fe uptake in wheat grains during the second year wheat (2016-17), but these treatments showed non-significant effect on Fe uptake in wheat grains during the first year (2015-16) of experiment. Among the tillage and rice straw management practices, ZTW+R is found to have 11.8 percent and 7.4 percent significantly higher Zn uptake in wheat grains as compared to the ZTW-R and CTW-R, respectively. Fe uptake ranged from 137.2 to 153.9 g ha^{-1} and from 143.8 to 163.0 g ha^{-1} in wheat grains of year 2015-16 and 2016-17 respectively, between tillage and rice straw management practices as well as rice establishment systems (Table 4.11). Rice establishment systems specified no significant difference among the treatments on following wheat. The interaction between tillage and rice straw management practices in wheat, and rice establishment methods found non-significant. As tillage and rice straw management practices in wheat did not significantly affected Fe content in wheat grain and straw in 2015-16, therefore, the effect on grain, straw and Fe uptake was solely attributed to the variability in wheat grain and straw yields. Prasad *et al* (2010) found that rice and wheat straw incorporation in soil significantly increased the Fe uptake as compared to the straw removal in RWS.

Manganese

Tillage and rice straw management practices as well as rice establishment systems indicated significantly higher Mn uptake in wheat grains during the second year wheat (2016-17), but these treatments showed non-significant effect on Mn uptake in wheat grains during the first year (2015-16) of experiment. Mn uptake ranged from 60.7 to 68.2 g ha^{-1} and from 63.6 to 75.1 g ha^{-1} in wheat grains of year 2015-16 and 2016-17 respectively, between tillage and rice straw management practices as well as rice establishment systems. Among the tillage and rice straw management practices, ZTW+R is found to have 9.9 percent and 9.2 percent significantly higher Mn uptake in wheat grains as compared to the ZTW-R and CTW-R, respectively. Rice establishment systems specified no significant difference among the treatments during the first year but it showed significant difference among the treatments during the second year of wheat (2016-17). Lowest uptake of Fe was recorded under DSR-ZT among rice establishment methods. The interaction between tillage and rice straw management practices in wheat, and rice establishment methods found non-significant. As per tillage and rice straw management practices in wheat, and rice establishment methods did not affect Mn content in wheat grain in 2015-16, therefore, the effect on grain, straw and Fe uptake was solely attributed to the variability in wheat grain and straw yields.

4.3.2 Micronutrients (Zn, Cu, Fe and Mn) uptake in wheat straw

Zinc

Zn uptake in wheat straw (Table 4.12) ranged from 97.6 to 115.8 g ha^{-1} and from 100.3 to 118.9 g ha^{-1} in wheat grains of year 2015-16 and 2016-17 respectively, between tillage and rice straw management practices as well as rice establishment systems. Tillage and rice straw management practices irrespective of the rice establishment systems significantly affected the Zn uptake in wheat straw (2015-16 and 2016-17). Rice establishment systems indicated no significant difference among the treatments, but the content was higher in PTR than DSR-ZT, DSR-CT and DSR-RT under both years. The interaction between tillage and rice straw management practices in wheat, and rice establishment methods found non-significant.

Copper

Tillage and rice straw management practices as well as the rice establishment systems found to have non significant effect on the Cu uptake in wheat straw in both years of experimentation (2015-16 and 2016-17). Cu uptake in wheat straw ranged from 17.5 to 21.2 g ha^{-1} and from 18.1 to 21.9 g ha^{-1} in wheat grains of year 2015-16 and 2016-17 respectively, between tillage and rice straw management practices as well as rice establishment systems. Rice establishment systems indicated no significant difference among the treatments under both years. The interaction between tillage and rice straw management practices in wheat, and rice establishment methods found non-significant.

Iron

Tillage and rice straw management practices irrespective of the rice establishment systems significantly affected the Fe uptake in wheat straw during both the years (2015-16 and 2016-17). Fe uptake in wheat straw ranged from 748.7 to 872.5 g ha^{-1} and from 769.9 to 896.6 g ha^{-1} in wheat straw during 2015-16 and 2016-17 respectively, between tillage and rice straw management practices as well as rice establishment systems (Table 4.12). Among the tillage and rice straw management practices irrespective of the rice establishment systems, ZTW+R indicated 14 percent and 8 percent higher Fe uptake with respect to CTW-R and ZTW-R. Rice establishment systems indicated no significant difference among the treatments. The interaction between tillage and rice straw management practices in wheat, and rice establishment methods was also found non-significant.

Table 4.12: Effect of rice establishment methods, tillage and straw management practices on uptake (g ha^{-1}) of micronutrients in wheat straw

Treatment	Zn		Cu		Fe		Mn	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
Rice establishment methods								
DSR-ZT	104.7	108.1	19.2	19.9	801.4	826.6	72.1	74.4
DSR-CT	100.8	103.8	18.4	19.1	794.5	821.4	69.3	71.7
DSR-RT	108.1	111.6	18.5	19.2	812.6	837.8	68.4	70.6
PTR	109.9	112.7	20.8	21.6	822.8	844.9	71.2	73.2
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Tillage and rice straw management practices								
CTW-R	104.3	107.9	19.5	19.7	803.7	831.6	68.7	71.0
ZTW-R	97.6	100.3	17.9	18.1	748.7	769.9	66.1	67.6
ZTW+R	115.8	118.9	21.2	21.9	872.5	896.6	76.1	78.8
LSD (0.05)	13.8	12.6	NS	NS	72.7	64.9	NS	NS
Interaction								
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Manganese

Tillage and rice straw management practices irrespective of the rice establishment systems significantly affected the Mn uptake in wheat straw during both the years (2015-16 and 2016-17). Uptake of Mn in wheat straw (Table 4.12) ranged from 66.1 to 76.1 g ha^{-1} and from 67.6 to 78.8 g ha^{-1} during 2015-16 and 2016-17 respectively, between tillage and rice straw management practices as well as rice establishment systems. Among the tillage and rice straw management practices irrespective of the rice establishment systems, ZTW+R indicated significantly higher Fe uptake in wheat straw with respect to ZTW-R treatment. Even Mn uptake was higher under CTW-R as compared to ZTW-R. The interaction between tillage and rice straw management practices in wheat, and rice establishment methods was also found non-significant.

4.3.3 Micronutrients (Zn, Cu, Fe and Mn) uptake in rice grains

Zinc

Tillage and rice straw management practices as well as rice establishment methods expressed significant effect on the Zn uptake in rice grains during both the years (2016 and 2017) of experimentation. Zn uptake ranged from 88.7 to 112.7 g ha^{-1} and from 77.7 to 103.6 g ha^{-1} in rice grains for the duration of 2016 and 2017 respectively, between tillage and rice straw management practices as well as rice establishment systems (Table 4.13). Rice establishment systems indicated significant difference among the treatments; the content was found higher in DSR-RT followed by PTR followed by DSR-CT and then DST-ZT. The trend was same during both the years. It varied as 112.7 and 97.13 g ha^{-1} in DSR-RT, 102.1 and 92.7 g ha^{-1} in DSR-CT, 88.7 and 77.7 g ha^{-1} in DSR-ZT and 106.7 and 93.2 g ha^{-1} in PTR during 2016 and 2017, respectively. Among the tillage and rice straw management practices, ZTW+R showed higher Zn uptake in rice grains as compared to ZTW-R and CTW-R in 2016 as well as in 2017. The interaction between tillage and rice straw management practices in wheat and rice establishment methods found non-significant.

Copper

The data pertaining to the effect oftillage and rice straw management practices as well as rice establishment systems did not significantly affected the Cu uptake in rice grains during both the years of experimentation (2016 and 2017). Cu uptake (Table 4.13) ranged from 22.2 to 34.9 g ha^{-1} and from 16.7 to 20.9 g ha^{-1} in rice grains during both the years i.e. 2016 as well as 2017 respectively, between tillage and rice straw management practices as well as rice establishment systems. Amongst the rice establishment methods, PTR is found to have higher Cu content in rice grains as compared to the DSR-RT, DSR-CT and DSR-ZT. It varied as 34.9 and 20.9 g ha^{-1} in PTR, 31.7 and 20.3 g ha^{-1} in DSR-RT, 29.6 and 19.3 g ha^{-1} in DSR-CT and 22.2 and 16.7 g ha^{-1} in DSR-ZT in 2016 as well as in 2017, respectively. Among the tillage and rice straw management practices irrespective of the rice establishment methods, ZTW+R is found to have slightly higher Cu uptake in rice grains as compared to the CTW-R and ZTW-R, respectively. The interaction between tillage and rice straw management practices in wheat and rice establishment methods found non-significant during both the years.

Table 4.13: Effect of rice establishment methods, tillage and straw management practices on uptake (g ha^{-1}) of micronutrients in rice grains

Treatment	Zn		Cu		Fe		Mn	
	2016	2017	2016	2017	2016	2017	2016	2017
Rice establishment methods								
DSR-ZT	88.7	77.7	22.2	16.7	217.5	237.3	49.2	36.9
DSR-CT	102.1	92.7	29.6	19.3	250.8	288.1	60.5	44.1
DSR-RT	112.7	97.1	31.7	20.3	280.9	302.5	71.7	48.2
PTR	106.7	93.2	34.9	20.9	307.1	334.1	80.8	50.0
LSD (0.05)	7.23	18.5	NS	NS	23.5	29.2	18.2	4.34
Tillage and rice straw management practices								
CTW-R	100.5	89.7	30.6	19.1	256.5	283.9	63.9	44.7
ZTW-R	95.7	86.4	29.1	18.6	248.3	272.6	60.1	41.2
ZTW+R	111.2	103.6	32.6	20.1	287.5	312.1	72.7	48.6
LSD (0.05)	6.73	7.73	NS	NS	20.8	21.3	6.33	4.68
Interaction								
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Iron

A close examination of the data (Table 4.13) expressed that the Fe uptake in rice grains ranged between 217.5 to 307.1 g ha^{-1} and 237.3 to 334.1 g ha^{-1} between the tillage and rice straw management practices and the rice establishment methods. Fe uptake showed significant results amongst the treatments. It was observed that Fe uptake was significantly higher in PTR (307.1 g ha^{-1}) in comparison with DSR-RT (280.9 g ha^{-1}), DSR-CT (250.8 g ha^{-1}) and DSR-ZT (217.5 g ha^{-1}) in 2016. Similarly, significant results among the treatments were also observed in 2017, it was indicated that Fe uptake was significantly higher in PTR (334.1 g ha^{-1}) as compared to the DSR-RT (302.5 g ha^{-1}), DSR-CT (288.1 g ha^{-1}) and DSR-ZT (237.3 g ha^{-1}) in 2017. However, in case of tillage and rice straw management practices, Fe uptake was found significantly higher in ZTW+R (287.5 and 312.1 g ha^{-1}) as compared to the ZTW-R (248.3 and 272.6 g ha^{-1}) and CTW-R (256.5 and 283.9 g ha^{-1}) during both the years i.e. 2016 and 2017. The interaction between tillage and rice straw management practices in wheat and rice establishment methods found non-significant during both the years.

Manganese

A glance at the data related to the Mn uptake (Table 4.13) in rice grain showed that the Mn content ranged from 49.2 to 80.8 g ha^{-1} and from 36.9 to 48.6 g ha^{-1} in both the years of experimentation i.e. 2016 and 2017, respectively. Mn uptake in rice grain was significantly affected among tillage and rice straw management practices as well as rice establishment systems. Amongst the rice establishment systems irrespective of the tillage and rice straw management practices it was observed that Mn uptake was significantly higher in PTR (80.8 g ha^{-1}) with respect to the DSR-CT (60.5 g ha^{-1}) and DSR-ZT (49.2 g ha^{-1}), but not significantly higher with respect to the DSR-RT (71.7 g ha^{-1}) in 2016. In case of tillage and rice straw management practices, ZTW+R (72.7 g ha^{-1}) treatment showed significantly higher content of Mn uptake in rice grain with respect to ZTW-R (60.1 g ha^{-1}) and CTW-R (63.9 g ha^{-1}). Similarly, in 2017, among the rice establishment systems, Mn uptake was found significantly higher in PTR with respect to DSR-ZT only. Tillage and rice straw management practices showed significantly higher content of Mn uptake in ZTW+R with respect to ZTW-R. The interaction between tillage and rice straw management practices in wheat, and rice establishment methods was also found non-significant.

4.3.4 Micronutrients (Zn, Cu, Fe and Mn) uptake in rice straw

Zinc

Zn uptake in rice straw (Table 4.14) varied from 403.7 to 482.7 g ha^{-1} and from 393.3 to 484.4 g ha^{-1} in both the years of experimentation i.e. 2016 and 2017 respectively, between tillage and rice straw management practices as well as rice establishment systems. Rice establishment systems irrespective of the tillage and rice straw management practices has indicated significant difference among the treatments, as the content was higher DSR-RT and DSR-CT as compared to the PTR during both years. Tillage and rice straw management practices in wheat irrespective of the rice establishment methods in rice did not significantly affected the Zn uptake in rice straw of following rice crop. Even then the content for Zn uptake in rice straw was higher in ZTW+R treatment as compared to the ZTW-R and CTW-R. The trend was similar during both the years. The interaction between tillage and rice straw management practices in wheat, and rice establishment methods found non-significant.

Copper

The rice establishment systems found to have significant effect on the Cu uptake in rice straw in both years of experimentation (2016 and 2017), in contrary, in case of tillage and rice straw management practices, no significant differences were found among treatments viz. ZTW+R, ZTW-R and CTW-R (Table 4.14). Cu uptake in rice straw ranged from 19.2 to 29.5 g ha^{-1} and from 18.7 to 32.7 g ha^{-1} during 2016 and 2017 respectively, between tillage and rice straw management practices as well as rice establishment methods. It was observed that the Cu uptake was higher in ZTW+R (25.6 and 25.2 g ha^{-1}) w.r.t. ZTW-R (22.8 and 22.9 g ha^{-1}) and CTW-R (23.1 and 23.2 g ha^{-1}) during both the years (2016 and 2017, respectively). The interaction between tillage and rice straw management practices in wheat, and rice establishment methods found non-significant.

Iron

A close examination of the data regarding thetillage and rice straw management practices as well as rice establishment systems significantly affected the Fe uptake in rice straw during both the years (2016 and 2017). Fe uptake in rice straw ranged from 1931.2 to 3023.8 g ha^{-1} and from 1921.3 to 2955.2 g ha^{-1} during 2016 and 2017 respectively, between tillage and rice straw management practices as well as rice establishment systems. Rice establishment systems indicated higher Fe uptake in difference among the treatments. Among the tillage and rice straw management practices irrespective of the rice establishment systems, ZTW+R indicated 14 percent and 8 percent higher Fe uptake with respect to CTW-R and ZTW-R. The interaction between tillage and rice straw management practices in wheat, and rice establishment methods was also found non-significant.

Table 4.14: Effect of rice establishment methods, tillage and straw management practices on uptake (g ha^{-1}) of micronutrients in rice straw

Treatment	Zn		Cu		Fe		Mn	
	2016	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**
Rice establishment methods								
DSR-ZT	403.7	393.3	19.2	18.7	1931.2	1921.3	1232.3	1126.1
DSR-CT	474.2	465.2	24.6	23.0	2413.9	2313.6	1661.6	1527.5
DSR-RT	478.2	450.2	22.5	21.5	2411.7	2358.3	1846.3	1721.6
PTR	454.9	432.6	29.5	32.7	3023.8	2955.2	2377.8	2208.9
LSD (0.05)	45.2	62.6	3.45	4.46	313.1	279.3	186.5	196.5
Tillage and rice straw management practices								
CTW-R	458.3	452.8	23.1	23.2	2471.6	2518.1	1799.4	1718.7
ZTW-R	422.1	417.1	22.8	22.9	2270.7	2215.4	1605.7	1534.0
ZTW+R	482.7	484.4	25.6	25.2	2653.5	2617.8	1874.2	1791.0
LSD (0.05)	NS	NS	NS	NS	301.7	292.9	NS	99.8
Interaction								
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Manganese

Tillage and rice straw management practices irrespective of the rice establishment systems significantly affected the Mn uptake in wheat straw during both the years (2015-16 and 2016-17). Uptake of Mn in wheat straw ranged from 1232.3 to 2377.8 g ha^{-1} and from 1126.1 to 2208.9 g ha^{-1} during 2015-16 and 2016-17 respectively, between tillage and rice straw management practices as well as rice establishment systems (Table 4.14). Among the tillage and rice straw management practices irrespective of the rice establishment systems, ZTW+R indicated significantly higher Fe uptake in wheat straw with respect to ZTW-R treatment in 2017. The interaction between tillage and rice straw management practices in wheat, and rice establishment methods was also found non-significant.

4.5 Effect of rice establishment methods, tillage and rice straw management practices on soil chemical properties

Soil samples collected before the experiment (2015) and at the end of an experiment (2017) in rice-wheat system were analyzed for basic chemical parameters viz. pH, EC and SOC are discussed below:

4.5.1 Distribution of soil pH in profile

Tillage and rice straw management practices in wheat and different establishment methods in rice did not significantly affected the soil pH in profile (0- 7.5 cm, 7.5-15 cm, 15-30 cm, 30-45 cm and 45-60 cm). In 0-7.5 cm soil layer, soil pH was higher in CTW-R than ZTW with or without rice straw as mulch (Table 4.15). It was observed that soil pH increases with increase in depth (7.5-15 cm and 15-30 cm) and then again it start decreases with further increase in soil depth (30-45 cm and 45-60 cm). The interaction between rice establishment methods, and tillage and rice straw management practices on soil pH were also found to be non-significant in both years. Thomas *et al* (2007) also reported that soil pH did not get affected in all the considered soil layers. They further informed that lower pH, especially in the surface layers, under CT systems rather than CTW because of surface application of nitrogen fertilizers as well as crop residues and also due to lack of soil mixing.

Similarly, Mishra *et al* (2010) observed that soil pH was not influenced by either ZT with rice straw as mulch or CT. However, Martinez *et al* (2013) found a significant decrease in pH upto 2 cm depth under ZT + residue compared to CT due to release of H^+ ions during decomposition of residues. Decline in soil pH was due to the acid producing nature of the nitrogenous fertilizers which upon nitrification release H^+ ions which are the potential source of soil acidity (Vasak *et al* 2015). Lower pH in residue retained plots can be attributed to organic acids produced by the decomposition of the organic matter in soil and these organic acids contribute to soil acidity (Zhang *et al* 2016). Soil pH did not follow any particular trend in profile however it generally tends to increase with increase in soil depth. This may be due to leaching of soluble salts from surface and their concentration in sub-surface soil (Antil and Singh 2007). Also lower surface pH may be due to presence of more organic matter content or residue retained which has acidifying effect after decomposition (Kumar *et al* 2016).

Table 4.15: Effect of rice establishment methods, tillage and straw management practices on distribution of soil pH in profile

Treatment	Soil depth (cm)				
	0-7.5	7.5-15	15-30	30-45	45-60
Rice establishment methods (2015)					
DSR-ZT	7.13	7.39	7.69	7.56	7.53
DSR-CT	7.16	7.46	7.79	7.57	7.59
DSR-RT	7.14	7.42	7.71	7.57	7.54
PTR	7.16	7.48	7.82	7.62	7.59
LSD (0.05)	NS	NS	NS	NS	NS
Tillage and rice straw management practices					
CTW-R	7.16	7.46	7.82	7.63	7.57
ZTW-R	7.12	7.41	7.76	7.54	7.53
ZTW+R	7.10	7.38	7.68	7.57	7.60
LSD (0.05)	NS	NS	NS	NS	NS
Interaction LSD (0.05)	NS	NS	NS	NS	NS
Rice establishment methods (2017)					
DSR-ZT	7.11	7.13	7.36	7.41	7.54
DSR-CT	7.14	7.31	7.54	7.45	7.37
DSR-RT	7.13	7.18	7.37	7.57	7.32
PTR	7.15	7.54	7.57	7.54	7.71
LSD (0.05)	NS	NS	NS	NS	NS
Tillage and rice straw management practices					
CTW-R	7.04	7.35	7.51	7.71	7.64
ZTW-R	6.86	7.28	7.52	7.52	7.46
ZTW+R	6.76	7.24	7.45	7.47	7.35
LSD (0.05)	NS	NS	NS	NS	NS
Interaction LSD (0.05)	NS	NS	NS	NS	NS

4.4.2 Distribution of electrical conductivity (EC) in profile

Data in Table 4.15 revealed that tillage and rice straw management practices in wheat and different establishment methods in rice did not significantly affected the soil EC in profile (0- 7.5cm, 7.5-15 cm, 15-30 cm, 30-45 cm and 45-60 cm). In 0-7.5 cm soil layer (Table 4.16) EC varied from 0.175 to 0.184 dS m^{-1} in the soil samples collected before the start of an experiment and it ranged from 0.174 to 0.187 dS m^{-1} in the soil samples collected after the harvest of rice crop (2017). Soil EC was found to decrease with increase in soil depths viz. 7.5-15 cm, 15-30 cm, 30-45 cm and 45-60 cm. This suggests that salts are transported and accumulated at higher depths (Melgar *et al* 2009). This process seems to be facilitated by the high sand content in soil allowing the free water circulation through the soil. The findings are in consonance with the results reported by Puli *et al* (2013). An increase in EC in the ZTW+R and ZTW-R was observed as compared to CTW-R (2015) which might be due to the accumulation of soluble salts at the surface soils where the residue was retained. Lower EC was recorded after the two years of the start of an experiment which might be due to the addition of several plant acids in soil during decomposition of crop residues in the field (Newaj and Yadav 1994). The interaction between rice establishment methods, and tillage and rice straw management practices on soil pH of wheat were also found to be non-significant in both years. Martinez *et al* (2013) reported that higher EC observed in the top 2 cm depth under ZT can be associated to the greater biological activity. Similarly, Mishra *et al* (2010) observed that soil EC did not influenced by either ZT with rice straw as mulch or CT. Kumar *et al* (2004) also observed that tillage and rice straw either removal or mulch did not affect EC but slightly decreased with application of rice straw as mulch.

Table 4.16: Effect of rice establishment methods, tillage and straw management practices on soil EC (dS m^{-1}) in profile

Treatment	**Soil depth (cm)**				
	0-7.5	**7.5-15**	**15-30**	**30-45**	**45-60**
Rice establishment methods (2015)					
DSR-ZT	0.184	0.157	0.137	0.122	0.085
DSR-CT	0.175	0.155	0.134	0.121	0.083
DSR-RT	0.183	0.155	0.132	0.121	0.079
PTR	0.179	0.152	0.134	0.123	0.082
LSD (0.05)	NS	NS	NS	NS	NS
Tillage and rice straw management practices					
CTW-R	0.175	0.131	0.117	0.096	0.095
ZTW-R	0.177	0.141	0.109	0.106	0.105
ZTW+R	0.178	0.151	0.108	0.107	0.107
LSD (0.05)	NS	NS	NS	NS	NS
Interaction LSD (0.05)	NS	NS	NS	NS	NS
Rice establishment methods (2017)					
DSR-ZT	0.174	0.151	0.137	0.112	0.085
DSR-CT	0.178	0.145	0.134	0.121	0.083
DSR-RT	0.179	0.147	0.132	0.121	0.079
PTR	0.175	0.145	0.134	0.123	0.082
LSD (0.05)	NS	NS	NS	NS	NS
Tillage and rice straw management practices					
CTW-R	0.174	0.149	0.130	0.121	0.078
ZTW-R	0.178	0.147	0.126	0.119	0.082
ZTW+R	0.187	0.143	0.133	0.119	0.087
LSD (0.05)	NS	NS	NS	NS	NS
Interaction LSD (0.05)	NS	NS	NS	NS	NS

4.4.3 Distribution of soil organic carbon (SOC) in profile

The effect of tillage and rice straw management practices in wheat and rice establishment methods on soil organic carbon content (SOC) is given in Table 4.17. Tillage and rice straw management practices in wheat, irrespective of different establishment methods in rice, significantly affected SOC content in 0-7.5 cm soil layer in the year 2015 as well as in 0-7.5 cm and 7.5-15 cm soil depths in case of year 2017. However, the effect of different rice establishment methods, irrespective of tillage and rice straw management practices in wheat, failed to cause significant effect on SOC content before the start of an experiment in year 2015 (Table 4.2).

Table 4.17: Effect of rice establishment methods, tillage and straw management practices on SOC (%) in profile

Treatment	Soil depth (cm)				
	0-7.5	**7.5-15**	**15-30**	**30-45**	**45-60**
Rice establishment methods (2015)					
DSR-ZT	0.614	0.487	0.294	0.189	0.156
DSR-CT	0.571	0.431	0.267	0.188	0.160
DSR-RT	0.604	0.470	0.301	0.197	0.153
PTR	0.564	0.445	0.340	0.200	0.158
LSD (0.05)	NS	NS	NS	NS	NS
Tillage and rice straw management practices					
CTW-R	0.548	0.426	0.292	0.187	0.157
ZTW-R	0.588	0.469	0.297	0.202	0.157
ZTW+R	0.630	0.480	0.313	0.192	0.156
LSD (0.05)	0.06	NS	NS	NS	NS
Interaction LSD (0.05)	NS	NS	NS	NS	NS
Rice establishment methods (2017)					
DSR-ZT	0.624	0.494	0.297	0.189	0.158
DSR-CT	0.587	0.443	0.270	0.191	0.164
DSR-RT	0.618	0.476	0.306	0.192	0.153
PTR	0.578	0.453	0.344	0.187	0.137
LSD (0.05)	NS	NS	NS	NS	NS
Tillage and rice straw management practices					
CTW-R	0.556	0.433	0.295	0.186	0.157
ZTW-R	0.604	0.476	0.300	0.194	0.157
ZTW+R	0.645	0.489	0.317	0.189	0.147
LSD (0.05)	0.06	0.04	NS	NS	NS
Interaction LSD (0.05)	NS	NS	NS	NS	NS

In 0-7.5 cm soil layer, SOC content ranged from 0.548 to 0.630 percent and it varied from 0.426 to 0.487, 0.267 to 0.340, 0.187 to 0.202 and 0.153 to 0.160 percent in 7.5-15 cm, 15-30 cm, 30-45 cm and 45-60 cm soil depths before the start of an experiment in the year

2015. The interaction between and tillage and rice straw management practices in wheat and rice establishment methods did not significantly affect the SOC content in 2015. Similarly, tillage and rice straw management practices in wheat, irrespective of different establishment methods in rice, significantly affected SOC content in 0-7.5 cm and 7.5-15 cm soil layers where it ranged from 0.556 to 0.645 percent and 0.433 to 0.494 percent in the year 2017. Tillage and rice straw management practices in wheat showed 14 percent and 6 percent higher content of SOC in ZTW+R plots than CTW-R and ZTW-R plots respectively. Even ZTW-R showed 8 percent higher soil OC content than CT at 0-7.5 cm soil layer. Similarly, tillage and rice straw management practices in wheat irrespective of the rice establishment methods showed 11 percent and 3 percent higher SOC content in ZTW+R or wheat sown with HS as compared to the CTW-R and ZTW-R plots respectively at 7.5-15 cm soil layer. However the SOC content decreased with increase in soil depths where it varied from 0.270 to 0.344, 0.186 to 0.194 and 0.137 to 0.164 percent at lower soil depths viz., 15-30 cm, 30-45 cm and 45-60 cm at the end of an experiment in the year 2017. Tillage and rice straw management practices showed non-significant effect at lower soil depths. Higher SOC content with crop residue incorporation might be attributed to the fact that continuous addition of organic matter through crop residue increased the microbial population which enhanced the decomposition of crop residue resulting in increased SOC content. Similar observations have also been reported by Prasad *et al* 2010, Nayak *et al* 2012, Adhikari *et al* 2012. Increased organic matter contents in the soil surface layers under NT is a common finding (Dao 1998) and can be ascribed to increased accumulation of crop residues, poor soil mixing and a decreased decomposition rate resulting from the poor contact between residues and the soil, lower aeration, and a lower soil temperature (Hussain *et al* 1999, Thomas *et al* 2007). The differences in SOM content between MT and CT can be ascribed at least partly to decreased mineralization of SOM resulting from non-inversion tillage relative to mouldboard plowing (Reicosky and Lindstrom 1993, Saavedra *et al* 2007).

The results revealed that build-up of soil OC was more in surface layers as compared to the lower layers due to more addition of root and rice straw in the surface layers. It was observed that soil OC decreased with the depth in all the treatments. These results suggested that beneficial effect of fertilizers and crop residues on SOC are primarily limited to the surface layer. Similarly, Yaduvanshi and Sharma (2008) revealed that SOC content was significantly higher in ZT wheat with rice straw as mulch than CT wheat at 0-15 cm depth. Martinez *et al* (2017) concluded that soil OC was significantly higher under ZT compared with CT due to the slow decomposition of soil residues in more compacted soil surface, which act as a physical barrier for organic matter decomposition. Zhu *et al* (1999) also observed a similar result where ZT had 4.3 percent SOM in the 0-30 cm soil layer compared to traditional tillage after 4 years.

During the first 4 years of tillage, Rhoton (2000) determined a 10% loss of initial soil organic matter content with plough tillage. Mann (1986) also estimated the soil organic matter depletion between 16 and 77% caused by the tillage. In most instances, increased levels of tillage or increased tillage periods resulted in reductions of soil carbon. Al-Kaisi (2001) reported that reducing tillage significantly decreases SOC loss from soils with high organic matter content. Continuous cultivation for cereal cropping in the major cereal growing areas of Bangladesh leads to lowering the nutritional status of soil in most of the areas.

Buildup of OM and nutrients near the soil surface under NT and RT were favorable consequences of not inverting the soil and by maintaining a mulch layer on the soil surface (Tebrugge and During 1999). With annual plough less tillage, plant residues will be left on the soil surface, resulting in increased organic matter in the top soil (Rasmussen 1999). The study by Gosai *et al* (2009) revealed higher concentration of soil organic matter in the no-till and shallow-tilled plots compared to the other conventionally tilled plots that confirms to the finding of Doran 1980, Robbins and Voss 1991, Angers *et al* 1995.

More plant residues were left on or near the soil surface under no tillage which led to lower evapotranspiration and higher content of soil water in the upper (0-10cm) soil layer (Rasmussen 1999). Surface residues under zero tillage system maintained moderate moisture fluctuations and thus reduce both evaporation and runoff (Blevins and Frye 1993). However, different types and extent of tillage did not have any major influence on the moisture content at harvest, although it was high at the time of initial tillage and reduced with subsequent tillage operations (Srivastava *et al* 2000). It has been well established that increasing amounts of crop residues on the soil surface reduce the evaporation rate (Gill and Jalota 1996, Prihar *et al* 1996)

4.6 Effect of rice establishment methods, tillage and rice straw management practices on DTPA-extractable micronutrients (Zn, Cu, Fe and Mn)

The crop residues are the plant parts left in the field after the crops have been harvested and thrashed. Crop residues are good sources of plant nutrients as well as essential components for the stability of agricultural ecosystems. Indeed, crop residues are as a kind of organic amendments that the use of them could be a viable means of improving the productivity of the soils. Recycling of crop residue has demonstrated to be one of the ways of improving soil nutrient content and maintaining soil productivity. Also, they can reduce fertilizers usage in soil (Beres and Kazinczi 2000). Crops residues as a source of organic matter are an important source of micronutrient and can play an important role in the soil cycling of micronutrients and reported that crop residues are considered as an important source of several micronutrients. For example about 50 to 80% of zinc, copper and manganese taken up by rice and wheat crops can be recycled through residue incorporation (Prasad and Sinha 1995).

4.6.1 Distribution of DTPA-extractable Zn in profile

The data presented in Table 4.18 indicated that the tillage and rice straw management practices as well as the rice establishment methods significantly affected the DTPA-extractable Zn concentration in surface layer (0-7.5 cm) in year 2015 and 2017. DTPA- extractable Zn content ranged between 5.84 to 6.64 mg $kg^{-1}$and from 4.81 to 5.63 mg kg^{-1}in 0-7.5 cm soil layer during 2015 and 2017 respectively, between tillage and rice straw management practices as well as rice establishment systems. DTPA-extractable Zn was found to be significantly higher in ZT wheat sown with happy seeder i.e. ZTW+R as compared to the ZTW-R in surface soil layer (0-7.5 cm), but it did not indicated significant difference with respect to CTW-R. DTPA-extractable Zn content was found to decrease with increase in soil depths i.e. 7.5-15, 15-30, 30-45 and 45-60 cm. The accumulation of Zn in surface soil layers might be due to (i) the addition through plant residues left over by the soils which have also been reported (Katyal and Sharma 1991, Setia and Sharma 2004, Verma *et al* 2005). In deeper layers, tillage and rice straw management practices as well as the rice establishment systems failed to cause significant effect on the DTPA-extractable Zn.

Rice establishment methods also significantly influenced the availability of Zn in soil, as it was found to be higher in DSR-RT followed by DSR-ZT followed by DSR-ZT and then PTR (2015). Similarly, rice establishment methods irrespective of the tillage and rice straw management practices in wheat also significantly affected the availability of Zn in soil during second year of the experiment (2017). Similar trend of decrease in DTPA-extractable Zn content was found in 2017 as that in 2015 among rice establishment methods. The interaction between tillage and rice straw management practices in wheat, and rice establishment methods was also found non-significant. Yadvinder-Singh *et al* (2000) observed that crop residues recycling increases the availability of micronutrients in the soil generally similar to that with green manuring in RWS. Martin-Rueda *et al* (2007) considered the effect of different tillage on soil micronutrient content at different depths in continuous barley and found ZT+R had higher DTPA-extractable Zn than CT in the 0-15 cm layer due to the higher soil organic carbon content. Santiago *et al* (2008) reported that availability of DTPA-extractable Zn were higher under ZT with crop residues as compared to CT but did not significantly influenced the availability of DTPA-extractable Fe. Prasad *et al* (2010) observed that rice and wheat residue incorporation in soil significantly increased DTPA-extractable Zn content in surface (0-15 cm) soil due to build up in organic carbon in soil.

Table 4.18: Effect of rice establishment methods, tillage and straw management practices on distribution of DTPA-Zn (mg kg^{-1}) in profile

Treatment	Soil depth (cm)				
	0-7.5	**7.5-15**	**15-30**	**30-45**	**45-60**
Rice establishment methods (2015)					
DSR-ZT	6.16	2.49	1.48	0.43	0.24
DSR-CT	6.52	2.60	1.52	0.42	0.33
DSR-RT	6.71	2.62	1.64	0.52	0.34
PTR	5.84	2.42	1.51	0.52	0.29
LSD (0.05)	0.48	NS	NS	NS	NS
Tillage and rice straw management practices					
CTW-R	6.28	2.56	1.44	0.48	0.31
ZTW-R	5.99	2.42	1.53	0.44	0.27
ZTW+R	6.64	2.62	1.64	0.59	0.33
LSD (0.05)	0.46	NS	NS	NS	NS
Interaction LSD (0.05)	NS	NS	NS	NS	NS
Rice establishment methods (2017)					
DSR-ZT	5.05	2.32	1.38	0.49	0.40
DSR-CT	5.32	2.35	1.46	0.55	0.46
DSR-RT	5.63	2.34	1.51	0.57	0.58
PTR	4.81	2.24	1.42	0.46	0.42
LSD (0.05)	0.38	NS	NS	NS	NS
Tillage and rice straw management practices					
CTW-R	5.30	2.33	1.38	0.41	0.41
ZTW-R	4.97	2.21	1.42	0.54	0.44
ZTW+R	5.35	2.39	1.53	0.60	0.55
LSD (0.05)	0.26	NS	NS	NS	NS
Interaction LSD (0.05)	NS	NS	NS	NS	NS

The organic matter addition plays vital role in governing the availability of soil Zn (Chami *et al* 2013). The effect of organic matter on the availability of soil-Zn depends on the maturity of organic amendments. The availability of Zn is small where mature organic materials are present such as compost because of the formation of stable organic complexes with organic matter such as humic acid (Smith 2009). In contrast, rapidly degradable organic matter added to soil effectively dissolves originally insoluble Zn, which improves its solubility and availability in soil-plant systems because of water-soluble or labile organic compounds rich in functional groups (e.g. amino, carboxyl, and phenolic) that have strong chelating abilities (Fuente *et al* 2011). Aghili *et al* (2014) found green manure of red clover and sunflower amendments to calcareous soil raised grain Zn concentration in bread wheat with the increased DTPA-extractable Zn in soils. Habiby *et al* (2014) considered that the Zn concentration of wheat grain increased owing to the increase of soil dissolved organic matter after the incorporation of plant residues such as safflower and clover. Even, Sinha and Prasad (1977) found that the direct addition of mobile organic chelating agents (e.g., fulvic and citric acids) enhances the rate of Zn diffusion into roots and consequently Zn uptake of wheat plants in calcareous soil.

4.5.2 Distribution of DTPA-extractable Cu in profile

Tillage and rice straw management practices irrespective of the rice establishment methods significantly affected the DTPA-extractable Cu content in surface soil when the soil samples were collected from the profile (0-60 cm). DTPA-extractable Cu content wavered between 1.17 to 1.33 mg $kg^{-1}$and from 1.04 to 1.12 mg kg^{-1}during the year 2015 and 2017 respectively, between tillage and rice straw management practices as well as rice establishment systems (Table 4.19). DTPA-extractable Cu in soil was found to be significantly higher in ZTW+R or ZT wheat sown with happy seeder (HS) as compared to the ZTW-R and CTW-R in surface soil (0-7.5 cm). DTPA-extractable Cu content started to decrease with increase in soil depths i.e. 7.5-15, 15-30, 30-45 and 45-60 cm. In deeper layers, tillage and rice straw management practices as well as the rice establishment systems failed to cause significant effect on the DTPA-extractable Cu.

Table 4.19: Effect of rice establishment methods, tillage and straw management practices on distribution of DTPA-Cu (mg kg^{-1}) in profile

Treatment	Soil depth (cm)				
	0-7.5	**7.5-15**	**15-30**	**30-45**	**45-60**
Rice establishment methods (2015)					
DSR-ZT	1.24	0.88	0.52	0.43	0.33
DSR-CT	1.17	0.97	0.53	0.39	0.31
DSR-RT	1.28	0.95	0.51	0.46	0.35
PTR	1.33	1.09	0.57	0.58	0.43
LSD (0.05)	NS	NS	NS	NS	NS
Tillage and rice straw management practices					
CTW-R	1.22	0.99	0.57	0.44	0.34
ZTW-R	1.22	0.83	0.56	0.47	0.34
ZTW+R	1.30	1.07	0.62	0.49	0.38
LSD (0.05)	0.02	NS	NS	NS	NS
Interaction LSD (0.05)	NS	NS	NS	NS	NS
Rice establishment methods (2017)					
DSR-ZT	1.04	0.88	0.58	0.52	0.40
DSR-CT	1.07	0.94	0.61	0.50	0.36
DSR-RT	1.09	0.98	0.53	0.48	0.36
PTR	1.11	1.08	0.66	0.51	0.41
LSD (0.05)	NS	NS	NS	NS	NS
Tillage and rice straw management practices					
CTW-R	1.07	0.99	0.56	0.51	0.38
ZTW-R	1.05	0.84	0.57	0.53	0.41
ZTW+R	1.12	1.07	0.66	0.47	0.36
LSD (0.05)	0.04	NS	NS	NS	NS
Interaction LSD (0.05)	NS	NS	NS	NS	NS

Among the different rice establishment methods, availability of Cu did not vary significantly in soil during first year (2015). Similar trend of decrease in DTPA-extractable Cu content was found in 2017 as that in 2015 among rice establishment methods. The interaction between tillage and rice straw management practices in wheat, and rice establishment methods was also found non-significant. Yadvinder-Singh *et al* (2000) found that recycling of crop residues increases the availability of micronutrients in the soil generally similar to that with green manuring in RWS. Martin-Rueda *et al* (2007) studied the effect of different tillage on soil micronutrient content at different depths in continuous barley and found ZT+R had higher DTPA-extractable Cu than CT in the 0-15 cm layer due to the higher soil organic carbon content. Santiago *et al* (2008) reported that availability of DTPA-extractable Cu were higher under ZT with crop residues as compared to CT.

Incorporation of crop residues by affected on reduce soil pH that it can increases the solubility of Cu compounds, also with increases organic matter content of soil and increases complexes of them can caused increase the amount of copper and manganese available. Stevenson (1991) reported applications of organic fertilizers helped in improving soil physical and biological properties and increased the concentration and availability of micronutrients (Zn, Cu, Fe and Mn) in the soil. The increase in DTPA-extractable Cu may be attributed to the chelating action of organic compounds released during decomposition of organic manures, which increased the availability of micronutrients by preventing fixation, oxidation, precipitation and leaching. Hao and Chang (2002) reported the effect of 25 annual cattle manure applications on soluble and exchangeable Cu in soil. In an acid soil Lal and Mathur (1989) reported higher levels of DTPA-Cu under combined use of manures and fertilizer treatments.

4.6.3 Distribution of DTPA-extractable Fe in profile

The data presented in Table 4.20 indicated that the tillage and rice straw management practices as well as the rice establishment systems significantly affected the DTPA-extractable Fe content in surface soil. DTPA-extractable Fe ranged between 26.23 to 37.12 mg kg^{-1} and from 22.98 to 27.63 mg kg^{-1} in the surface layer (0-7.5 cm) during the year 2015 and 2017 respectively, between tillage and rice straw management practices as well as rice establishment systems. DTPA-extractable Fe content was highest at the surface layer (0-7.5 cm), whereas it was found to decrease with increase in soil depths i.e. 7.5-15, 15-30, 30-45 and 45-60 cm. DTPA-extractable Fe was found to be significantly higher in ZTW+R (31.63 mg kg^{-1}) as compared to the ZTW-R (27.94 mg kg^{-1}) in surface soil layer (0-7.5 cm) in 2015, but it did not indicated significant difference with respect to CTW-R. Similarly, DTPA-extractable Fe exhibited significantly higher content in ZTW+R (27.63 mg kg^{-1}) as compared to the ZTW-R (23.91 mg kg^{-1}) in surface soil layer (0-7.5 cm) in 2017. Increased accumulation of micronutrients in the surface of no tilled soils has frequently been ascribed to the accumulation of plant residues on the surface and poor soil mixing (Saavedra *et al* 2007).

The most significant influence of crop residues in increasing the solubility and availability of Fe in the soil is through solubilization of native soil insoluble Fe and enhanced diffusion and mass flow in the immediate vicinity of plant (Dhaliwal *et al* 2012).

Table 4.20: Effect of rice establishment methods, tillage and straw management practices on distribution of DTPA-Fe (mg kg^{-1}) in profile

Treatment	Soil depth (cm)				
	0-7.5	**7.5-15**	**15-30**	**30-45**	**45-60**
Rice establishment methods (2015)					
DSR-ZT	27.25	23.79	6.78	6.37	6.43
DSR-CT	26.23	20.71	7.78	6.83	7.22
DSR-RT	28.95	24.27	8.15	7.17	7.14
PTR	37.12	29.47	8.90	8.53	7.30
LSD (0.05)	3.33	NS	NS	NS	NS
Tillage and rice straw management practices					
CTW-R	30.10	24.36	8.09	7.03	6.86
ZTW-R	27.94	23.15	7.18	7.11	6.97
ZTW+R	31.63	26.17	8.44	7.54	7.24
LSD (0.05)	1.97	NS	0.68	NS	NS
Interaction LSD (0.05)	NS	NS	NS	NS	NS
Rice establishment methods (2017)					
DSR-ZT	22.98	18.99	6.38	5.92	5.46
DSR-CT	25.67	19.17	6.66	7.02	6.36
DSR-RT	25.71	19.70	6.82	6.00	6.28
PTR	27.58	20.11	8.00	6.43	7.22
LSD (0.05)	1.72	NS	NS	NS	NS
Tillage and rice straw management practices					
CTW-R	24.92	19.66	7.07	6.20	6.20
ZTW-R	23.91	18.55	6.48	5.99	6.13
ZTW+R	27.63	20.27	7.34	6.83	6.66
LSD (0.05)	1.73	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS

An increase in the availability of Fe was observed in soil with the application of crop residue in rice-wheat cropping system (Yadvinder-Singh *et al* 2000, Yadav and Kumar 2000). However, crop residue management increased the micronutrients supply to a reasonable extent. Mann *et al* (1978) reported an increase in DTPA-Fe by manure application in maize-wheat cropping system. Yadvinder-Singh *et al* (2000) found that recycling of crop residues increases the availability of micronutrients in the soil generally similar to that with green manuring in RWS. Martin-Rueda *et al* (2007) studied the effect of different tillage on soil micronutrient content at different depths in continuous barley and found ZTW+R had higher DTPA-extractable Fe than CTW in the 0-15 cm layer due to the higher soil organic carbon content. Prasad *et al* (2010) found that incorporation of residue both rice and wheat significantly increased DTPA-extractable Fe content in surface (0-15 cm) soil due to build up in organic carbon in soil.

Rice establishment methods also influenced the availability of DTPA-extractable Fe significantly in soil, as it was observed that DTPA-extractable Fe was higher in PTR followed by DSR-RT and then DSR-ZT and DSR-CT. Decreasing trend of DTPA-extractable Fe was found with increase in soil depth. The interaction between tillage and rice straw management practices in wheat, and rice establishment methods was found to be non-significant.

4.6.4 Distribution of DTPA-extractable Mn in profile

The tillage and rice straw management practices in wheat as well as the rice establishment methods showed that DTPA- extractable Mn content (Table 4.21) ranged within 4.20 to 5.87 mg kg^{-1} at the time of first soil sampling in 2015 and from 7.91 to 9.55 mg kg^{-1} in 2017 in surface soil layer (0-7.5 cm). DTPA-extractable Mn was significantly higher in ZTW+R or ZT wheat sown with happy seeder (HS) as compared to the ZTW-R and CTW-R during the first year of experimentation. DTPA-extractable Mn content was found to increase with increase in soil depths i.e. 7.5-15, 15-30, 30-45 and 45-60 cm. Moreover, rice establishment methods irrespective of the tillage and rice straw management practices in wheat also indicated significant effect on the DTPA-extractable Mn content. The availability of Mn was found higher under PTR as compared to DSR-RT, DSR-CT and DSR-ZT. Yadvinder-Singh *et al* (2000) found that recycling of crop residues increases the availability of micronutrients in the soil generally similar to that with green manuring in RWS. Martin-Rueda *et al* (2007) studied the effect of different tillage on soil micronutrient content at different depths in continuous barley and found ZTW+R had higher DTPA-extractable Mn than CTW in the 0-15 cm layer due to the higher soil organic carbon content. Prasad *et al* (2010) found that incorporation of residue both rice and wheat significantly increased DTPA-extractable Mn content in surface (0-15 cm) soil due to build up in organic carbon in soil.

Table 4.21: Effect of rice establishment methods, tillage and straw management practices on distribution of DTPA-Mn (mg kg^{-1}) in profile

Treatment	Soil depth (cm)				
	0-7.5	**7.5-15**	**15-30**	**30-45**	**45-60**
Rice establishment methods(2015)					
DSR-ZT	4.20	4.58	4.70	5.61	5.70
DSR-CT	4.91	5.42	5.55	5.88	6.50
DSR-RT	5.22	5.28	6.04	6.20	6.49
PTR	5.87	6.07	6.99	6.93	7.03
LSD (0.05)	0.41	NS	1.18	0.47	NS
Tillage and rice straw management practices					
CTW-R	5.08	5.29	5.81	6.04	6.48
ZTW-R	4.80	5.16	5.50	5.78	6.12
ZTW+R	5.26	5.57	6.15	6.64	6.71
LSD (0.05)	0.34	NS	NS	NS	NS
Interaction LSD (0.05)	NS	NS	NS	NS	NS
Rice establishment methods (2017)					
DSR-ZT	7.91	7.48	7.91	8.42	8.55
DSR-CT	8.29	8.03	8.29	8.16	8.85
DSR-RT	8.61	8.04	8.61	8.22	8.56
PTR	9.55	8.61	9.55	7.89	9.15
LSD (0.05)	0.87	NS	0.86	NS	0.44
Tillage and rice straw management practices					
CTW-R	8.53	7.98	8.53	8.23	8.44
ZTW-R	8.19	7.64	8.19	7.90	8.51
ZTW+R	9.06	8.51	9.06	8.39	9.38
LSD (0.05)	NS	NS	NS	NS	NS
Interaction LSD (0.05)	NS	NS	NS	NS	NS

4.7 Effect of rice establishment methods, tillage and straw management practices on chemical fractions of micronutrients (Zn, Cu, Fe and Mn) in surface soil

4.7.1 Water soluble plus exchangeable fraction (WSEX) of Zn, Cu, Fe and Mn

The data with respect to different pools of micronutrient cations (Zn, Cu, Fe and Mn) i.e. water soluble plus exchangeable fraction (WSEX), specifically adsorbed fraction (SpAd), Mn-oxide bound fraction (MnOx), amorphous Fe-oxide bound fraction (AFeOx), crystalline Fe-oxide bound fraction (CFeOx), organically bound fraction (OM), residual fraction (RES) and total fraction as affected by the tillage and rice straw management practices in wheat and rice establishment methods in the surface soil has been presented below.

Water soluble and exchangeable zinc (WSEX-Zn)

Table 4.22 below revealed that WSEX-Zn content ranged between 2.42 to 2.58 mg kg^{-1} and from 2.28 to 3.42 mg kg^{-1} in the surface soil samples (0-7.5 cm) during the year 2015 and 2017, respectively, and it was observed that WSEX-Zn was higher under ZTW+R or ZT wheat sown with happy seeder treatment as compared to the ZTW-R and CTW-R within tillage and rice straw management practices. Although, the tillage and rice straw management practices failed to cause significant effect on the WSEX-Zn content but still the content was higher under residue retained treatments compared to the conventional tilled treatments during both the years. Rice establishment methods irrespective of the tillage and rice straw management practices also indicated non-significant effect on WSEX-Zn in soil, but the content was higher in DSR-RT followed by DSR-CT followed by DSR-ZT and then in PTR. The trend within the rice establishment methods was similar during both the years. The interaction between tillage and rice straw management practices as well as the rice establishment methods was also found non-significant.

The WSEX-Zn content was found higher under ZTW+R treatments which might be due to the decrease in pH, increase in organic matter content and cation exchange capacity as compared to the CTW-R treatment. Our results are in agreement with Falatah (2009) who stated that the Zn in the EXCH form was significantly higher for NT (no tillage) and HR (harrowing) tillage systems as compared to DS (disking) and MB (moldboard) treatments. Several soil characteristics, such as cation exchange capacity and organic matter content, are known to affect exchangeable Zn by soil (Shuman 1976, 1977). Similarly, Shuman and Hargrove (1985), using various tillage systems, found a significant increase in EXCH Zn for NT and minimum tillage practices compared to MB tillage.

Water soluble and exchangeable copper (WSEX-Cu)

A persual of data in Table 4.22 revealed that WSEX-Cu content ranged between 0.05 to 0.07 mg kg^{-1} and from 0.27 to 0.29 mg kg^{-1} in the surface soil samples (0-7.5 cm) during the year 2015 and 2017, respectively, and it was found that WSEX-Cu was almost similar but slightly higher under ZTW+R or ZT wheat sown with happy seeder treatment as compared to the ZTW-R and CTW-R within tillage and rice straw management practices. Rice establishment methods irrespective of the tillage and rice straw management practices also indicated non-significant effect on WSEX-Cu content in soil and it was almost similar under DSR-RT, DSR-CT, DSR-ZT and in PTR. The trend within the rice establishment systems was similar during both the years. The interaction between tillage and rice straw management practices as well as the rice establishment methods was also found non-significant.

Water soluble and exchangeable iron (WSEX-Fe)

The effect of tillage and rice straw management practices as well as the rice establishment methods on WSEX-Fe content of surface soil (0-7.5 cm) ranged between 0.22 to 0.59 mg kg^{-1} and from 1.26 to 1.67 mg kg^{-1} during 2015 and 2017, respectively. Here, rice establishment methods irrespective of the tillage and rice straw management practices indicated significant differences among the different treatments i.e. PTR, DSR-RT, DSR-CT and DSR-ZT. WSEX-Fe content was found to be significantly higher in PTR with respect to other treatments viz. DSR-RT, DSR-CT and DSR-ZT. In PTR, the WSEX-Fe was almost more than double as compared to DSR-RT, DSR-CT and DSR-ZT in 2015 due to reduced conditions under puddled transplanted rice. Reduction of Fe^{3+} takes place under anaerobic conditions in rice soils due to land submergence. The intensity of reduction depends upon time of flooding, organic matter content and active iron content. Similarly in 2017, rice establishment systems irrespective of the tillage and rice straw management practices again showed significant differences among the different treatments, but the content of WSEX-Fe was not as much higher as in 2015.

Tillage and rice straw management practices showed non-significant differences within ZTW+R, ZTW-R and CTW-R treatments but the content was higher under ZTW+R as compared to the ZTW-R and CTW-R during both the years. The interaction between tillage and rice straw management practices as well as the rice establishment methods was also found non-significant. The higher content of WSEX-Fe under ZTW+R treatment than CTW-R can be attributed to higher soil organic carbon content and cation exchange capacity of the soil in this treatment which might have provided the suitable sites (broken edges) for the adsorption of iron from the soil solution. Similar findings have also been reported by Malewar and Randhawa (1978) under different soils. WSEX and organic Fe were higher for the conservation tillages (NT, HR, and CH) than for the conventional tillage (DS and MB) treatments (Falatah 2009).

Table 4.22: Effect of rice establishment methods, tillage and straw management practices on WSEX fraction of micronutrients (mg kg^{-1}) in soil

Treatment	Zn	Cu	Fe	Mn
Rice establishment methods (2015)				
DSR-ZT	2.48	0.05	0.22	11.08
DSR-CT	2.57	0.05	0.28	11.44
DSR-RT	2.58	0.06	0.29	12.14
PTR	2.42	0.06	0.59	13.56
LSD (0.05)	NS	NS	0.04	NS
Tillage and rice straw management practices				
CTW-R	2.51	0.05	0.34	11.46
ZTW-R	2.46	0.06	0.32	11.90
ZTW+R	2.56	0.07	0.39	12.81
LSD (0.05)	NS	NS	NS	NS
Interaction LSD (0.05)	NS	NS	NS	NS
Rice establishment methods (2017)				
DSR-ZT	2.47	0.28	1.26	6.53
DSR-CT	2.93	0.29	1.29	6.58
DSR-RT	3.42	0.28	1.41	6.58
PTR	2.28	0.29	1.67	6.63
LSD (0.05)	NS	NS	0.14	0.14
Tillage and rice straw management practices				
CTW-R	2.74	0.29	1.41	6.59
ZTW-R	2.70	0.27	1.36	6.54
ZTW+R	2.89	0.29	1.45	6.60
LSD (0.05)	NS	NS	NS	NS
Interaction LSD (0.05)	NS	NS	NS	NS

Water soluble and exchangeable manganese (WSEX-Mn)

An examination of the data in Table 4.22 revealed that the that WSEX-Mn content varied from 11.08 to 13.56 mg $kg^{-1}$and from 6.53 to 6.63 mg kg^{-1}in the surface soil samples

(0-7.5 cm) during the year 2015 and 2017, respectively, and it was observed that no significant difference was found to observe in WSEX-Mn for ZTW+R or ZT wheat sown with happy seeder treatment with respect to the ZTW-R and CTW-R within tillage and rice straw management practices. Although, the tillage and rice straw management practices indicated non-significant effect on the WSEX-Mn content but still the content was higher under ZTW+R treatment compared to the ZTW-R and CTW-R treatments during both the years. Rice establishment methods irrespective of the tillage and rice straw management practices indicated significant effect on WSEX-Mn in soil in 2017 but the results were non-significant in 2015. WSEX-Mn content was found to be higher under PTR (i.e. 13.56 mg kg^{-1} and 6.63 mg kg^{-1} in 2015 and 2017, respectively) as compared to DSR-RT, DSR-CT and DSR-ZT. The trend within the rice establishment systems was similar during both the years. The interaction within tillage and rice straw management practices as well as the rice establishment systems was also found non-significant.

The higher content of WSEX-Mn under ZTW+R treatment as compared to the other treatments were attributed to comparatively lower pH and higher organic matter content in the soil under these treatments which might have solubilized the bound forms of Mn in the solution. WSEX-Mn form is considered to be held by weak electrostatic forces. Similar results were provided by Mandal and Mitra (1982), who reported that the application of organic matter brought an increase in the water soluble and exchangeable Mn in soils.

4.7.2 Specifically adsorbed fraction (SpAd) of Zn, Cu, Fe and Mn

Specifically adsorbed zinc (SpAd-Zn)

A persual of data in Table 4.23 revealed that tillage and rice straw management practices as well as the rice establishment methods did not significantly influenced the specifically adsorbed zinc (SpAd-Zn) during 2015. The content for SpAd-Zn varied from 6.18 to 7.24 mg kg^{-1} and from 4.43 to 6.69 mg kg^{-1} during 2015 and 2017, respectively. Among the rice establishment methods, the content for SpAd-Zn was found to be higher in DSR-RT i.e. 7.24 mg kg^{-1} followed by DSR-CT (6.74 mg kg^{-1}) followed by DSR-ZT (6.43 mg kg^{-1}) as compared to PTR (6.18 mg kg^{-1}) in 2015. Among these management practices, the SpAd-Zn was highest in ZTW+R (6.89) followed by CTW-R (6.72) and then in ZTW-R (6.33), respectively. The interaction between tillage and rice straw management practices and the rice establishment methods showed non-significant differences.

In 2017, rice establishment methods as well as tillage and rice straw management practices significantly influenced the SpAd-Zn content within the treatments. Among rice establishment methods, DSR-RT indicated significantly higher content for SpAd-Zn with respect to DSR-ZT and PTR. The puddled transplanted rice showed the lowest content of SpAd-Zn. Among the tillage and rice straw management practices, ZTW+R treatments showed significantly higher content for SpAd-Zn (6.24 mg kg^{-1}) with respect to ZTW-R (5.33

mg kg^{-1}), but it had no significant difference with CTW-R treatment. The interactive effects among tillage and rice straw management practices as well as the rice establishment methods were non-significant.

The water soluble, exchangeable and organically complexed Zn forms are plant available (Viets 1962). WSEX-Zn and SpAd-Zn were higher in plots with higher OC, CEC and lower pH. Increase in the exchangeable fraction because of pH was also observed in other works (Sims and Patrick 1978, Iyenger *et al* 1981) and has been attributed to the conversion of Zn into bioavailable forms. Sekhon *et al* (2006) observed increase in soluble and exchangeable zinc forms with integrated use of manure or crop residue along with fertilizers. The content for WSEX-Zn and SpAd-Zn were found higher on the surface soil due to higher OC content on the surface of residue retained treatment. Tiecher *et al* (2013) also observed greater soluble and exchangeable Zn concentrations in the surface layer.

Specifically adsorbed copper (SpAd-Cu)

A close examination of the data presented in table revealed that the SpAd-Cu content ranged between 0.11 to 0.15 mg kg^{-1} and from 0.06 to 0.07 mg kg^{-1} in the surface soil samples (0-7.5 cm) during the year 2015 and 2017, respectively, and it was found that SpAd-Cu was almost similar under ZTW+R or ZT wheat sown with happy seeder treatment as well as in ZTW-R and CTW-R treatments within tillage and rice straw management practices. Among the tillage and rice straw management practices, no significant differences among the treatments were observed. Rice establishment methods irrespective of the tillage and rice straw management practices also indicated non-significant effect on SpAd-Cu content in soil and it was nearly similar under DSR-RT, DSR-CT and DSR-ZT but higher in PTR. The interaction among tillage and rice straw management practices in addition to the rice establishment methods was also found non-significant.

WSEX-Cu and SpAd-Cu are the fractions which directly contribute to plant availability (Iyenger *et al* 1981). The lower Cu value in exchangeable and specifically adsorbed forms indicates the low affinity of soil exchange sites for Cu ions (Atanassova and Okazaki 1997). WSEX-Cu and SpAd-Cu increase with decrease in pH, which might be due to the precipitation of Cu as hydroxides and hydroxycarbonates at higher soil pH. It may also be due to decreased specific adsorption of Cu by soil components (Saha and Mandal 2000). Fathi *et al* (2014) also observed negative correlation of exchangeable and specifically adsorbed Cu with pH. Higher content of WSEX-Cu and SpAd-Cu fractions in residue retained plots as compared to the other treatments might be due to the fact that the content of these two fractions also depends upon organic carbon content and cation exchange capacity (CEC) of the soil, which increases with the application of organic manures (Sharma *et al* 2014).

Table 4.23: Effect of rice establishment methods, tillage and straw management practices on SpAd fraction of micronutrients (mg kg^{-1}) in soil

Treatment	Zn	Cu	Fe	Mn
Rice establishment methods (2015)				
DSR-ZT	6.43	0.12	0.11	5.12
DSR-CT	6.74	0.11	0.14	5.62
DSR-RT	7.24	0.12	0.13	6.61
PTR	6.18	0.15	0.15	7.12
LSD (0.05)	NS	NS	0.02	0.71
Tillage and rice straw management practices				
CTW-R	6.72	0.13	0.13	6.18
ZTW-R	6.33	0.12	0.12	5.78
ZTW+R	6.89	0.13	0.15	6.39
LSD (0.05)	NS	NS	0.02	NS
Interaction LSD (0.05)	NS	NS	NS	NS
Rice establishment methods (2017)				
DSR-ZT	5.54	0.07	1.43	3.53
DSR-CT	6.51	0.07	1.52	3.62
DSR-RT	6.69	0.06	1.56	3.67
PTR	4.43	0.07	1.59	3.73
LSD (0.05)	1.07	NS	NS	0.13
Tillage and rice straw management practices				
CTW-R	5.80	0.07	1.51	3.64
ZTW-R	5.33	0.06	1.47	3.58
ZTW+R	6.24	0.07	1.58	3.71
LSD (0.05)	0.62	NS	NS	0.08
Interaction LSD (0.05)	NS	NS	NS	NS

Specifically adsorbed iron (SpAd-Fe)

The persual of data regarding the effect of tillage and rice straw management practices as well as the rice establishment methods on SpAd-Fe content of surface soil (0-7.5 cm) ranged between 0.11 to 0.15 mg kg^{-1} and from 1.43 to 1.59 mg kg^{-1} during 2015 and 2017, respectively. The rice establishment systems as well as the tillage and rice straw management practices indicated significant differences among the different treatments in the year 2015, but on the other hand, the results showed non-significant difference in 2017. Among rice establishment methods, SpAd-Fe in PTR showed significantly higher content than DSR-ZT and was at par with DSR-RT in 2015. In 2017, rice establishment systems irrespective of the tillage and rice straw management practices showed non-significant differences among the different treatments. In case of tillage and rice straw management practices, SpAd-Fe was found higher in ZTW+R as compared to the ZTW-R and CTW-R which might be due to the higher OM and CEC and lower pH under these treatments which resulted in dissolution of iron from other fractions. The interaction among tillage and rice straw management practices as well as the rice establishment systems was also found non-significant.

Specifically adsorbed manganese (SpAd-Mn)

The data pertaining to the effect of tillage and rice straw management practices as well as the rice establishment methods in Table 4.23 revealed that the SpAd-Mn content varied from 5.12 to 7.12 mg kg^{-1} and from 3.53 to 3.73 mg kg^{-1} during the year 2015 and 2017 respectively, in the surface soil samples (0-7.5 cm) and it was found that SpAd-Mn was higher under ZTW+R or ZT wheat sown with happy seeder treatment as compared to the ZTW-R and CTW-R within tillage and rice straw management practices during both the years, but this effect was significantly higher in 2017 but not in 2015 (Table 4.23). Among the rice establishment methods during 2015, PTR (7.12 mg kg^{-1}) showed significantly higher content with respect to DSR-CT (5.62 mg kg^{-1}) and DSR-ZT (5.12 mg kg^{-1}) but not to DSR-RT (6.61 mg kg^{-1}). The interaction amongst tillage and rice straw management practices as well as the rice establishment methods was also found non-significant. The SpAd-Mn (specifically adsorbed manganese) fraction was observed to be higher in residue retained plots under tillage and rice straw management practices which might be due to the combined effect of higher CEC and lower pH under these treatments which might have increased surface area and adsorption sites provided by the presence of higher amounts of organic matter and at the same time low pH facilitated the dissolution of Mn from other fractions particularly oxide bound and residual fraction of mineral. This form of Mn is generally held on soil surfaces by forces ranging from weak electrostatic to strong ligand-exchange bonds.

4.6.3 Manganese oxide bound (MnOx) fraction of Zn, Cu, Fe and Mn

Manganese oxide bound zinc (MnOx-Zn)

A glance at data in Table 4.24 showed that manganese oxide bound zinc (MnOx-Zn) in surface layer (0-7.5 cm) ranged from 5.26 to 6.27 mg $kg^{-1}$and from 2.89 to 4.01 mg kg^{-1}in the year 2015 and 2017. Amongst rice establishment methods, in 2015, the trend for MnOx-Zn content was DSR-RT > DSR-CT > DSR-ZT > PTR. The content for MnOx-Zn was found significantly higher under DSR-CT and DSR-RT as compared to the PTR. On the other hand, such significant difference was not observed in the year 2017, but still the content was higher in DSR-RT (4.01 mg kg^{-1}) followed by DSR-CT (3.66 mg kg^{-1}) and DSR-ZT (3.58 mg kg^{-1}) as compared to PTR (3.22 mg kg^{-1}). Tillage and rice straw management practices also found to have significant effect on MnOx-Zn during both the years. Here, among the different treatments of tillage and rice straw management practices, ZTW+R treatment found to have significantly higher content of MnOx-Zn as compared to the ZTW-R and CTW-R in 2015 and 2017. Shuman *et al* (2001) also found an increase in Zn in manganese fractions due to organic amendments. However the interaction concerning tillage and rice straw management practices as well as the rice establishment methods was also found non-significant.

Manganese oxide bound copper (MnOx-Cu)

A review of the data presented in Table 4.24 specified that that MnOx-Cu content varied between 0.11 to 0.17 mg kg^{-1} and from 0.14 to 0.22 mg kg^{-1} in the surface soil samples (0-7.5 cm) during the year 2015 and 2017, respectively, and it was found that MnOx-Cu was nearly similar under all the treatments amongst tillage and rice straw management practices viz. ZTW+R, ZTW-R and CTW-R during both the years. Among the tillage and rice straw management practices, no significant differences among the treatments were observed. Rice establishment methods irrespective of the tillage and rice straw management practices also indicated non-significant effect on MnOx-Cu content in soil under DSR-RT, DSR-CT, DSR-ZT and in PTR treatments. The interaction among tillage and rice straw management practices as well as the rice establishment methods was also found non-significant.

Low amount of Cu bound to manganese oxide bound fraction denotes that more of the copper is bound in crystalline form. Sims (1986) also observed that only small portion of total copper is bound to manganese oxide bound fraction. Increase in MnOx-Cu might be due to transformation of Cu from iron oxide pools to manganese oxide bound pool. Agbenin and Henningsen (2004) observed increase in MnOx-Cu with the application of crop residue and chemical fertilizers.

Table 4.24: Effect of rice establishment methods, tillage and straw management practices on Mn-oxide bound fraction of micronutrients (mg kg^{-1}) in soil

Treatment	Zn	Cu	Fe	Mn
Rice establishment methods (2015)				
DSR-ZT	5.39	0.11	81.23	24.23
DSR-CT	6.13	0.17	87.88	31.07
DSR-RT	6.27	0.14	87.11	33.98
PTR	5.26	0.17	91.78	44.33
LSD (0.05)	0.34	NS	NS	4.40
Tillage and rice straw management practices				
CTW-R	5.32	0.15	87.78	39.31
ZTW-R	5.75	0.13	82.54	40.36
ZTW+R	6.21	0.16	90.69	43.03
LSD (0.05)	0.38	NS	3.69	NS
Interaction LSD (0.05)	NS	NS	NS	NS
Rice establishment methods (2017)				
DSR-ZT	3.58	0.15	22.33	22.29
DSR-CT	3.66	0.15	23.36	23.53
DSR-RT	4.01	0.14	23.57	26.43
PTR	3.22	0.22	25.42	27.32
LSD (0.05)	NS	0.03	0.03	3.01
Tillage and rice straw management practices				
CTW-R	2.89	0.17	24.37	25.57
ZTW-R	3.97	0.16	23.29	23.99
ZTW+R	3.99	0.17	26.35	26.13
LSD (0.05)	0.69	NS	NS	NS
Interaction LSD (0.05)	NS	NS	NS	NS

Manganese oxide bound iron (MnOx-Fe)

The data in Table 4.24 revealed that the MnOx-Fe content indicated significant differences among the different treatments between tillage and rice straw management practices in 2015 and 2017 in surface soil (0-7.5 cm). In 2015, among rice establishment methods, MnOx-Fe was higher under PTR (91.78 mg kg^{-1}) as compared to the DSR-RT (87.11 mg kg^{-1}), DSR-CT (87.88 mg kg^{-1}) and DSR-ZT (81.23 mg kg^{-1}). Similarly, in 2017, the content for MnOx-Fe was significantly higher in PTR (25.42 mg kg^{-1}) as compared to the DSR-RT (23.57 mg kg^{-1}), DSR-CT (23.36 mg kg^{-1}) and DSR-ZT (22.33) mg kg^{-1}). Moreover, the content for MnOx-Fe was found higher in ZTW+R treatment as compared to the ZTW-R as well as CTW-R during both the years among the tillage and rice straw management practices in wheat. The interaction between tillage and rice straw management practices as well as the rice establishment methods was also found non-significant.

Manganese oxide bound manganese (MnOx-Mn)

An examination of the data in Table 4.24 indicated that the MnOx-Mn content varied from 24.23 to 44.33mg $kg^{-1}$and from 22.29 to 37.32 mg kg^{-1}in the surface soil samples (0-7.5 cm) during the year 2015 and 2017, respectively. Although, the tillage and rice straw management practices indicated non-significant effect on the MnOx-Mn content, still the content was higher under ZTW+R treatment compared to the ZTW-R and CTW-R treatments during both the years. Rice establishment methods irrespective of the tillage and rice straw management practices indicated significant effect on MnOx-Mn in soil in both years i.e 2015 and 2017. MnOx-Mn content was higher under PTR (i.e. 44.33 mg $kg^{-1}$and 37.32 mg kg^{-1}) as compared to DSR-RT, DSR-CT and DSR-ZT where it ranged from 33.98 mg $kg^{-1}$and 26.43 mg kg^{-1}, 31.07 mg $kg^{-1}$and 23.53 mg $kg^{-1}$and 24.23 mg $kg^{-1}$and 22.29 mg kg^{-1}in 2015 and 2017, respectively. The interaction among tillage and rice straw management practices and the rice establishment methods was also found non-significant.

4.7.4 Amorphous iron oxide bound (AFeOx) fraction of Zn, Cu, Fe and Mn

Amorphous iron oxide bound zinc (AFeOx-Zn)

A close examination of data (Table 4.25) indicated that rice establishment methods did not significantly affected the amorphous iron oxide bound zinc (AFeOx-Zn) fraction during 2015 but it was found significant in 2017. The content for AFeOx-Zn varied from 10.94 to 12.74 mg kg^{-1} and from 7.16 to 8.84 mg kg^{-1} during the year 2015 and 2017, respectively. Among the rice establishment methods, the content for AFeOx-Zn was found significantly higher in direct seeded rice treatments viz. DSR-RT (8.84 mg kg^{-1}), DSR-ZT (8.61 mg kg^{-1}) and DSR-CT (8.51 mg kg^{-1}) as compared to PTR (7.16 mg kg^{-1}) in 2017, similarly the AFeOx-Zn was higher in 2015 in direct seeded rice treatments viz. DSR-RT (12.74 mg kg^{-1}), DSR-ZT (12.26 mg kg^{-1}) and DSR-CT (12.55 mg kg^{-1}) as compared to PTR (10.94 mg kg^{-1}) in 2015. However, in 2015 and 2017, among the tillage and rice straw management practices, the AFeOx-Zn showed reverse trend as compared to the previous fractions by indicating higher content under CTW-R instead of ZTW+R and ZTW-R, but the results were found non-significant during both the years of experimentation amongst the tillage and rice straw management practices. The interaction between tillage and rice straw management practices as well as the rice establishment methods showed non-significant difference.

On contrary to WSEX-Zn, the Zn fraction combined with AFeOx was significantly more for disking and moldboard treatments as compared to other tillage systems i.e. no tillage. This observation was partially ascribed to high pH values of these two tillage treatments (Falatah 2009). Sims (1986) observed that theleading form of soil-Zn to be AFeOx at pH > 6.9. Alternative descriptions for this observation are (1) that the mechanical effects of these two tillage systems may have altered other forms of the Zn fraction to the AFeOx fraction, which has a greater surface area and may have adsorbed a greater amount of Zn; and (2) that the DS and MB treatments may have transported this Zn fraction from subsoil. Studies by Shuman (1976, 1977) showed that the Fe oxide fraction contained considerable amounts of Zn. Moreover, there was no significant difference in Zn combined with AFeOx fraction among DS and MB practices.

Amorphous iron oxide bound copper (AFeOx-Cu)

A persual of the data in Table 4.25 revealed that amorphous iron oxide bound copper ranged between 2.37 to 2.84 mg kg^{-1} and from 2.48 to 2.79 mg kg^{-1} during first and second year of the experimentation i.e. in 2015 and 2017, respectively. The rice establishment methods irrespective of tillage and rice straw management practices, the AFeOx-Cu did not differ significantly among the treatments during both the years. The content for AFeOx-Cu was found higher in PTR as compared to the DSR-RT, DSR-CT and DSR-ZT treatments. On the other hand, tillage and rice straw management practices irrespective of the rice establishment methods, showed significant difference amongst the treatments in 2017 but no such significant difference was observed in 2015. The content for AFeOx-Cu followed the reverse trend as compared to the other fractions, as it was found higher under ZTW-R and CTW-R instead of ZTW+R. Cu in the AFeOx fraction was significantly higher under DS (disking) and MB (moldboard) treatments as compared to NT (no tillage), HR (harrowing), and CH (chiseling) systems. Le Riche and Weir (1963) also observed higher amounts of Cu in the Fe oxide fraction. Some studies on Cu in soil revealed that for pH > 6.9, more Cu was in combined with AFeOx. The DS and MB tillage treatments may have shifted Cu in the AFeOx fraction to the soil surface (McLaren and Grawford 1973).

Table 4.25: Effect of rice establishment methods, tillage and straw management practices on AMOR Fe-oxide bound fraction of micronutrients (mg kg^{-1}) in soil

Treatment	Zn	Cu	Fe	Mn
Rice establishment methods (2015)				
DSR-ZT	12.26	2.37	298.9	12.61
DSR-CT	12.55	2.51	282.5	16.11
DSR-RT	12.74	2.41	306.5	14.53
PTR	10.94	2.84	391.9	14.77
LSD (0.05)	NS	NS	19.71	2.16
Tillage and rice straw management practices				
CTW-R	12.46	2.64	292.5	16.09
ZTW-R	12.74	2.58	327.2	13.40
ZTW+R	11.99	2.38	340.2	14.02
LSD (0.05)	NS	NS	11.97	1.57
Interaction LSD (0.05)	NS	NS	NS	NS
Rice establishment methods (2017)				
DSR-ZT	8.61	2.70	124.2	23.37
DSR-CT	8.51	2.62	126.5	27.70
DSR-RT	8.84	2.63	127.2	22.01
PTR	7.16	2.75	136.7	25.82
LSD (0.05)	0.95	NS	3.92	1.80
Tillage and rice straw management practices				
CTW-R	8.27	2.79	128.9	26.09
ZTW-R	8.07	2.76	127.2	22.03
ZTW+R	8.50	2.48	129.8	26.05
LSD (0.05)	NS	0.15	NS	2.25
Interaction LSD (0.05)	NS	NS	NS	NS

Amorphous iron oxide bound iron (AFeOx-Fe)

The data pertaining to the effect of tillage and rice straw management practices as well as the rice establishment methods in Table 4.25 revealed that the AFeOx-Fe content indicated significant difference among the different treatments between tillage and rice straw management practices in 2015 in surface soil (0-7.5 cm). No such significant difference was found to observe in 2017 among tillage and rice straw management practices. Moreover, the content for AFeOx-Fe was found higher in ZTW+R (340.2 mg kg^{-1}) treatment as compared to the ZTW-R (327.2 mg kg^{-1}) as well as CTW-R (292.5 mg kg^{-1}) in 2015. Similar trend was observed in 2017, where AFeOx-Fe was likewise found higher in ZTW+R (129.8 mg kg^{-1}) treatment as compared to the ZTW-R (127.2 mg kg^{-1}) as well as CTW-R (128.9 mg kg^{-1}). On the other hand, in case of rice establishment methods, significant differences amongst the treatments were observed during both the years. The AFeOx-Fe content was found higher under PTR (391.9 mg kg^{-1}) as compared to the DSR-RT (306.5 mg kg^{-1}), DSR-CT (282.5 mg kg^{-1}) and DSR-ZT (298.9 mg kg^{-1}). Similarly, in 2017, the content for AFeOx-Fe was significantly higher in PTR (136.7 mg kg^{-1}) as compared to the DSR-RT (127.2 mg kg^{-1}), DSR-CT (126.5 mg kg^{-1}) and DSR-ZT (124.2) mg kg^{-1}). The interaction between tillage and rice straw management practices as well as the rice establishment methods was found non-significant.

Amorphous iron oxide bound manganese (AFeOx-Mn)

The values in Table 4.25 indicated that AFeOx-Mn content varied from 12.61 to 16.11 mg kg^{-1} and from 22.01 to 27.70 mg kg^{-1} in the surface soil samples (0-7.5 cm) during the year 2015 and 2017, respectively, and it was observed that AFeOx-Mn was higher under CTW-R instead of ZTW+R or ZT wheat sown with happy seeder as well as ZTW-R within tillage and rice straw management practices during both the years. Rice establishment methods irrespective of the tillage and rice straw management practices also indicated significant increase in AFeOx-Mn during both years i.e 2015 and 2017. AFeOx-Mn content was higher under PTR (i.e. 14.77 mg kg^{-1} and 25.82 mg kg^{-1} in 2015 and 2017, respectively) as compared to DSR-RT, DSR-CT and DSR-ZT where it ranged from 14.53 mg kg^{-1} and 16.11 mg kg^{-1}, 12.61 mg kg^{-1} and from 22.01 mg kg^{-1} and 27.70 mg kg^{-1} and 23.37 mg kg^{-1} in 2015 and 2017, respectively. The interaction among tillage and rice straw management practices as well as the rice establishment methods was also found non-significant. Organically bound fraction, AFeOx bound and residual Mn were significantly influenced by the different tillage systems. The total Mn was higher for DS and MB as compared to NT, HR, and CH treatments. It is possible that part of the total Mn was altered to AFeOx and RES forms of Mn. Organic manganese was lower for DS and MB tillage systems than for NT, HR, and CH treatments. The higher OM content of the latter three tillage treatments advises that Mn may have been linked with the organic fraction (Falatah 2009).

4.7.5 Crystalline iron oxide bound (CFeOx) fraction of Zn, Cu, Fe and Mn

Crystalline iron oxide bound zinc (CFeOx-Zn)

A glance at the data in Table 4.26 below showed that CFeOx-Zn content ranged between 14.91 to 19.41 mg kg^{-1} and from 10.29 to 11.16 mg kg^{-1} respectively amongst the tillage and rice straw management practices as well as rice establishment methods in the surface soil samples (0-7.5 cm) during the year 2015 and 2017. It was observed that among the tillage and rice straw management practices, CFeOx-Zn was found higher under CTW-R (19.41 mg kg^{-1}) as compared to the ZTW+R (15.00 mg kg^{-1}) and ZTW-R (17.77 mg kg^{-1}) in 2015, whereas it varied significantly in 2017, and was found higher in CTW-R (11.16 mg kg^{-1}) as compared to ZTW+R (10.29 mg kg^{-1}) as well as ZTW-R (10.81 mg kg^{-1}). On the other hand, rice establishment systems irrespective of the tillage and rice straw management practices failed to cause significant effect on the CFeOx-Zn content but still the content was higher under direct seeded rice treatments i.e. DSR-CT, DSR-RT and DSR-ZT as compared to the puddled transplanted rice (PTR).

Zn occluded in oxides of Fe and Mn as primary and secondary minerals is not readily available (Viets 1962). The decrease in Zn in crystalline and amorphous iron oxide bound fractions was accompanied by a concomitant increase in the WSEX, specifically absorbed, organic and Mn oxide. It denotes that a large part of the Zn released from crystalline (CFeOx) and amorphous iron oxide (AFeOx) bound fraction was mobilized into the organic fraction (OM), manganese oxide fraction (MnOx), water soluble plus exchangeable fraction (WSEX) and specifically adsorbed (SpAd) fractions (Sekhon *et al* 2006). Mandal *et al* (1988) reported that addition of organic matter caused a significant increase in soil Zn in the water-soluble plus exchangeable, specifically absorbed, organic and amorphous iron oxide fractions with a simultaneous decrease in the crystalline iron oxide fractions.

Reduction of Zn bound to crystalline and amorphous iron oxide in residue retained plots might be due to solubilization of non-labile form into labile form (Iyenger *et al* 1981, Mandal and Mandal 1987, Sharma *et al* 2004, Dhiman 2007). Since the addition of crop residues increased the soil organic matter content, so most of Fe might have formed strong complexes with the soil organic matter and thus render little amount of oxides for zinc adsorption. So a decrease in Zn bound to crystalline and amorphous iron oxides was observed. Besides this, the zinc released during organic complexes formation with Fe might have converted to other Zn fractions. This explains the decrease in the content of amorphous and crystalline iron oxide bound zinc with application of residues (Mandal and Mandal 1987, Dhiman 2007). Another reason for decline in Zn bound on iron oxide might be decline in soil pH. Stahl and James (1991) observed that with decrease in pH, Zn sorbed on the surface of Fe-oxides transformed from non-exchangeable form to more exchangeable form.

Crystalline iron oxide bound copper (CFeOx-Cu)

A close examination of the contents of data in Table 4.26 revealed that CFeOx-Cu content amongst the tillage and rice straw management practices as well as rice establishment methods ranged between 1.38 to 1.48 mg kg^{-1} and from 2.88 to 3.63 mg kg^{-1} in the surface soil samples (0-7.5 cm) during the year 2015 and 2017, respectively. Amongst the rice establishment methods, CFeOx-Cu content was found to have non-significant effect between the treatments. It was revealed that CFeOx-Cu content was varied in 2015 as 1.38 mg kg^{-1}, 1.47 mg kg^{-1}, 1.40 mg kg^{-1} and 1.46 mg kg^{-1} in DSR-ZT, DSR-CT, DSR-RT and PTR, respectively. In the next year, CFeOx-Cu content was ranged as 3.56 mg kg^{-1}, 3.63 mg kg^{-1}, 3.59 mg kg^{-1} and 3.54 mg kg^{-1} in DSR-ZT, DSR-CT, DSR-RT and PTR, respectively. Tillage and rice straw management practices irrespective of the rice establishment methods indicated non-significant effect on CFeOx-Cu content in soil in 2015 but the effect was found significant in 2017. The content was significantly higher in ZTW+R (3.43 mg kg^{-1}) as compared to ZTW-R (2.93 mg kg^{-1}) and CTW-R (2.88 mg kg^{-1}) in 2017. The interaction among tillage and rice straw management practices as well as the rice establishment methods was observed as non-significant. Cu in crystalline Fe oxide form was declined only in the CTW treatment. In comparison to this, Shuman and Hargrove (1985) found similar decrease. On the other hand, the mechanism involved in the CFeOx Cu reduction due to MB tillage is not clearly identified. In general, the data seem indicative of strong CFeOx-Cu adsorption that resists transformation into other soil fractions under various tillage systems.

Amorphous and crystalline iron oxide bound fractions as considered relative unavailable forms. Metals with the higher electro-negativity form strong covalent bond with oxygen atoms from soil colloids and have higher hysteresis for the adsorption (Mc Bridge 1994). Sekhon *et al* (2006) observed decrease in Cu content in the crystalline iron oxide fractions and increase water soluble plus exchangeable and comparatively more soluble (organic, manganese oxides and amorphous iron oxides) fractions in soils under long-term experiment at Kaul. Additions of organic matter caused the transformation of Cu from the non-mobile fraction to mobile fractions (Saha and Mandal 2000) due to an increase in the complexing capacity of organic matter.

Table 4.26: Effect of rice establishment methods, tillage and straw management practices on CRYS Fe-oxide bound fraction of micronutrients (mg kg^{-1}) in soil

Treatment	Zn	Cu	Fe	Mn
Rice establishment methods (2015)				
DSR-ZT	17.73	1.38	1486.7	14.37
DSR-CT	18.95	1.47	1814.5	17.17
DSR-RT	17.99	1.40	1691.5	18.40
PTR	14.91	1.46	1823.1	16.20
LSD (0.05)	NS	NS	NS	NS
Tillage and rice straw management practices				
CTW-R	19.41	1.39	1831.9	16.45
ZTW-R	17.77	1.42	1584.8	15.15
ZTW+R	15.00	1.48	1695.0	18.02
LSD (0.05)	3.11	NS	140.0	NS
Interaction LSD (0.05)	NS	NS	NS	NS
Rice establishment methods (2017)				
DSR-ZT	10.92	3.56	234.8	37.99
DSR-CT	10.91	3.63	235.8	45.11
DSR-RT	10.81	3.59	237.9	44.14
PTR	10.37	3.54	235.6	42.24
LSD (0.05)	NS	NS	NS	3.25
Tillage and rice straw management practices				
CTW-R	11.16	2.88	237.8	40.46
ZTW-R	10.81	2.93	234.9	40.46
ZTW+R	10.29	3.43	235.2	46.18
LSD (0.05)	0.60	0.44	NS	3.56
Interaction LSD (0.05)	NS	NS	NS	NS

Crystalline iron oxide bound iron (CFeOx-Fe)

The data pertaining to CFeOx-Fe fraction as affected by the tillage and rice straw management practices and rice establishment methods indicated that CFeOx-Fe content varied from 1486.7 to 1831.9 mg kg^{-1} and from 234.8 to 237.8 mg kg^{-1} in the surface soil samples (0-7.5 cm) during the year 2015 and 2017, respectively. It was observed that CFeOx-

Fe was higher under CTW-R instead of ZTW+R and ZTW-R within tillage and rice straw management practices during both the years. The tillage and rice straw management practices indicated significant effect on the CFeOx-Fe content under CTW-R (1831.9 mg kg^{-1}) as compared to ZTW-R (1584.8 mg kg^{-1}) treatment in 2015 but results were non-significant during 2017. Rice establishment methods irrespective of the tillage and rice straw management practices indicated non-significant effect on CFeOx-Fe during both years i.e 2015 and 2017. CFeOx-Fe content was higher under PTR as compared to DSR-RT, DSR-CT and DSR-ZT in 2015 as well as 2017. The interaction between tillage and rice straw management practices as well as the rice establishment methods was also found non-significant.

Crystalline iron oxide bound Fe fraction is the second most dominant fraction of iron after residual Fe. The hydroxides or oxides might have provided the sites for adsorption of the cations on the broken edges therefore increasing the amount of AFeOx-Fe and CFeOx-Fe bound fraction of Fe. The differences in the contents of AFeOx-Fe and CFeOx-Fe under different treatments might be due to the effect of soil pH and soil organic matter. “Iron associated with either CFeOx fractions was significantly higher for the DS and MB tillage treatments. Similar distribution patterns were found with total Fe (Falatah 2009), suggesting that part of the total Fe under the management of DS and MB tillage was associated with the Mn and Fe oxide fractions.It is probable that these two tillage practices may have transported these fractions of iron from the lower layers.

Crystalline iron oxide bound manganese (CFeOx-Mn)

A glance at data in Table 4.26 showed that CFeOx-Mn content ranged between 14.37 to 18.40 mg kg^{-1} and from 37.99 to 46.18 mg kg^{-1} respectively amongst the tillage and rice straw management practices as well as rice establishment methods in the surface soil samples (0-7.5 cm) during the year 2015 and 2017. It was observed that amongst the tillage and rice straw management practices, CFeOx-Mn was found higher under ZTW+R (18.02 mg kg^{-1}) as compared to the ZTW-R (15.15 mg kg^{-1}) and CTW-R (16.45 mg kg^{-1}) in 2015, whereas it varied significantly in 2017, as it was found significantly higher in ZTW+R (46.18 mg kg^{-1}) as compared to ZTW-R (40.46 mg kg^{-1}) as well as CTW-R (40.46 mg kg^{-1}). On the other hand, rice establishment systems irrespective of the tillage and rice straw management practices failed to cause significant effect on the CFeOx-Mn content in 2015 but it cause significant effect within the treatments in 2017. Lowest content for CFeOx-Mn was observed in DSR-ZT treatment amongst all the treatments. The interaction between tillage and rice straw management practices as well as the rice establishment methods was also observed as non-significant.

As it was observed from the data that contents for CFeOx-Mn was higher in ZTW+R treatments, it seems that crop residue mobilize non-labile Mn sources into labile forms of Mn.

Several mechanisms could be proposed for this phenomenon, which include surface complexation of Mn by organic ligands produced from the decomposition of the crop residue; improved the CEC conferred on the soil by crop residues probably induced by sorption of organic ligands to oxide surfaces; and the inhibition of Fe crystallization by crop residue. Either of these mechanisms could lead to decreasing Cryst Fe-Mn, and the increasing Amor Fe-Mn, MnOx-Mn, OM-Mn, and SpAd-Mn and WSEX-Mn fractions in residue retained plots.

4.7.6 Organically bound (OM) fraction Zn, Cu, Fe and Mn

Organically bound zinc (OM-Zn)

A persual of data in Table 4.27 revealed the content for OM-Zn varied from 4.31 to 5.61 mg kg^{-1} and from 4.96 to 6.34 mg kg^{-1} within all the treatment combinations during 2015 and 2017, respectively. It was observed that tillage and rice straw management practices irrespective of the rice establishment methods significantly influenced the organic matter bound zinc (OM-Zn) during 2015 and 2017. Rice establishment systems also vary significantly during both the years, and it was observed that the content for OM-Zn was found higher in DSR-RT (5.60 mg kg^{-1}) followed by DSR-CT (5.35 mg kg^{-1}) followed by DSR-ZT (4.88 mg kg^{-1}) as compared to PTR (4.31 mg kg^{-1}) in 2015. Similarly, in 2017, OM-Zn was higher for DSR-RT (6.08 mg kg^{-1}) followed by DSR-ZT (6.34 mg kg^{-1}) followed by DSR-CT (5.32 mg kg^{-1}) as compared to PTR (4.96 mg kg^{-1}) However, among the tillage and rice straw management practices, the OM-Zn was highest for ZTW+R followed by ZTW-R and then in CTW-R, respectively in both the years. The increase in ZTW+R treatments might be due to the higher soil organic carbon content in these treatments. Zinc forms strong complexes with soil organic matter (Sharad and Verma 2001, Umesh *et al* 2013). The interaction between tillage and rice straw management practices as well as the rice establishment methods showed non-significant differences.

Organically bound copper (OM-Cu)

A close examination of the contents of data in Table 4.27 revealed that OM-Cu content amongst the tillage and rice straw management practices as well as rice establishment methods ranged between 0.77 to 0.87 mg kg^{-1} and from 0.18 to 0.21 mg kg^{-1} in the surface soil samples (0-7.5 cm) during the year 2015 and 2017, respectively. Amongst the rice establishment methods, OM-Cu content was found to have non-significant effect between the treatments during both the years. It was revealed that OM-Cu content was varied in 2015 as 0.81 mg kg^{-1}, 0.77 mg kg^{-1}, 0.82 mg kg^{-1} and 0.85 mg kg^{-1} in DSR-ZT, DSR-CT, DSR-RT and PTR, respectively. In the next year, OM-Cu content was ranged as 0.19 mg kg^{-1}, 0.20 mg kg^{-1}, 0.18 mg kg^{-1} and 0.21 mg kg^{-1} in DSR-ZT, DSR-CT, DSR-RT and PTR, respectively.

Table 4.27: Effect of rice establishment methods, tillage and straw management practices on OM-bound fraction of micronutrients (mg kg^{-1}) in soil

Treatment	Zn	Cu	Fe	Mn
Rice establishment methods (2015)				
DSR-ZT	4.88	0.81	171.0	2.59
DSR-CT	5.35	0.77	172.8	2.55
DSR-RT	5.60	0.82	175.1	2.69
PTR	4.31	0.85	180.7	2.93
LSD (0.05)	0.57	NS	4.99	0.18
Tillage and rice straw management practices				
CTW-R	4.44	0.77	170.3	2.34
ZTW-R	5.05	0.80	175.6	2.61
ZTW+R	5.61	0.87	178.8	3.13
LSD (0.05)	0.57	NS	3.48	0.42
Interaction LSD (0.05)	NS	NS	NS	NS
Rice establishment methods (2017)				
DSR-ZT	6.34	0.19	147.5	2.71
DSR-CT	5.32	0.20	150.4	2.84
DSR-RT	6.08	0.18	153.8	3.30
PTR	4.96	0.21	157.9	3.59
LSD (0.05)	0.58	NS	NS	NS
Tillage and rice straw management practices				
CTW-R	5.63	0.19	152.8	2.99
ZTW-R	5.46	0.20	148.2	2.93
ZTW+R	5.94	0.19	156.2	3.42
LSD (0.05)	NS	NS	5.40	0.32
Interaction LSD (0.05)	NS	NS	NS	NS

Tillage and rice straw management practices irrespective of the rice establishment methods also indicated non-significant effect on OM-Cu content in soil in 2015 as well as 2017. Even then the content was found higher in 2015 in case of ZTW+R and ZTW-R as compared to CTW-R. This increase might be because of increase in organic matter on the surface layer. The organic matter content in soil is one of the key factors which play an important role in the distribution of the Cu among different fractions. An addition of crop residues in soil not only supplied the additional nutrients to the growing plants. Due to presence of more organic matter, it influences the forms and availability of Cu due to release of organic acids and other microbial products during decomposition (Verma and Bhagat 1992). However, the interaction between tillage and rice straw management practices as well as the rice establishment methods was observed as non-significant.Cu in the organic fraction was significantly higher for NT (no tillage), HR (harrowing), and CH (chiseling) than for DS (disking) and MB (moldboard) treatments. Many authors have reported that Cu is often associated with organic matter (Miller and McFee 1983, Sims and Patrick 1978). Therefore, the augmented Cu in the organic fraction for NT, HR, and CH practices can be ascribed to the higher OM content in these treatments.

Organically bound iron (OM-Fe)

The data pertaining to the effect of tillage and rice straw management practices in wheat as well as the rice establishment methods in Table 4.27 revealed that the OM-Fe content indicated significant differences among the different treatments between tillage and rice straw management practices in surface soil (0-7.5 cm) in 2015 and 2017. The content for OM-Fe was found higher in ZTW+R (178.8 mg kg^{-1}) treatment as compared to the ZTW-R (175.6 mg kg^{-1}) as well as CTW-R (170.3 mg kg^{-1}) in 2015. Similar trend was observed in 2017, where OM-Fe was likewise found significantly higher in ZTW+R (156.2 mg kg^{-1}) treatment as compared to the ZTW-R (148.2 mg kg^{-1}) but not significantly higher with respect to CTW-R (152.8 mg kg^{-1}). A persual of the data suggested that higher SOM content in these treatments might have resulted in higher OM-Fe content. Soil organic matter plays a major role in influencing organically bound fraction micronutrients. Similar results have also been reported by Sharma *et al* (2008) in different parts of country.

On the other hand, in case of rice establishment methods, significant differences amongst the treatments were observed during both the years. The OM-Fe content was found significantly higher under PTR (180.7 mg kg^{-1}) as compared to the DSR-RT (175.1 mg kg^{-1}), DSR-CT (172.8 mg kg^{-1}) and DSR-ZT (171.0 mg kg^{-1}). Although no significant results were found in 2017, the content for OM-Fe was higher in PTR (157.9 mg kg^{-1}) as compared to the DSR-RT (153.8 mg kg^{-1}), DSR-CT (150.4 mg kg^{-1}) and DSR-ZT (147.5 mg kg^{-1}). The interaction between tillage and rice straw management practices as well as the rice establishment methods was found non-significant.

Organically bound manganese (OM-Mn)

A glance at data in Table 4.27 showed that OM-Mn content ranged between 2.34 to 3.13 mg kg^{-1} and from 2.71 to 3.59 mg kg^{-1} respectively amongst the tillage and rice straw management practices as well as rice establishment methods in the surface soil samples (0-7.5 cm) during the year 2015 and 2017. It was observed that amongst the tillage and rice straw management practices, OM-Mn was found under higher under ZTW+R (3.13 mg kg^{-1}) as compared to the ZTW-R (2.61 mg kg^{-1}) and CTW-R (2.34 mg kg^{-1}) in 2015, whereas it also varied significantly in 2017, as it was found significantly higher in ZTW+R (3.42 mg kg^{-1}) as compared to ZTW-R (2.93 mg kg^{-1}) as well as CTW-R (2.99 mg kg^{-1}). The increase in organic fraction in residue retained plots can probably be ascribed to the formation of organic complexes of Mn with organic acids produced during decomposition of the organic materials (Sekhon *et al* 2006).

Rice establishment systems irrespective of the tillage and rice straw management practices failed to cause significant effect on the OM-Mn content in 2017 but it cause significant effect within the treatments in 2015. Highest content for OM-Mn was observed in PTR treatment as compared to the DSR-RT, DSR-CT and DSR-ZT amongst all the treatments. The interaction amongst tillage and rice straw management practices as well as the rice establishment methods was also observed as non-significant.

4.7.7 Residual fraction (RES) of Zn, Cu, Fe and Mn

Residual zinc (RES-Zn)

The Table 4.28 below revealed that RES-Zn content ranged between 43.6 to 53.3mg kg^{-1}and from 66.6 to 77.8 mg kg^{-1} in the surface soil samples (0-7.5 cm) during the year 2015 and 2017, respectively, and it was observed that amongst the tillage and rice straw management practices in wheat, RES-Zn was significantly higher under ZTW+R or ZT wheat sown with happy seeder treatment (53.3 and 77.8 mg kg^{-1}) as compared to the ZTW-R (43.6 and 73.2 mg kg^{-1}) and CTW-R (45.5 and 66.6 mg kg^{-1}) within tillage and rice straw management practices during both the years of experimentation (2015 and 2017). Rice establishment methods irrespective of the tillage and rice straw management practices indicated non-significant effect on RES-Zn in soil, but the content was higher in DSR-RT followed by DSR-ZT followed by PTR and then DSR-CT. The different treatments followed almost similar trend as observed in the surface layer. In other studies by Nogueira *et al* (2010), Iyengar *et al* (1981) the residual fraction was also evidenced as the larger Zn reservoir. The interaction between tillage and rice straw management practices in wheat as well as the rice establishment methods was also found non-significant.

Residual Zn associated with the mineral fraction constituted the major amount of native soil Zn and was the most dominant portion of total-Zn. The formation of metallo-organic complexes with ligands, mineralization and solubilization from organic sources might be the reason for increased concentration of zinc fractions in plots receiving crop residues or organic materials. As the pH increases, the number of negative pH-dependent charges also increases, but the negative charge density at the surface of the colloid increases, and the micronutrients available for the plant decrease. Application of organic residues can alter Zn forms through a number of mechanisms involving: (1) surface complexation of the bound Zn form by organic ligands produced from manure decomposition; (2) the inhibition of Fe and Al crystallization providing reactive surfaces and effective sinks for Zn, thus enhancing further dissolution of bound Zn; and (3) by the adsorption of organic ligands to the oxide surface. Ligand adsorption usually conveys negative charge onto the oxide surfaces, and thus increases Zn adsorption by oxides (Barrow 1987).

Residual copper (RES-Cu)

A persual of data in Table 4.28 revealed thatRES-Cu content ranged between 9.28 to 10.7 mg kg^{-1} and from 14.1 to 15.2 mg kg^{-1} in the surface soil samples (0-7.5 cm) during the year 2015 and 2017, respectively, and it was found that RES-Cu was higher under ZTW+R or ZT wheat sown with happy seeder treatments as compared to the ZTW-R and CTW-R within tillage and rice straw management practices during both the years. Rice establishment methods irrespective of the tillage and rice straw management practices also indicated non-significant difference within the treatments on RES-Cu content in soil. The interaction between tillage and rice straw management practices as well as the rice establishment methods was also found non-significant.

A glance at the contents of different fractions of Cu in the surface layer showed that Residual Cu was the most dominant form of soil Cu contributing towards total copper followed by Cu bound to crystalline Fe oxides. The soil solution plus exchangeable Cu formed the least contributing fraction. Major part of the Total-Cu concentration was present as residual i.e. held within the silicate mineral structure, regardless of soil depth. The dominance of residual Cu (RES-Cu) accords with reports that oxides in soils and clays provide reactive sites for the chemisorptions of Cu, copper sorbed by these oxides is almost irreversible (Agbenin and Henningsen 2004).

Table 4.28: Effect of rice establishment methods, tillage and straw management practices on RES fraction of micronutrients (mg kg^{-1}) in soil

Treatment	Zn	Cu	Fe (%)	Mn
Rice establishment methods (2015)				
DSR-ZT	46.6	9.28	1.14	74.9
DSR-CT	45.7	9.91	1.02	57.9
DSR-RT	47.7	10.3	1.21	44.3
PTR	49.8	10.2	1.14	41.9
LSD (0.05)	NS	NS	NS	3.59
Tillage and rice straw management practices				
CTW-R	45.5	9.71	1.18	54..7
ZTW-R	43.6	9.3	1.07	53.6
ZTW+R	53.3	10.7	1.13	56.0
LSD (0.05)	2.48	NS	0.07	1.80
Interaction				
LSD (0.05)	NS	NS	NS	NS
Rice establishment methods (2017)				
DSR-ZT	72.7	14.2	1.56	76.8
DSR-CT	70.7	14.3	1.45	71.8
DSR-RT	74.7	14.1	1.67	64.9
PTR	71.9	15.2	1.61	70.3
LSD (0.05)	NS	NS	NS	NS
Tillage and rice straw management practices				
CTW-R	66.6	14.5	1.65	70.7
ZTW-R	73.2	14.3	1.49	70.8
ZTW+R	77.8	14.6	1.58	71.3
LSD (0.05)	2.30	NS	NS	0.45
Interaction LSD (0.05)	NS	NS	NS	NS

Residual iron (RES-Fe)

The effect of tillage and rice straw management practices as well as the rice establishment methods on RES-Fe content of surface soil (0-7.5 cm) ranged between 1.02 to 1.18 percent and from 1.45 to 1.67 percent during 2015 and 2017, respectively. Here, rice establishment systems irrespective of the tillage and rice straw management practices indicated non-significant differences among the different treatments i.e. PTR, DSR-RT, DSR-CT and DSR-ZT. However, among the tillage and rice straw management practices in wheat, significantly higher RES-Fe content was observed under CT treatment (1.18 percent) as compared to ZTW-R (1.07 percent) during 2015. On the other hand, no significant differences were found among the treatments in 2017 under tillage and rice straw management practices in wheat. Moreover, the different treatments under rice establishment methods also showed non-significant effect within the treatments.

Residual manganese (RES-Mn)

A glance at data in Table 4.28 showed that RES-Mn content ranged between 41.9 to 74.9 mg kg^{-1} and from 64.9 to 76.8 mg kg^{-1} respectively amongst the tillage and rice straw management practices as well as rice establishment methods in the surface soil samples (0-7.5 cm) during the year 2015 and 2017. Data revealed that amongst the tillage and rice straw management practices, RES-Mn was found significantly higher under ZTW+R (56.0 mg kg^{-1}) as compared to the ZTW-R (53.6 mg kg^{-1}) and CTW-R (54.7 mg kg^{-1}) in 2015, whereas it also varied significantly in 2017, as it was found significantly higher in ZTW+R (71.3 mg kg^{-1}) as compared to ZTW-R (70.8 mg kg^{-1}) as well as CTW-R (70.7 mg kg^{-1}). Rice establishment systems irrespective of the tillage and rice straw management practices failed to cause significant effect on the RES-Mn content in 2017 but it cause significant effect within the treatments in 2015. Highest content for RES-Mn was observed in DSR-CT treatment as compared to the DSR-RT, DSR-ZT and PTR amongst all the treatments in 2015. The interaction between tillage and rice straw management practices as well as the rice establishment methods was also observed as non-significant.

The combined effect of pH and SOC have been reported to influenced different fractions of soil Mn. Res-Mn was the most dominant fraction contributing towards Total-Mn followed by Cryst Fe-Mn, whereas, WSEX-Mn was the minimum.

4.7.8 Total fraction (Total) of Zn, Cu, Fe and Mn

Total zinc (Total-Zn)

A close examination of data in Table 4.29 revealed that the content for total-Zn varied from 92.87 to 100.71 mg kg^{-1} and from 104.3 to 115.3 mg kg^{-1} within all the treatments combinations during 2015 and 2017, respectively. It was observed that tillage and rice straw management practices irrespective of the rice establishment methods, significantly influenced the total-Zn content during 2017 but these treatments did not showed significant effect within the treatments in 2015. Rice establishment systems also vary significantly during 2017 but not in 2015. It was observed that among the rice establishment methods, the content for OM-Zn was found higher in DSR-RT (99.75 mg kg^{-1}) followed by DSR-CT (98.30 mg kg^{-1}) followed by DSR-ZT (95.80 mg kg^{-1}) as compared to PTR (93.87 mg kg^{-1}) in 2015. Similarly, in 2017, total-Zn was significantly higher for DSR-RT (114.6 mg kg^{-1}) as compared to DSR-CT (107.6 mg kg^{-1}) as compared to PTR (104.3 mg kg^{-1}) However, among the tillage and rice straw management practices, the total-Zn was highest for ZTW+R (100.71 mg kg^{-1}) followed by CTW-R (97.22 mg kg^{-1}) and then in ZTW-R (92.87 mg kg^{-1}), respectively in 2015. Likewise, in 2017, total-Zn was significantly higher in ZTW+R (115.3 mg kg^{-1}) followed by CTW-R (108.5 mg kg^{-1}) and then in ZTW-R (104.5 mg kg^{-1}). The increase in ZTW+R treatments might be due to the higher soil organic carbon content in these treatments. The interaction between tillage and rice straw management practices as well as the rice establishment methods showed non-significant differences.

Total copper (Total-Cu)

The data in Table 4.29 regarding the effect tillage and rice straw management practices as well as the rice establishment methods revealed thattotal-Cu content ranged between 14.11 to 15.96 mg kg^{-1} and from 20.1 to 21.5 mg kg^{-1} in the surface soil samples (0-7.5 cm) during the year 2015 and 2017, respectively. Amongst the rice establishment methods, total-Cu content was found to have non-significant effect between the treatments during both the years. It was revealed that total-Cu content was varied in 2015 as 14.11 mg kg^{-1}, 15.00 mg kg^{-1}, 15.28 mg kg^{-1} and 15.79 mg kg^{-1} in DSR-ZT, DSR-CT, DSR-RT and PTR, respectively. In the next year, OM-Cu content was ranged as 20.1 mg kg^{-1}, 21.3 mg kg^{-1}, 21.0 mg kg^{-1} and 21.2 mg kg^{-1} in DSR-ZT, DSR-CT, DSR-RT and PTR, respectively. Tillage and rice straw management practices irrespective of the rice establishment methods also indicated non-significant effect on total-Cu content in soil in 2015 as well as 2017. Even then the content was found higher in case of ZTW+R (15.96 and 21.5 mg kg^{-1}) and CTW-R (14.84 and 20.8 mg kg^{-1}) as compared to ZTW-R (14.34 and 20.3 mg kg^{-1}) during 2015 and 2017. High total-Cu content in FYM treated plots might be due to build-up of organic matter under continuous manuring possibly results in higher total micronutrients content in soil (Chaudhary and Narwal 2005).

Total iron (Total-Fe)

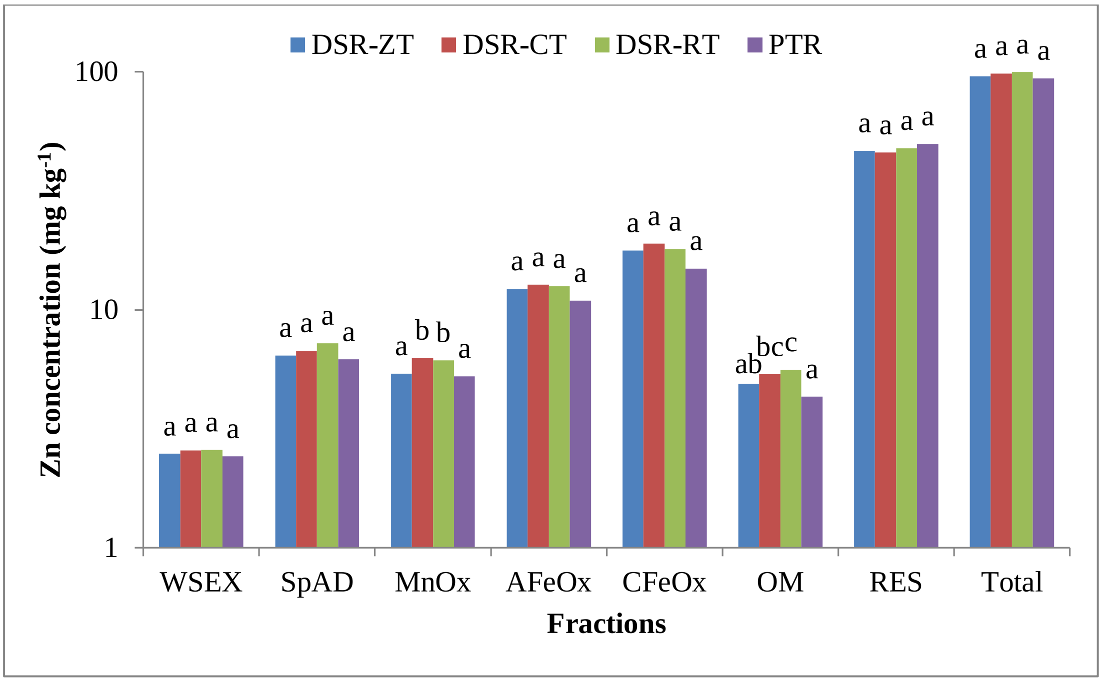
An examination of the data in Table 4.29 indicated that the that total-Fe content varied from 1.36 to 1.45 percentand from 1.51 to 1.72 percent in the surface soil samples (0-7.5 cm) during the year 2015 and 2017, respectively, and it was observed that total-Fe was higher under ZTW+R or ZT wheat sown with happy seeder treatment (1.45 and 1.71 percent) as compared to the ZTW-R (1.36 and 1.55 percent) and CTW (1.41 and 1.63 percent) within tillage and rice straw management practices. Although, the tillage and rice straw management practices indicated non-significant effect on the total-Fe content but still the content was higher under ZTW+R treatment compared to the ZTW-R and CTW-R treatments during both the years. Rice establishment methods irrespective of the tillage and rice straw management practices indicated that the total-Fe in soil during both years i.e. 2015 and 2017 found higher under PTR (i.e. 1.43 and 1.72 percent) followed by DSR-RT (1.41 and 1.67 percent), DSR-CT (1.40 and 1.51 percent) and DSR-ZT (1.37 and 1.61 percent) in 2015 and 2017, respectively. The interaction between tillage and rice straw management practices as well as the rice establishment methods was also found non-significant.

Table 4.29: Effect of rice establishment methods, tillage and straw management practices on total fraction of micronutrients (mg kg^{-1}) in soil

Treatment	Zn	Cu	Fe (%)	Mn
Rice establishment methods (2015)				
DSR-ZT	95.80	14.11	1.37	138.8
DSR-CT	98.30	15.00	1.40	146.5
DSR-RT	99.75	15.28	1.41	149.9
PTR	93.87	15.79	1.43	150.6
LSD (0.05)	NS	NS	NS	5.79
Tillage and rice straw management practices				
CTW-R	97.22	14.84	1.41	144.6
ZTW-R	92.87	14.34	1.36	141.6
ZTW+R	100.71	15.96	1.45	153.1
LSD (0.05)	NS	NS	NS	4.79
Interaction LSD (0.05)	NS	NS	NS	NS
Rice establishment methods (2017)				
DSR-ZT	111.1	20.1	1.61	168.9
DSR-CT	107.6	21.3	1.51	170.7
DSR-RT	114.6	21.0	1.67	172.2
PTR	104.3	21.2	1.72	157.3
LSD (0.05)	6.78	NS	NS	5.78
Tillage and rice straw management practices in wheat				
CTW-R	108.5	20.8	1.63	161.8
ZTW-R	104.5	20.3	1.55	161.7
ZTW+R	115.3	21.5	1.71	178.3
LSD (0.05)	3.36	NS	0.09	4.45
Interaction				
LSD (0.05)	NS	NS	NS	NS

Total manganese (Total-Mn)

A close examination of data indicated that rice establishment methods significantly affected the total-Mn content during 2015 as well as 2017. The content for total-Mn varied from 138.8 to 153.1 mg kg^{-1} and from 157.3 to 178.3 mg kg^{-1} during the year 2015 and 2017, respectively. Among the rice establishment methods, the content for total-Mn was found higher in PTR (150.6 and 157.3 mg kg^{-1}) as compared to direct seeded rice treatments viz. DSR-RT (149.9 and 172.2 mg kg^{-1}), DSR-CT (146.5 and 170.7 mg kg^{-1}) and DSR-ZT (138.8 and 168.9 mg kg^{-1}) during both the years of experimentation i.e. 2015 and 2017. However, among the tillage and rice straw management practices irrespective of the rice establishment methods, the total-Mn indicated higher content under ZTW+R (153.1 and 178.3 mg kg^{-1}) as compared to ZTW-R (141.6 and 161.7 mg kg^{-1}) and CTW-R (144.6 and 161.8 mg kg^{-1}) during both the years. The interaction between tillage and rice straw management practices as well as the rice establishment methods showed non-significant differences. Total-Mn content of the soil depends mainly upon nature of parent material, their weathering, movement and assimilations of Mn in soil.



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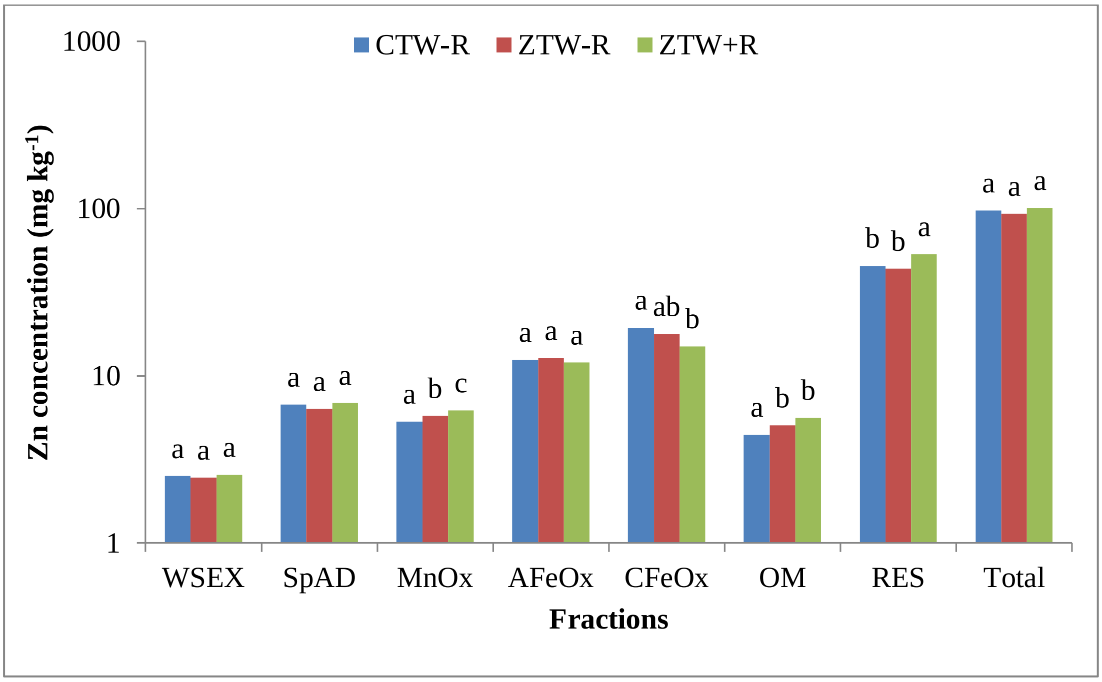
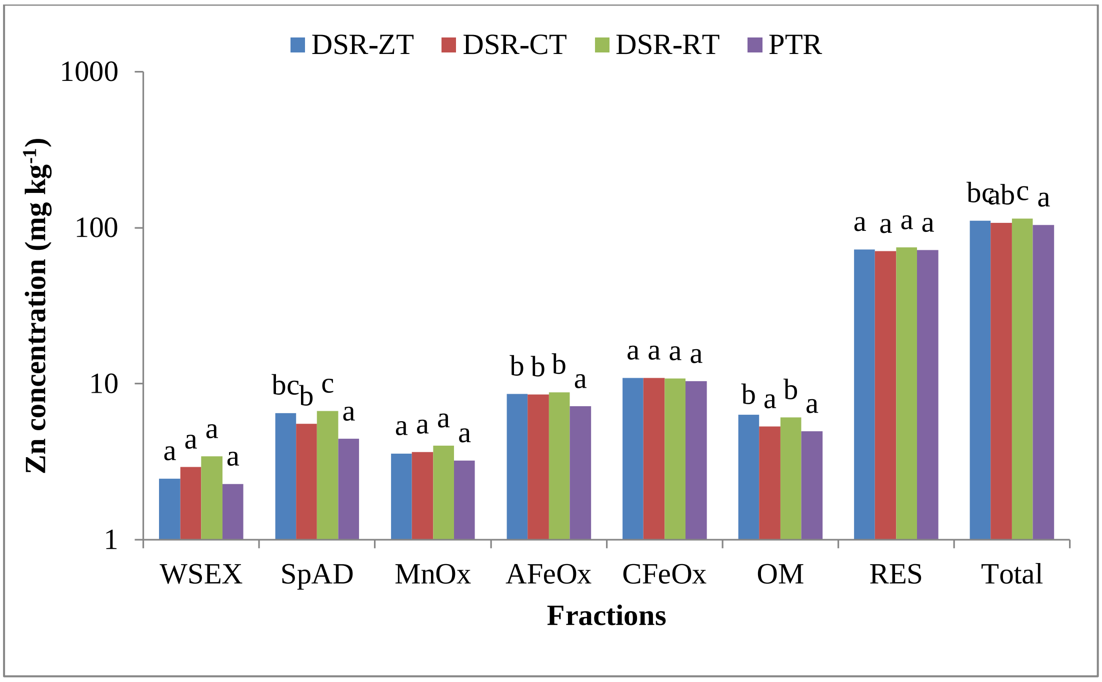


(b)

Fig. 4.1: Effect of rice establishment methods, tillage and rice straw management practices on different fractions of Zn during 2015 (a) main plots and (b) sub plots



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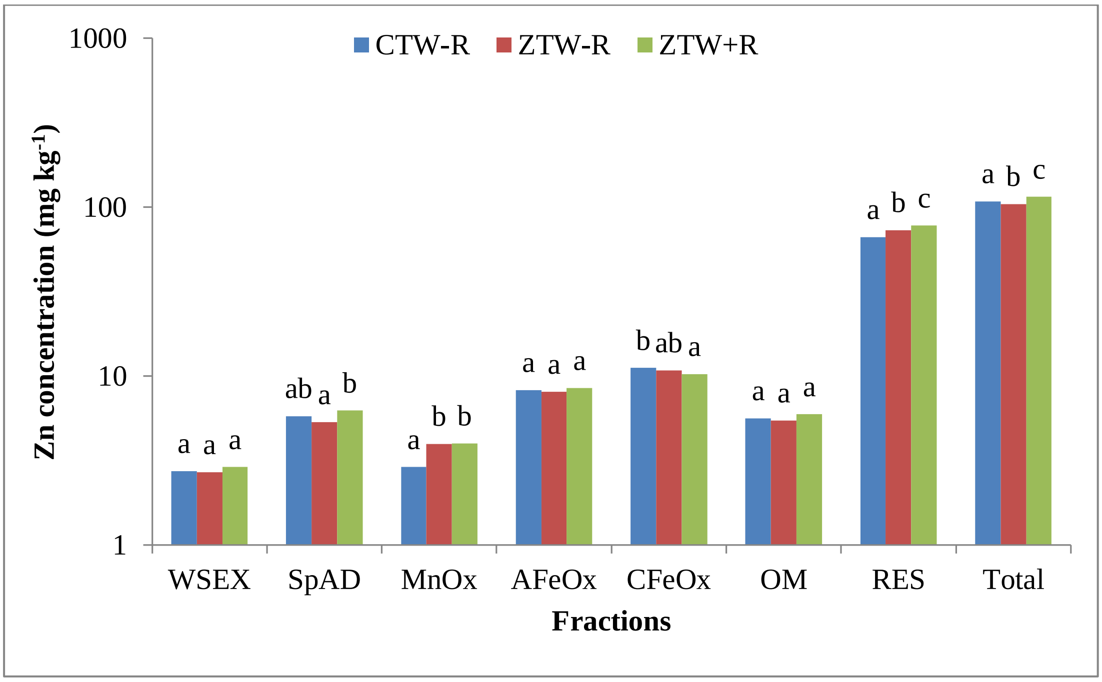
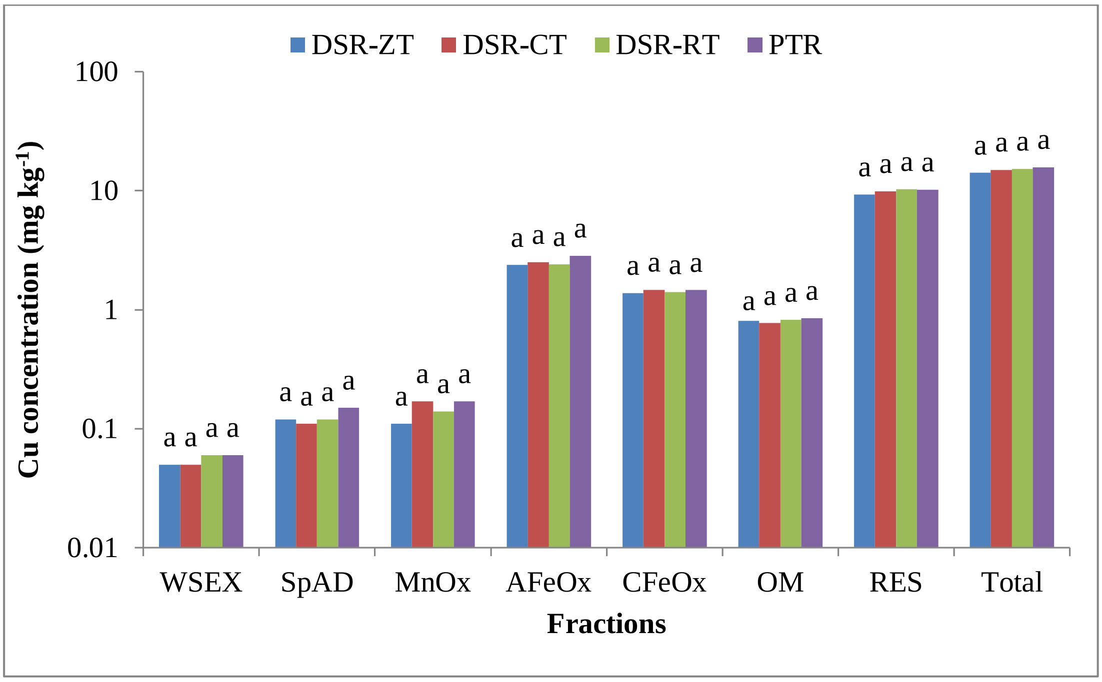
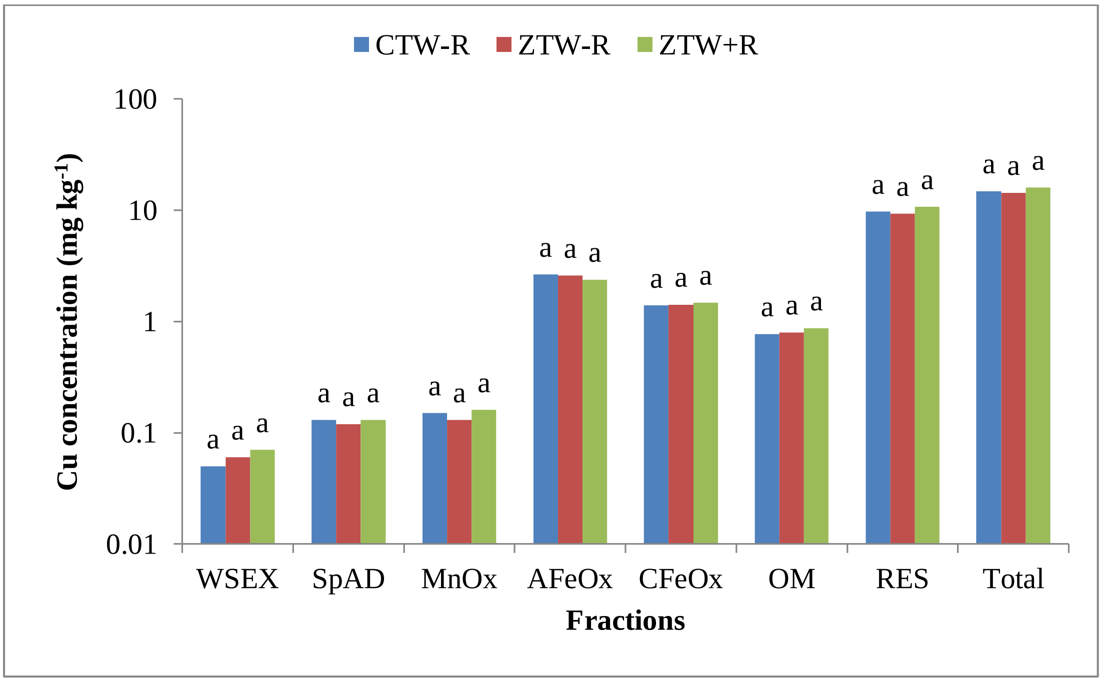


(b)

Fig. 4.2: Effect of rice establishment methods, tillage and rice straw management practices on different fractions of Zn during 2017 (a) main plots and (b) sub plots

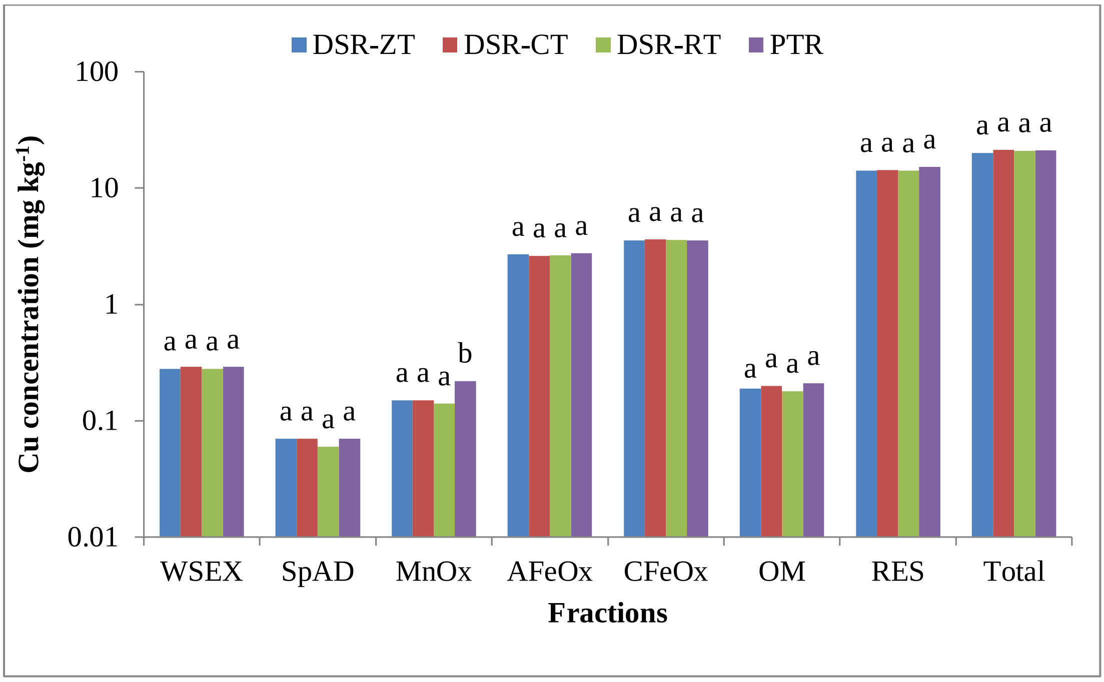


(a)

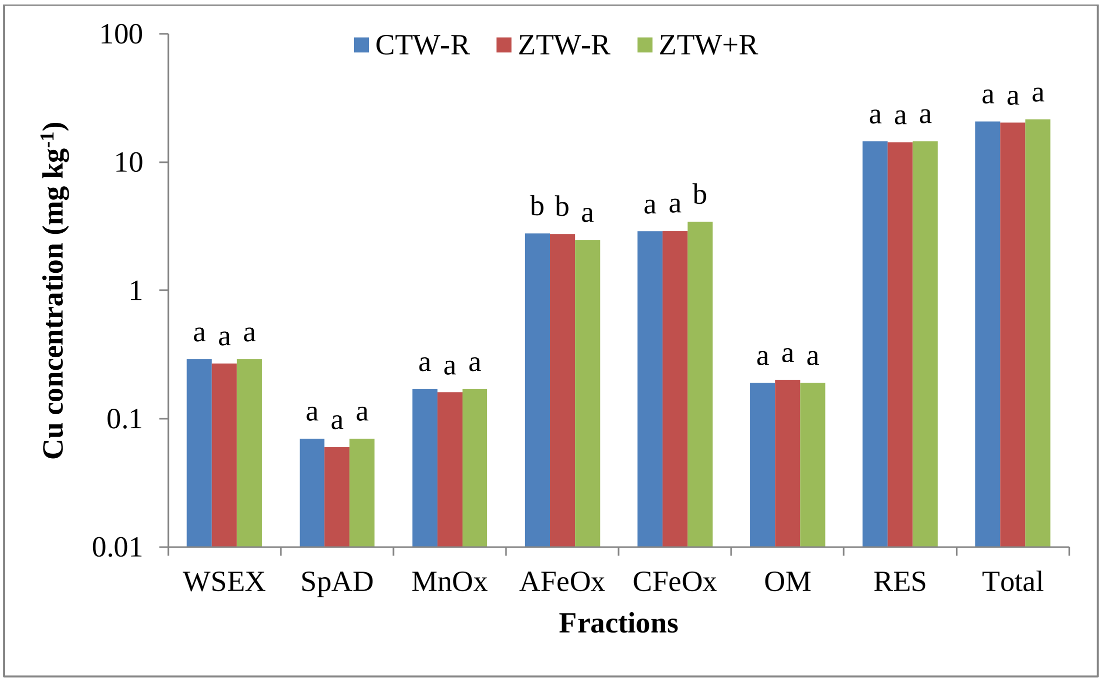


(b)

Fig. 4.3: Effect of rice establishment methods, tillage and rice straw management practices on different fractions of Cu during 2015 (a) main plots and (b) sub plots

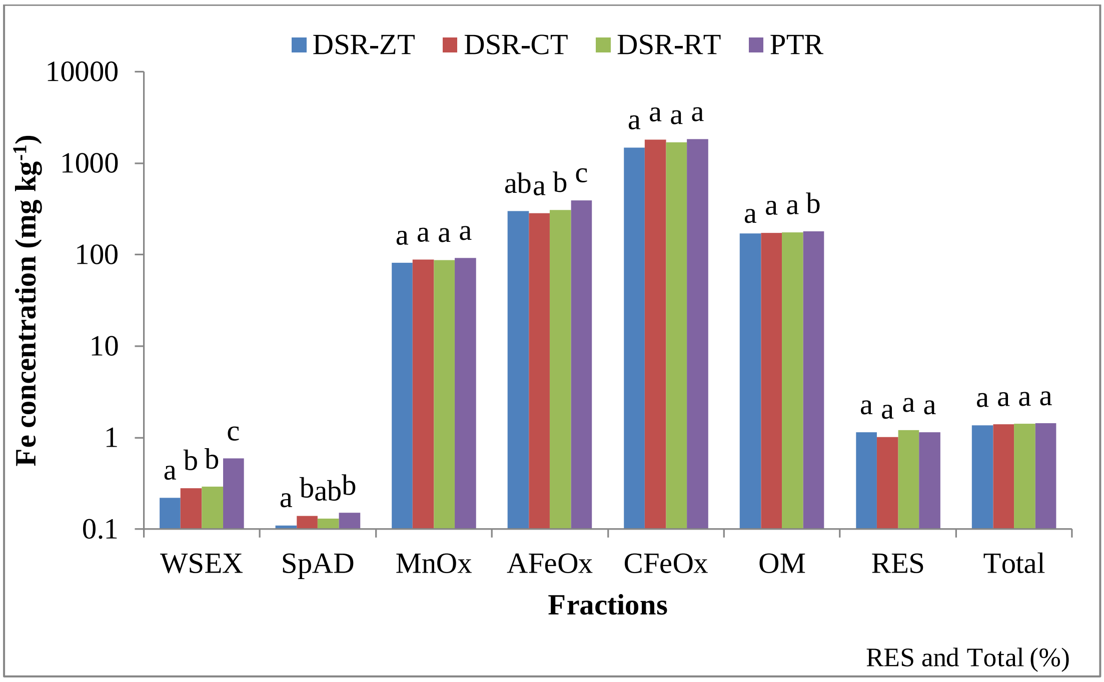


(a)

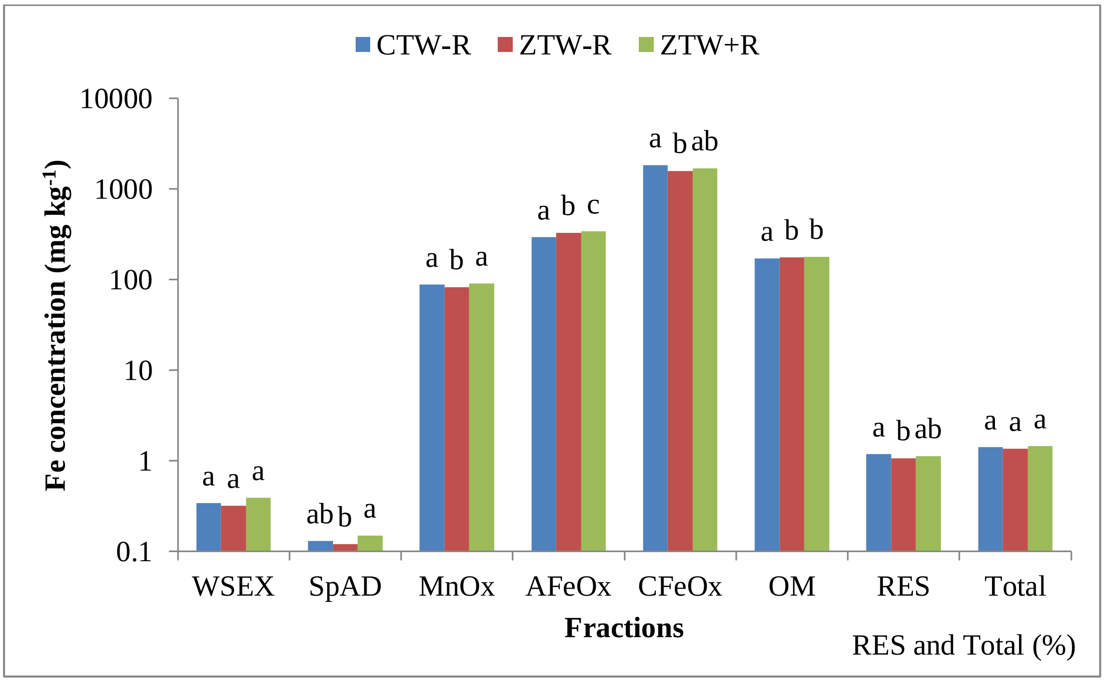


(b)

Fig. 4.4: Effect of rice establishment methods, tillage and rice straw management practices on different fractions of Cu during 2017 (a) main plots and (b) sub plots

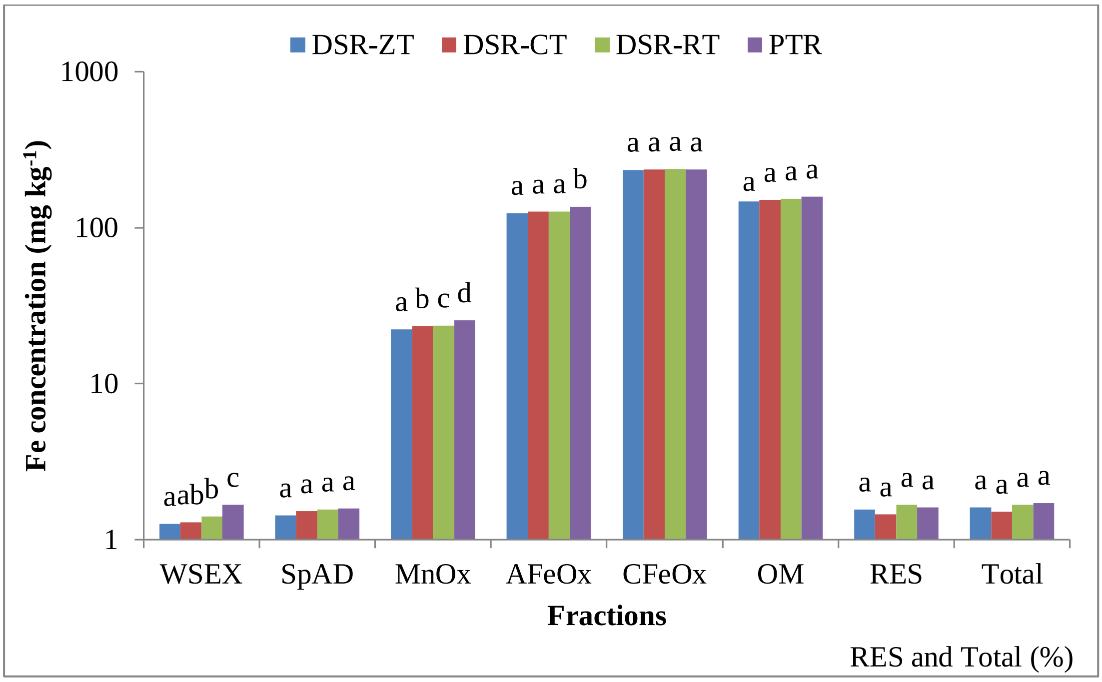


(a)

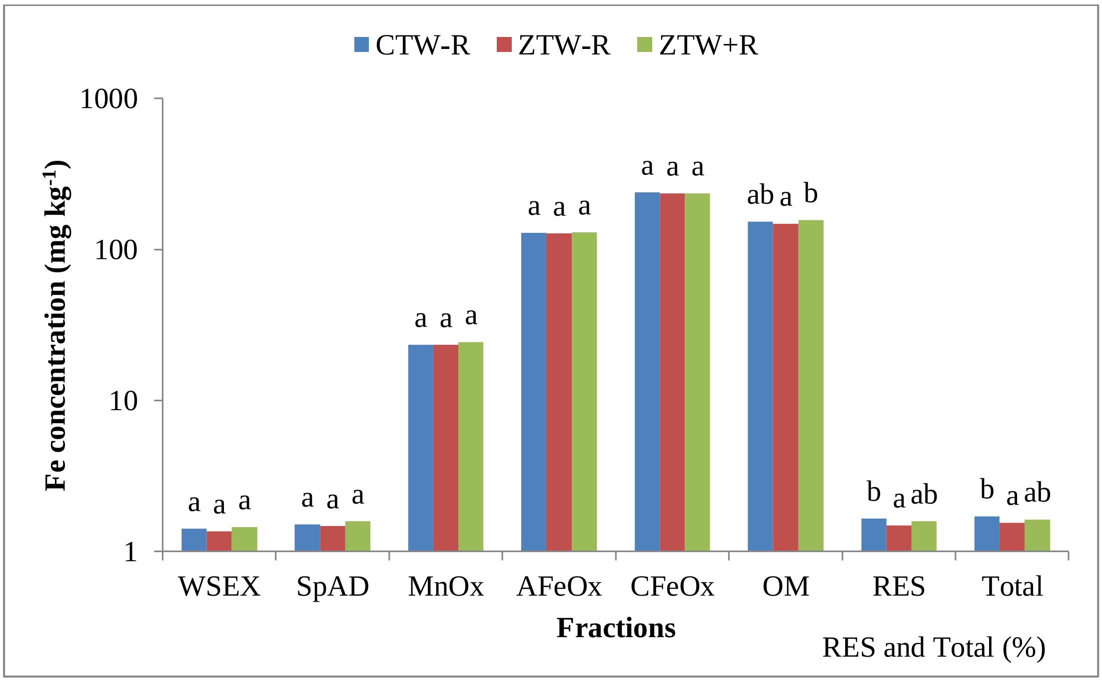


(b)

Fig. 4.5: Effect of rice establishment methods, tillage and rice straw management practices on different fractions of Fe during 2015 (a) main plots and (b) sub plots

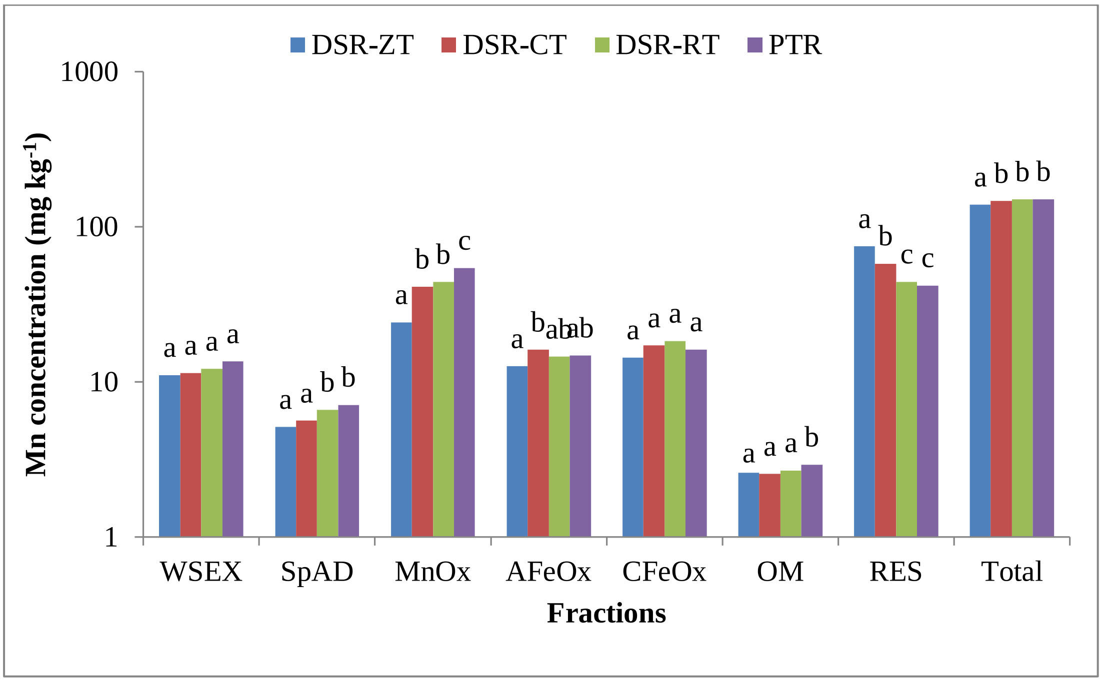


(a)

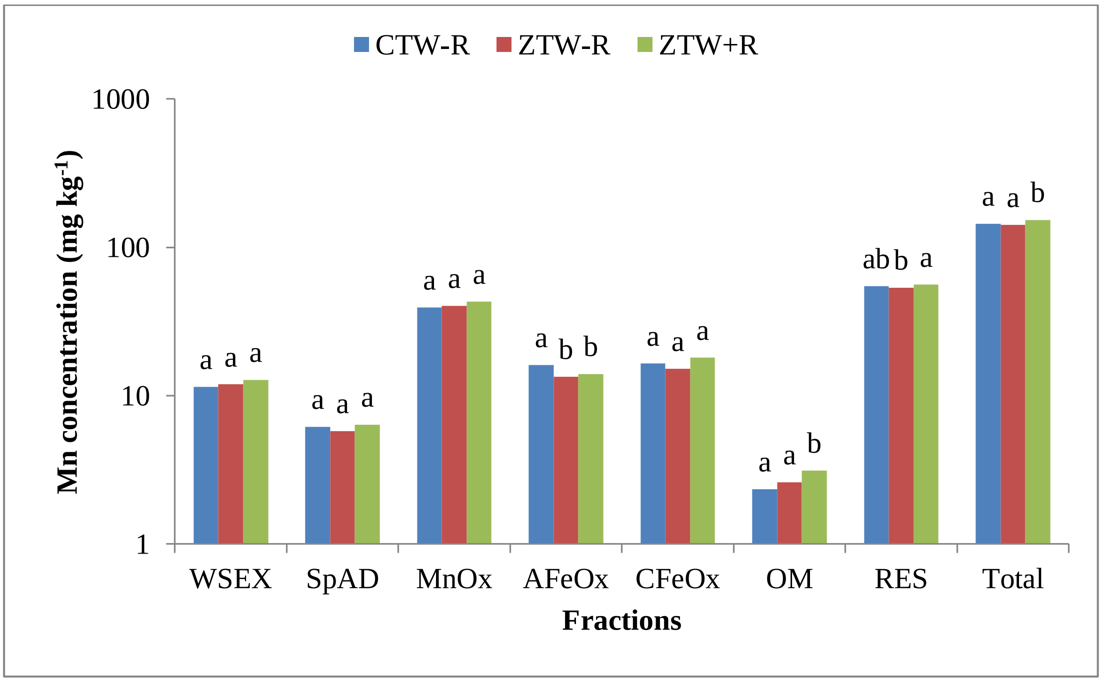


(b)

Fig. 4.6: Effect of rice establishment methods, tillage and rice straw management practices on different fractions of Fe during 2017 (a) main plots and (b) sub plots

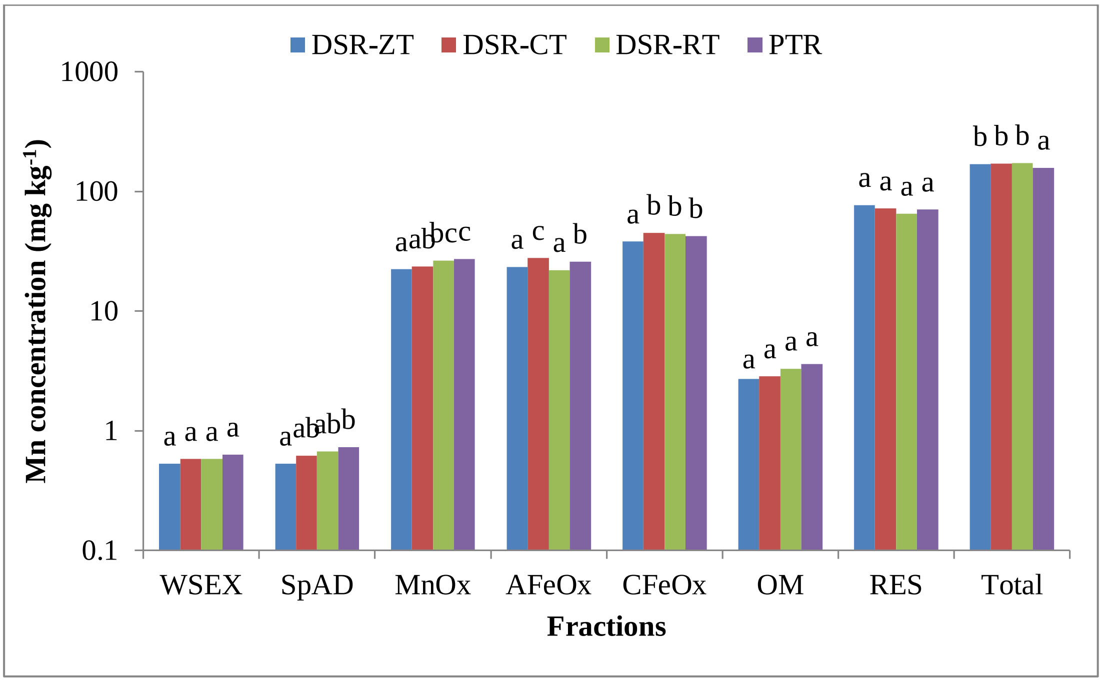


(a)

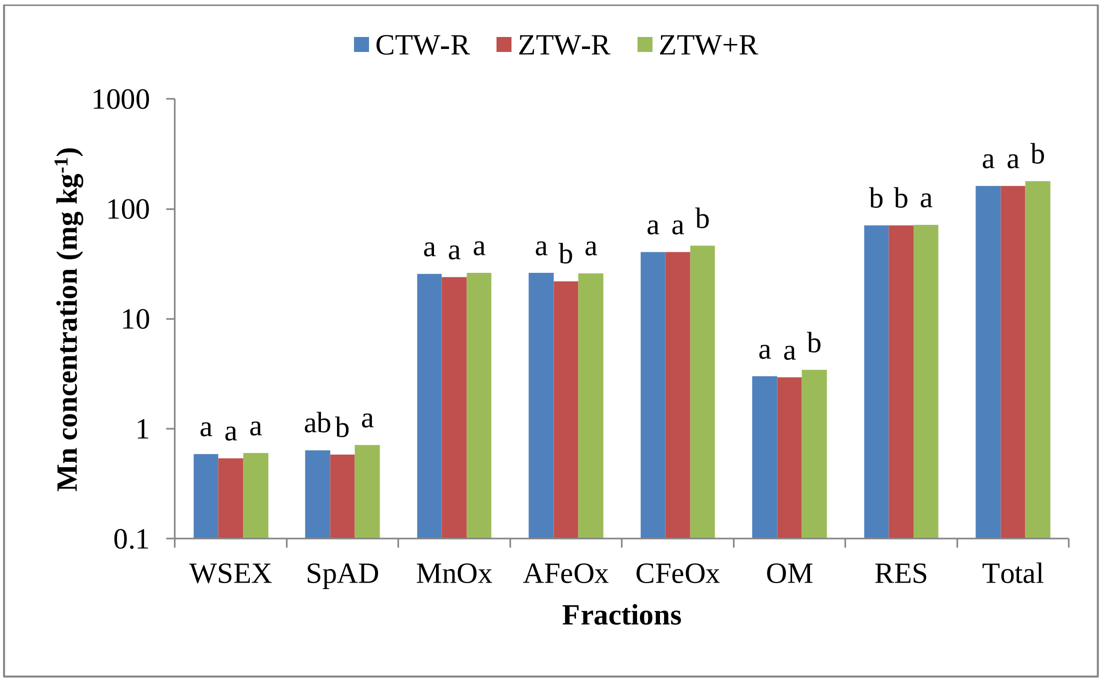


(b)

Fig. 4.7: Effect of rice establishment methods, tillage and rice straw management practices on different fractions of Mn during 2015 (a) main plots and (b) sub plots



(a)



(b)

Fig. 4.8: Effect of rice establishment methods, tillage and rice straw management practices on different fractions of Mn during 2017 (a) main plots and (b) sub plots

Experiment No. 2: Effect of tillage, green manuring andwheat straw management practices on micronutrient uptake and their transformation in rice-wheat system

4.8 Effect of tillage, green manuring and wheat straw management practices on yield parameters of wheat and rice

4.8.1 Grain and straw yield of wheat

4.8.2 Yield attributes of wheat

4.8.3 Grain and straw yield of rice

4.8.4 Yield attributes of rice

4.9 Effect of tillage, green manuring and wheat straw management practices on concentration of micronutrients at maximum tillering of wheat and rice

4.9.1 Micronutrients (Zn, Cu, Fe and Mn) concentration at maximum tillering of wheat

4.9.2 Micronutrients (Zn, Cu, Fe and Mn) concentration at maximum tillering of rice

4.10 Effect of tillage, green manuring and wheat straw management practices on micronutrients concentration in wheat and rice

4.10.1 Micronutrients (Zn, Cu, Fe and Mn) concentration in wheat grains

4.10.2 Micronutrients (Zn, Cu, Fe and Mn) concentration in wheat straw

4.10.3 Micronutrients (Zn, Cu, Fe and Mn) concentration in rice grains

4.10.4 Micronutrients (Zn, Cu, Fe and Mn) concentration in rice straw

4.11 Effect of tillage, green manuring and wheat straw management practices on micronutrients uptake in wheat and rice

4.11.1 Micronutrients (Zn, Cu, Fe and Mn) uptake in wheat grains

4.11.2 Micronutrients (Zn, Cu, Fe and Mn) uptake in wheat straw

4.11.3 Micronutrients (Zn, Cu, Fe and Mn) uptake in rice grains

4.11.4 Micronutrients (Zn, Cu, Fe and Mn) uptake in rice straw

4.12 Effect of tillage, green manuring and wheat straw management practices on soil chemical properties in wheat and rice experimental field

4.12.1 Distribution of soil pH in profile

4.12.2 Distribution of electrical conductivity in profile

4.12.3 Distribution of soil organic carbon in profile

4.13 Effect of tillage, green manuring and wheat straw management practices on soil DTPA-extractable micronutrients (Zn, Cu, Fe and Mn)

4.13.1 Distribution of DTPA-extractable Zn in profile

4.13.2 Distribution of DTPA-extractable Cu in profile

4.13.3 Distribution of DTPA-extractable Fe in profile

4.13.4 Distribution of DTPA-extractable Mn in profile

4.14 Effect of tillage, green manuring and wheat straw management practices on chemical fractions of micronutrients (Zn, Cu, Fe and Mn) in surface soil

4.14.1 Water soluble plus exchangeable fraction (WSEX)

4.14.2 Specifically adsorbed fraction (SpAd)

4.14.3 Mn-oxide bound fraction (MnOx)

4.14.4 Amorphous Fe-oxide bound fraction (AFeOx)

4.14.5 Crystalline Fe-oxide bound fraction (CFeOx)

4.14.6 Organically bound fraction (OM)

4.14.7 Residual fraction (RES)

4.14.8 Total fraction

4.8 Effect of tillage, green manuring and wheat straw management practices on yield parameters of wheat and rice

4.8.1 Grain and straw yield of wheat

A close examination of the data in Table 4.30 expressed that wheat straw and green manure practice in rice, irrespective of tillage and rice straw management practices in wheat significantly affected the grain yield of the subsequent wheat. Similarly, grain yield of wheat was significantly affected by tillage and rice straw management practices in wheat. Wheat grain yield under PTR_{W25}+GM was 14.7 percent higher than $PTR_{W25}$and in PTR_{W0}+GM; grain yield was 14 percent higher than PTR_{W0}, respectively. Yadvinder-Singh *et al* (2005) observed higher wheat grain yield in plots where wheat residues along with green manure (*Sesbania cannabina* L.) was incorporated in the preceding rice crop as compared with removal or burning of residue. Jat *et al* (2015) reported significantly higher (18.3%) grain yield of maize mulching with *Sesbania rostrata* than without mulching in a maize-wheat cropping system. Lower lignin content (8.7 %), higher decomposition and mobilization of the nutrients of *Sesbania* had positive effect on maize yield. Amongst the different tillage and rice straw management practices in wheat, wheat yield was found significantly higher in ZTW_{R100} as compared to the CTW_{R0} and ZTW_{R0}. In ZTW_{R100}, wheat grain yield was 7.69 and 13.7 percent higher than CTW_{R0} and ZTW_{R0} treatments, respectively. Sidhu *et al* (2007) observed that grain yield of wheat sown with happy seeder (HS) was comparable with or higher than conventional tilled wheat after burning or removal of rice straw. The increase of grain yield of wheat sown with HS is possibly due to decrease in soil evaporation which leads to the greater availability of water to the wheat crop (Singh *et al* 2011). Usman *et al* (2104) reported significant increase of grain yield of wheat in a rice-wheat system under straw retained or incorporated. Hariram *et al* (2013) reported that grain yield of zero tilled wheat was significantly higher under rice straw mulch, which may be ascribed to better hydrothermal regime and root growth, which increased nutrient uptake and crop growth.The interaction between the wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was not significant.

Salahin *et al* (2017) reported significant increase in grain yield of wheat under minimum tillage followed by deep tillage and conventional tillage after 3 years of adoption of minimum tillage in a rice-wheat-mungbean cropping cycle. Choudhury *et al* (2007) reported that wheat yield in a rice-wheat system was 12-17 percent lower under raised bed system as compared with flat and conventional tillage system. Talukder *et al* (2008) recorded increase in grain yield of each crop in a rice-wheat-maize system in a north-west Bangladesh with 50-100% straw retention on permanent bed than conventional tillage flat-bed without straw retention. Better utilization of soil moisture, improvement in water use efficiency, higher nutrient uptake and lesser degree of variation in soil temperature could be credited to higher grain yield under ZTW_{R0} (Malhi *et al* 2006). Martinez *et al* (2017) recorded significantly higher aerial biomass and grain yield of wheat under no tillage than conventional tillage in a semi-humid climate after 4 years field experimentation in Argentina. Similar results of greater wheat yield under no tillage than conventional tillage were reported by Govaerts *et al* (2006) in a long term trial in the semi-arid region of Mexico. Ruisi *et al* (2016) reported that biomass and grain yield of durum wheat under wheat-wheat (WW) system was substantially lower than wheat-faba bean (WF) and wheat-berseem clover (WB) systems. Under these two systems (WF and WB), grain yield of wheat was significantly higher under no tillage than conventional tillage, respectively.

Tillage and rice straw management practices in wheat significantly affected the straw yield of wheat (Table 4.30). Wheat straw and green manure practices in rice irrespective of tillage and rice straw management practices in wheat produce significant effect on straw yield of wheat in 2016-17 but showed non-significant results in 2015-16. Amongst the tillage and rice straw management practices in wheat, straw yield was higher in plots where green manure was incorporated i.e. PTR_{W25}+GM and PTR_{W0}+GMas compared to the treatments where no green manure was incorporated i.e. PTR_{W25} and $PTR_{W0.}$during both the years. The straw yield of the treatment PTR_{W25}+GM (7.13 t ha^{-1}) was significantly higher as compared to the PTR_{W25} (6.90 t ha^{-1}) and PTR_{W0} (6.83 t ha^{-1}) in year 2017. Amongst the tillage and rice straw management practices in wheat irrespective of the wheat straw and green manure practices in rice observed significantly higher straw yield in ZTW_{R100} i.e. 7.09 and 7.22 t ha^{-1} as compared to the CTW_{R0} i.e 6.79 and 6.94 t ha^{-1} and ZTW_{R0} i.e 6.69 and 6.83 t ha^{-1} during both the years of experimentation i.e. 2015-16 and 2016-17. The interaction between the wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was not significant.

Salahin *et al* (2017) observed that the straw yield of wheat was significantly higher under deep tillage and conventional tillage systems as compared to the minimum tillage in the first year of adoption of the minimum tillage practices. They also observed that in third cropping cycle, rice straw yield was significantly higher (5.85 t ha^{-1}) in treatments where crop residues were retained as compared with treatments without residue retention. Singh *et al* (2013) revealed that straw yield of wheat sown with HS was significantly higher than conventional tillage without residue retention. Bakht *et al* (2009) recorded 1.31 and 1.39 time increase of wheat grain and straw yield with the incorporation of crop residues of the previous crop in wheat maize/mungbean cropping system. The wheat crop responded more positively to the preceding legume crop (*Vigna radiata* L.) in terms of better grain yield by 2.09 times and straw yield by 2.16 times more than the preceding maize crop. It is an important organic source for retaining and improving soil fertility (Wang *et al* 2012). Residue retention/incorporation into soil is an essential management practice to handle crop residue (Jiang *et al* 2011).

Table 4.30: Effect of tillage, green manuring and wheat straw management practices on wheat yield

Treatment	Grain yield (t ha^{-1})		Straw yield (t ha^{-1})		Harvest index (%)		1000 grain weight (gram)	
	2015-16	**2016-17**	**2015-16**	**2016-17**	**2015-16**	**2016-17**	**2015-16**	**2016-17**
Wheat straw and green manure practices in rice								
PTR_{W0}	5.03	5.30	6.71	6.83	42.9	43.7	32.1	32.7
PTR_{W25}	5.30	5.81	6.79	6.90	45.0	45.6	33.2	33.6
PTR_{W0}+GM	5.85	6.06	6.95	7.11	45.7	46.0	33.9	34.4
PTR_{W25}+GM	6.21	6.45	6.97	7.13	47.1	47.5	34.8	35.2
LSD (0.05)	0.13	0.26	NS	0.22	NS	NS	NS	1.45
Tillage and rice straw management practices in wheat								
CTW_{R0}	5.64	5.85	6.79	6.94	45.3	45.7	34.1	34.5
ZTW_{R0}	5.27	5.53	6.69	6.83	43.8	44.8	31.4	31.9
ZTW_{R100}	6.11	6.33	7.09	7.22	46.3	46.7	35.0	35.6
LSD (0.05)	0.16	0.16	0.26	0.18	NS	NS	NS	1.35
Interaction								
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

The harvest index is the ratio of economic yield (grain yield) to the biological yield (grain yield + straw yield), which represent better productivity of crop. Wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat did not significantly affected the harvest index during both the years of experimentation. However, the interaction between wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was also found non-significant. In tillage and rice straw management practices in wheat, harvest index was found higher under ZTW_{R100} as compared to the CTW_{R0} and ZTW_{R0}. Among the wheat straw and green manure practices in rice, harvest index was found higher in PTR_{W25}+GM (47.1 and 47.5 percent in 2015-16 and 2016-17, respectively) as compared to the other treatments viz. PTR_{W25} and PTR_{W0}, where no green manure was incorporated in the soil.

Thousand grain weight is a function of production factors that give indication of the grain development and filling pattern as influenced by crop management practices. Wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat failed to cause significant effect on thousand grain weight in 2015-16. But significantly higher thousand grain weight was found in PTR_{W25}+GM as compared to PTR_{W25} and PTR_{W0} (where no green manure was incorporated in the soil) amongst the wheat straw and GM practices in rice in 2016-17. Similarly, among the tillage and rice straw management practices in wheat, thousand grain weight was found significantly higher in $ZTWR_{100}$ and CTW_{R0} as compared to the $ZTW_{R0.}$ The interaction between wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was found non-significant. He *et al* (2009) observed higher thousand grain weight of wheat under ZT with maize residue as compared to the ZT without residues and conventional tillage. Similar results were forwarded by Usman *et al* (2014), they observed that thousand grain weight of wheat under rice-wheat system was higher under ZT with rice residues retention than other tillage methods with removal or burning of rice residues. Ruisi *et al* (2016) reported significant increase in thousand grain weight of wheat under no tillage than conventional tillage under wheat-faba bean and wheat-berseem clover system. Seddaiu *et al* (2016) observed that after 20 years tillage experiment, thousand grain weight of wheat was significantly higher under no tillage than conventional tillage. Monsefi *et al* (2014) recorded highest pod/ plant of soybean under ZT with wheat residue retention than ZT and CT without retention of wheat residue in a soybean-wheat cropping system.Zero tillage (ZT) is a possible alternative to CT which simultaneously cuts cultivation costs and advances wheat sowing about 2-3 weaks by drilling directly into the previous crop residues (Sidhu *et al* 2007). Research revealed that ZT with residue cover had higher aggregate stability, higher aggregate size and total organic carbon in soil aggregates than CT (Madari *et al* 2005). ZT in the long run may sustainably produce more food from less land through more efficient use of natural resources and with least impact on the environment (Lal 2009).

4.8.2 Yield attributes of wheat

The data in Table 4.31 revealed that plant height was significantly higher under the treatments where green manure was incorporated in soil i.e. PTR_{W25}+GM and PTR_{W0}+GM as compared to the treatments where no green manuring was done i.e. PTR_{W25} and $PTR_{W0.}$It was observed from the data that plant height was highestin PTR_{W25}+GM (94.7 and 96.8 cm in 2015-16 and 2016-17, respectively) as compared to other treatments. Amongst the tillage and rice straw management practices, treatments showed non-significant effect. Under these treatments, plant height was higher in ZTW_{R100} as compared to ZTW_{R0} and CTW_{R0}.

Table 4.31: Effect of tillage, green manuring and wheat straw management practices on yield attributes of wheat

Treatment	Plant height (cm)		Effective tillers (m^{-2})		Panicle length (cm)	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
Wheat straw and green manure practices in rice						
PTR_{W0}	87.1	90.3	337.1	345.1	11.9	12.4
PTR_{W25}	89.9	92.2	342.1	345.8	12.0	12.6
PTR_{W0}+GM	93.0	95.7	359.2	363.9	12.2	12.5
PTR_{W25}+GM	94.7	96.8	369.0	373.5	12.3	12.8
LSD (0.05)	3.87	3.72	14.8	NS	NS	NS
Tillage and rice straw management practices in wheat						
CTW_{R0}	91.2	93.7	351.3	357.1	12.1	12.5
ZTW_{R0}	89.9	92.9	347.6	352.5	11.9	12.5
ZTW_{R100}	92.4	94.6	356.6	361.6	12.2	12.7
LSD (0.05)	NS	NS	5.95	5.46	NS	0.18
Interaction						
LSD (0.05)	NS	NS	NS	NS	NS	NS

The number of effective tillers m^{-2} and panicle length were found higher in PTR_{W25}+GM and PTR_{W0}+GM treatments as compared to PTR_{W25} and PTR_{W0}among the wheat straw and green manure practices in rice. Moreover, the number of effective tillers m^{-2} and panicle length was also found higher under ZTW_{R100} as compared to ZTW_{R0} and CTW_{R0}. The interaction between the wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was not significant.

4.8.3 Grain and straw yield of rice

Grain yield of rice was significantly affected by the wheat straw and green manure practices in rice during both the years. It was observed that grain yield was significantly higher in the treatments where green manure was incorporated in the soil (PTR_{W25}+GM and PTR_{W0}+GM) w.r.t. the treatments where no green manure was incorporated (PTR_{W25} and PTR_{W0}). It was indicated that grain yield in PTR_{W25}+GM treatment was 17 percent higher as compared to the PTR_{W25} treatment and 18.3 percent higher than PTR_{W0} in rice 2016 (Table 4.32). Similarly, grain yield in the next year i.e. in 2017 was 16.9 percent higher in PTR_{W25}+GM as compared to the PTR_{W25} treatment and 18.1 percent higher than $PTR_{W0.}$ However, the tillage and rice straw management practices in wheat irrespective of wheat straw and green manure practices in rice, significantly affected the rice grain yield in 2016 and 2017. It was observed that rice grain yield was significantly higher in $ZTWR_{100}$ (7.31 and 7.39 t ha^{-1}) as compared to the CTW_{R0} (6.94 and 7.00 t ha^{-1}) as well as ZTW_{R0} (6.40 and 6.49 t ha^{-1}) treatments during both the years (2016 and 2017). The interaction between the wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was not significant.

Sharma and Prasad (1999) reported that the effects of *S. aculeata* and *S. rostrata* green manuring were similar and increased rice yields over no summer crop by 0.6-1.0 t $ha^{-1}y^{-1}$ and the succeeding wheat yield by 0.2-0.3 t ha^{-1} y^{-1}, whereas mungbean residue incorporation significantly increased rice yield over fallow by 0.6-0.8 t $ha^{-1}y^{-1}$ and wheat yield by 0.5 t ha^{-1} y^{-1}. It is well documented that the incorporation of organic manure or crop straw into soil improves soil fertility and increases crop yield (Singh *et al* 2001). Grain yield of rice were significantly increased by 1.6 and 1.1 t ha^{-1}, through application of *Sesbania*, over no green manure control. Kumar and Goh (2000) examined that crop residues have positive effects on soil quality, soil nitrogen dynamics and recovery and crop yield. They concluded that crop residue is a significant factor for crop production through their effects on soil physical, chemical and biological properties as well as water and soil quality. Retention of crop residues has led to the increase in the C and N contents of soil and microbial activity which is clear indication of an improvement in soil health and yield (Pankhurst *et al* 2002, Nie *et al* 2007).

Table 4.32: Effect of tillage, green manuring and wheat straw management practices on rice yield

Treatment	Grain yield (t ha^{-1})		Straw yield (t ha^{-1})		Harvest index (%)		1000 grain weight (gram)	
	2016	2017	2016	2017	2016	2017	2016	2017
Wheat straw and green manure practices in rice								
PTR_{W0}	6.29	6.36	8.26	8.33	43.4	43.5	20.2	20.4
PTR_{W25}	6.39	6.45	8.39	8.47	43.4	43.3	22.7	23.3
PTR_{W0}+GM	7.14	7.24	9.49	9.63	43.1	43.0	23.9	24.3
PTR_{W25}+GM	7.70	7.77	9.71	9.73	44.3	44.4	24.5	25.1
LSD (0.05)	0.56	0.51	1.07	NS	NS	NS	2.97	2.69
Tillage and rice straw management practices in wheat								
CTW_{R0}	6.94	7.00	9.05	9.16	43.5	43.4	22.7	23.1
ZTW_{R0}	6.40	6.49	8.42	8.51	43.4	43.3	22.0	22.4
ZTW_{R100}	7.31	7.39	9.42	9.47	43.7	43.9	23.9	24.3
LSD (0.05)	0.63	0.59	NS	NS	NS	NS	NS	NS
Interaction								
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Wheat straw and green manure practices in rice significantly affected the straw yield of rice in 2016 but not in 2017. It was observed that straw yield was significantly higher in the treatment where green manure was incorporated in the soil (PTR_{W25}+GM and PTR_{W0}+GM) as compared to the treatments where no green manure was incorporated (PTR_{W25} and PTR_{W0}). It was indicated that straw yield in PTR_{W25}+GM treatment was 13.5 percent higher as compared to the PTR_{W25} treatment and 15.0 percent higher than PTR_{W0} in rice 2016. Similarly, straw yield in the next year i.e. in 2017 was also found higher in PTR_{W25}+GM and PTR_{W0}+GM as compared to the PTR_{W25} and $PTR_{W0.}$ However, in case of tillage and rice straw management practices in wheat irrespective of wheat straw and green manure practices in rice, non-significantly affected the rice straw yield in 2016 and 2017. It was observed that rice straw yield was higher in $ZTWR_{100}$ (9.42 and 9.47 t ha^{-1}) as compared to the CTW_{R0} (9.05 and 9.16 t ha^{-1}) as well as ZTW_{R0} (8.42 and 8.51 t ha^{-1}) treatments during both the years (2016 and 2017). The interaction between the wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was not significant.

Green manuring resulted in significant increase in straw yield, number of tillers, filled spikelets and 1000 grain weight (Prasad *et al* 2010). Organic manure plays an important role in improving soil permeability to air and water and water stable aggregates. Thus application of organic materials such as crop residues considerably improves soil physical properties and nutrient uptake resulting in greater growth, yield and yield components. (Singh *et al* 1994, Pandey *et al* 1999, Mondal and Chetri 1998) Long-term studies on rice have shown increased yield and yield components due to application of crop residue (Singh *et al* 1999). Combined application of crop residues and green manure could meet all the nitrogen requirement (150 kg fertilizer N ha^{-1}) of the high yielding varieties and yielded better than the application of inorganic fertilizer alone (Singh *et al* 1994). Thus application of organic materials have potential of not only improving crop yield, but also reducing dependence on fossil fuel based inorganic fertilizers, thereby reducing hazards caused by continuous and indiscriminate use of chemical fertilizers.

The harvest index was found higher in PTR_{W25}+GM as compared to the PTR_{W0}+GM, PTR_{W25} and PTR_{W0} treatments among the wheat straw and green manure practices in rice during both the years (Table 4.32). However, in case of the tillage and rice straw management practices in wheat irrespective of the wheat straw and green manure practices in rice, it was observed that harvest index was found higher in ZTW_{R100} (43.7 and 43.9 percent) followed by CTW_{R0} (43.5 and 43.4 percent) and then in ZTW_{R0} (43.4 and 43.3 percent) treatments during both the years of experimentation (2016 and 2017). The interaction between the wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was not significant.

A close examination of the data regarding the effect of the tillage and rice straw management practices in wheat as well as the wheat straw and green manure practices in rice on thousand grain weight, showed non-significant effect within the treatments. Thousand grain weight was significantly higher in PTR_{W25}+GM and PTR_{W0}+GM as compared to the PTR_{W0} treatment. Amongst the tillage and rice straw management practices in wheat irrespective wheat straw and green manure practices in rice, no significant difference among the treatments were found during both the years. But the thousand grain weight was found higher in $ZTWR_{100}$ (23.9 and 24.3 gram) followed by CTW_{R0} (22.7 and 23.1 gram) and then in ZTW_{R0} (22.0 and 22.4 gram) treatments during 2016 and 2017. The interaction between the wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was not significant. Sharma and Prasad (1999) reported that *Sesbania* green manuring increased the rice-straw yield significantly over fallow, but wheat straw yield only in the second year, whereas mungbean residue incorporation significantly increased straw yields of rice and wheat in both years. Mungbean without residue incorporation gave significantly higher straw yields of wheat than no summer crop in both years.

4.8.4 Yield attributes of rice

The data in Table4.33 showed that the plant height was significantly affected within the different treatments under wheat straw and green manure practices in rice. Plant height was found significantly higher under PTR_{W25}+GM (105.4 and 108.2 cm) as compared to PTR_{W0} (96.9 and 97.7 cm) and it was at par with PTR_{W0}+GM (104.3 and 106.3 cm) during both the years (2015 and 2017). The residual effect of tillage and rice straw management practices in wheat showed non-significant effect on plant height of rice. It was observed that the treatment where residue was retained as well as green manure was incorporated in soil before rice was the best treatment as compared to the other treatments.

Table 4.33: Effect of tillage, green manuring and wheat straw management practices on yield attributes of rice

Treatment	Plant height (cm)		Effective tillers (m^{-2})		Panicle length (cm)	
	2016	2017	2016	2017	2016	2017
Wheat straw and green manure practices in rice						
PTR_{W0}	96.9	97.7	339.1	348.5	21.5	21.1
PTR_{W25}	101.2	102.4	350.8	351.3	22.3	22.5
PTR_{W0}+GM	104.3	106.3	356.5	357.0	23.7	23.7
PTR_{W25}+GM	105.4	108.2	360.1	362.3	24.1	24.6
LSD (0.05)	4.63	2.69	10.2	6.22	0.81	0.51
Tillage and rice straw management practices in wheat						
CTW_{R0}	101.6	104.1	352.1	348.9	22.9	22.9
ZTW_{R0}	101.1	103.0	348.4	352.9	22.5	22.7
ZTW_{R100}	103.2	105.4	354.4	357.4	23.3	23.3
LSD (0.05)	NS	NS	NS	NS	NS	NS
Interaction						
LSD (0.05)	NS	NS	NS	NS	NS	NS

The number of effective tillers as well as panicle length (Table 4.33) wasalso found significantly higher under PTR_{W25}+GM as compared to PTR_{W25} and PTR_{W0} treatments among wheat straw and green manure practices in rice. All the yield attributing parameters were found significantly lower under the treatments where no residue was retained as well as no green manure was incorporated into the soil. However, tillage and rice straw management practices in wheat indicated no significant residual effect on different yield attributes of rice. The interaction between wheat straw and green manure practices in rice as well as tillage and rice straw management practices in wheat found non-significant.

4.10 Effect of tillage, green manuring and wheat straw management practices on concentration of micronutrients at maximum tillering of wheat and rice

4.10.1 Micronutrients (Zn, Cu, Fe and Mn) concentration at maximum tillering of wheat

Zinc

The data in Table 4.34 showed the effect of wheat straw and green manure practices in rice on concentration of Zn in wheat at maximum tillering stage. It was observed that the Zn concentration was found significantly higher in PTR_{W25}+GM (24.3 and 29.5 mg kg^{-1}) as compared to PTR_{W25} (20.2 and 24.1 mg kg^{-1}) and PTR_{W0} (19.5 and 20.9 mg kg^{-1}) during both the years of experimentation (2015-16 and 2016-17). Moreover, the Zn concentration was also found higher in PTR_{W0}+GM as compared to PTR_{W25} and $PTR_{W0.}$The tillage and rice straw management practices in wheat also showed significant effect among the different treatments. The Zn concentration was found significantly higher in ZTW_{R100} with respect to ZTW_{R0}. Even the Zn concentration was also higher in CTW_{R0} as compared to ZTW_{R0}. Zn concentration was found higher in the second year as compared to the first year experiment. The interaction was found non-significant among the different treatment combinations.

Copper

The concentration of Cu at maximum tillering stage of wheat did not show significant effect among the different treatments under tillage and rice straw management practices in wheat. The Cu concentration at maximum tillering stage was found higher in ZTW_{R100} with respect to ZTW_{R0} and $CTW_{R0.}$ In case of ZTW_{R100}, Cu concentration was (6.54 and 6.29 mg kg^{-1}) higher as compared to ZTW_{R0} (6.41 and 5.46 mg kg^{-1}) and CTW_{R0}(6.09 and 5.88 mg kg^{-1}) during 2015-16 and 2016-17. However, the incorporation of green manure before rice indicated residual effect on the concentration of Cu at maximum tillering stage of wheat. It was observed that Cu concentration was found higher under the treatments where green manure was incorporated into the soil before rice i.e. PTR_{W25}+GM and PTR_{W0}+GM as compared to the treatments where no green manure was incorporated into the soil i.e. PTR_{W25} and $PTR_{W0.}$

Table 4.34: Effect of tillage, green manuring and wheat straw management practices on micronutrients concentration (mg kg^{-1}) at maximum tillering of wheat

Treatment	Zn		Cu		Fe		Mn	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
Wheat straw and green manure practices in rice								
PTR_{W0}	19.5	20.9	5.91	5.61	220.9	231.2	12.1	12.7
PTR_{W25}	20.2	24.1	6.15	5.83	225.7	234.8	13.7	15.1
PTR_{W0}+GM	21.8	26.1	6.55	5.94	242.1	252.8	14.5	16.3
PTR_{W25}+GM	24.3	29.5	6.77	6.11	255.4	265.6	15.6	16.9
LSD (0.05)	2.25	1.98	NS	NS	NS	15.8	NS	2.91
Tillage and rice straw management practices in wheat								
CTW_{R0}	21.6	25.2	6.09	5.88	235.9	244.5	13.9	15.4
ZTW_{R0}	20.2	23.4	6.41	5.46	228.7	237.8	13.2	13.9
ZTW_{R100}	22.5	26.8	6.54	6.29	243.6	256.0	14.8	16.4
LSD (0.05)	1.26	2.33	NS	NS	NS	12.6	NS	NS
Interaction								
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Iron

The data showed that the Fe concentration at maximum tillering stage of wheat was significantly higher in ZTW_{R100} (256.0 mg kg^{-1}) as compared to ZTW_{R0} (237.8 mg kg^{-1}) in 2016-17 (Table 4.34). But no significant difference was found to observe between the treatments among tillage and rice straw management practices in 2015-16 sown wheat. Whereas, amongst the wheat straw and green manure practices in rice, the residual effect of incorporation of green manure was observed on concentration of Fe at maximum tillering stage. The concentration of Fe in wheat was found higher in green manure incorporated treatments as compared to the treatments where no green manure was incorporated.

Manganese

The Mn concentration in wheat ranged from 12.1 to 15.6 mg kg^{-1} and 12.7 to 16.9 mg kg^{-1} during both the years of experimentation i.e. 2015-16 and 2016-17. There was no significant effect on Mn concentration within the treatments among tillage and rice straw management practices in wheat was observed. However, wheat straw and green manure practices in rice irrespective of the tillage and rice straw management practices in wheat indicated significant effect within the treatments in 2016-17 only. The interaction was found non-significant among the different treatment combinations within tillage and rice straw management practices in wheat as well as wheat straw and green manure practices in rice.

4.10.2 Micronutrients (Zn, Cu, Fe and Mn) concentration at maximum tillering of rice

Zinc

A persual of the data (Table 4.35) indicated that the Zn concentration in rice at maximum tillering stage ranged from 54.2 to 64.9 mg kg^{-1} and 51.4 to 63.5 mg kg^{-1}during 2016 and 2017, respectively. Zn concentration among the wheat straw and green manure practices in rice was found significantly higher under PTR_{W25}+GM (63.5 mg kg^{-1}) as compared to the PTR_{W25} (54.1 mg kg^{-1}) and PTR_{W0} (51.4 mg kg^{-1}) in 2017. But no significant difference was observed within the treatments among wheat straw and green manure practices in ricein 2016. Tillage and rice straw management practices in wheat found to have residual effect on Zn concentration in rice at maximum tillering stage. Amongst these treatments, Zn concentration was significantly higher under ZTW_{R100} with respect to ZTW_{R0}. Even the Zn concentration was found higher under CTW_{R0} than ZTW_{R0}. The interaction between the different treatment combinations was found non-significant.

Copper

The wheat straw and green manure practices in rice showed non-significant effect within the different treatments on Cu concentration during both the years of experimentation. Although the results were non-significant, the Cu concentration was found higher in the treatments where green manure was incorporated in the soil (PTR_{W25}+GM and PTR_{W0}+GM) as compared to the treatments where no green manure was incorporated (PTR_{W25} and PTR_{W0}). However, among the tillage and rice straw management practices in wheat, the Cu concentration was found higher under ZTW_{R100} as compared to ZTW_{R0} and CTW_{R0}. The trend was found similar during both the years.

Iron

The Fe concentration at maximum tillering stage of rice varied from 145.8 to 160.9 mg kg^{-1} and 143.3 to 158.5 mg kg^{-1}among the different treatment combinations. The Fe concentration was significantly higher under PTR_{W25}+GM (160.9 and 158.5 mg kg^{-1}) with respect to PTR_{W25} (151.7 and 148.8 mg kg^{-1}) and PTR_{W0} (145.8 and 143.3 mg kg^{-1}) during 2016 and 2017, respectively. Even the Fe concentration was found higher under PTR_{W0}+GM (156.5 and 154.6 mg kg^{-1}) as compared to PTR_{W25} and $PTR_{W0.}$ Amongst the tillage and rice straw management practices in wheat, Fe concentration was found higher under ZTW_{R100} as compared to ZTW_{R0} and $CTW_{R0.}$ However, the interaction between wheat straw and green manure practices in rice as well as the tillage and rice straw management practices in wheat was found non-significant.

Table 4.35: Effect of tillage, green manuring and wheat straw management practices on micronutrients concentration (mg kg^{-1}) at maximum tillering of rice

Treatment	Zn		Cu		Fe		Mn	
	2016	2017	2016	2017	2016	2017	2016	2017
Wheat straw and green manure practices in rice								
PTR_{W0}	54.2	51.4	5.11	4.89	145.8	143.3	162.9	160.2
PTR_{W25}	57.1	54.1	5.45	5.34	151.7	148.8	170.8	168.8
PTR_{W0}+GM	61.7	59.7	5.64	5.57	156.5	154.6	173.7	171.4
PTR_{W25}+GM	64.9	63.5	5.79	5.69	160.9	158.5	175.9	174.1
LSD (0.05)	NS	3.39	NS	NS	8.29	6.39	3.06	4.13
Tillage and rice straw management practices in wheat								
CTW_{R0}	59.1	57.2	5.46	5.38	153.1	150.8	169.8	168.3
ZTW_{R0}	56.9	54.6	5.37	5.22	152.2	149.9	168.7	166.3
ZTW_{R100}	62.5	59.7	5.67	5.54	155.9	153.2	173.9	171.4
LSD (0.05)	4.07	3.31	NS	NS	NS	NS	NS	NS
Interaction LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Manganese

The Mn concentration in rice at maximum tillering stage ranged from 162.9 to 175.9 mg kg^{-1} and 160.2 to 174.1 mg kg^{-1} during both the years of experimentation i.e. 2016 and 2017 (Table 4.35). The residual effect of tillage and rice straw management practices in wheat indicated non-significant relation among the different treatments during both the years of experimentation. However, wheat straw and green manure practices in rice irrespective of the tillage and rice straw management practices in wheat indicated significant effect within the treatments during 2016 and 2017. The Mn concentration was found significantly higher under the treatments where green manure was incorporated into the soil before rice crop as compared to the treatments where no green manure was incorporated. The interaction was found non-significant among the different treatment combinations within tillage and rice straw management practices in wheat as well as wheat straw and green manure practices in rice.

4.10 Effect of tillage, green manuring and wheat straw management practices on micronutrients concentration in wheat and rice

4.10.1 Micronutrients (Zn, Cu, Fe and Mn) concentration in wheat grains

Zinc

The data (Table 4.36) pertaining to the effect of wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat on micronutrients concentration in wheat grains (2015-16 and 2016-17) showed that the Zn concentration in wheat grains ranged from 22.3 to 25.5 mg kg^{-1} and 25.9 to 30.0 mg kg^{-1} in both the years of experimentation i.e.2015-16 and 2016-17, respectively. Amongst the tillage and rice straw management practices in wheat, no significant difference in Zn concentration of wheat grains was found within the treatments during both the years (2015-16 and 2016-17). But the concentration of Zn in wheat grains was observed higher in ZTW_{R100} (24.6 and 29.9 mg kg^{-1}) treatment as compared to the CTW_{R0} (23.8 and 27.8 mg kg^{-1}) and ZTW_{R0} (23.1 and 25.9 mg kg^{-1}) during both the years (2015-16 and 2016-17). However, in wheat straw and green manure practices in rice, significant effect was observed for Zn concentration in wheat grains in the second year of experiment but not in the first year. Zn concentration in wheat grains was significantly higher in PTR_{W25}+GM (30.0 mg kg^{-1}) with respect to the PTR_{W0} (26.1 mg kg^{-1}) and PTR_{W25} (26.9 mg kg^{-1}) treatments in 2016-17. The interaction between the wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was not significant.

Copper

Cu concentration in wheat grains ranged between 3.26 to 4.09 mg kg^{-1} and between 3.82 to 4.45 mg kg^{-1} during both the years i.e.2015-16 and 2016-17 (Table 4.36). Wheat straw and green manure practices in rice irrespective of the tillage and rice straw management practices in wheat did not showed significant difference among the treatments during both the years. The data indicated that the Cu concentration in wheat grains was found higher in PTR_{W25}+GM (4.09 and 4.45 mg kg^{-1}) and PTR_{W0}+GM (3.82 and 4.29 mg kg^{-1}) as compared to the PTR_{W0} (3.26 and 3.82 mg kg^{-1}) and PTR_{W25} (3.33 and 4.05 mg kg^{-1}) treatments. Amongst the tillage and rice straw management practices in wheat irrespective of the wheat straw and green manure practices in rice, Cu concentration in wheat grains was found higher in ZTW_{R100} (3.78 and 4.39 mg kg^{-1}) followed by CTW_{R0} (3.64 and 4.17 mg kg^{-1}) and then ZTW_{R0} in (3.46 and 3.90 mg kg^{-1}) treatments during both the years (2015-16 and 2016-17). The interaction between the wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was not significant.

Iron

The data regarding the effect of wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat on Fe concentration in wheat grains (2015-16 and 2016-17) showed that the concentration of Fe in wheat grains ranged from 23.0 to 28.8 mg kg^{-1} and 30.6 to 35.2 mg kg^{-1} in both the years of experimentation i.e. 2015-16 and 2016-17, respectively. Amongst the tillage and rice straw management practices in wheat, no significant difference in Fe concentration in wheat grains were found within the treatments during both the years (2015-16 and 2016-17). But the concentration of Fe in wheat grains was observed higher in ZTW_{R100} (26.9 and 34.8 mg kg^{-1}) treatment as compared to the CTW_{R0} (25.2

and 32.7 mg kg^{-1}) and ZTW_{R0} (24.6 and 32.0 mg kg^{-1}) during both the years (2015-16 and 2016-17). However, in wheat straw and green manure practices in rice, significant effects were observed for Fe concentration in wheat grains in the first as well as second year of experimentation. Fe content in wheat grain was significantly higher in PTR_{W25}+GM (28.8 and 35.2 mg kg^{-1}) with respect to the PTR_{W0} (23.0 and 30.6 mg kg^{-1}) and PTR_{W25} (24.1 and 32.3 mg kg^{-1}) treatments in 2015-16 and 2016-17. The interaction between the wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was not significant.

Table 4.36: Effect of tillage, green manuring and wheat straw management practices on micronutrients concentration (mg kg^{-1}) in wheat grains

Treatment	Zn		Cu		Fe		Mn	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
Wheat straw and green manure practices in rice								
PTR_{W0}	22.3	26.1	3.26	3.82	23.0	30.6	12.2	13.1
PTR_{W25}	23.2	26.9	3.33	4.05	24.1	32.3	13.5	14.5
PTR_{W0}+GM	24.3	28.7	3.82	4.29	26.7	34.5	14.9	16.8
PTR_{W25}+GM	25.5	30.0	4.09	4.45	28.8	35.2	15.5	17.9
LSD (0.05)	NS	1.92	NS	NS	2.74	2.24	1.72	1.63
Tillage and rice straw management practices in wheat								
CTW_{R0}	23.8	27.8	3.64	4.17	25.2	32.7	13.8	15.8
ZTW_{R0}	23.1	25.9	3.46	3.90	24.6	32.0	13.4	14.7
ZTW_{R100}	24.6	29.9	3.78	4.39	26.9	34.8	14.8	16.2
LSD (0.05)	NS	NS	NS	0.25	NS	NS	1.11	NS
Interaction								
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Manganese

A glance at the data (Table 4.36) showed that the Mn concentration in wheat grain varied from 12.2 to 15.5 mg kg^{-1} and from 13.1 to 17.9 mg kg^{-1} during both the years of experimentation i.e. 2015-16 and 2016-17. Amongst the wheat straw and green manure practices in rice irrespective of the tillage and rice straw management practices in wheat, data showed that the Mn concentration was significantly higher in PTR_{W25}+GM (15.5 and 17.9 mg kg^{-1}) with respect to the PTR_{W0} (12.2 and 13.1 mg kg^{-1}) and PTR_{W25} (13.5 and 14.5 mg kg^{-1}). Moreover, it was observed that the Mn concentration in wheat grains was higher in the treatments where green manure was incorporated (PTR_{W25}+GM and PTR_{W0}+GM) as compared to the treatments where no green manuring was done (PTR_{W0} and PTR_{W25}). Even the concentration was found significantly higher in PTR_{W0}+GM as compared to the PTR_{W0} treatment in 2015-16 and 2016-17. However, in case of tillage and rice straw management practices in wheat irrespective of the wheat straw and green manure practices in rice, significant difference was observed within the treatments in 2015-16 but no significant difference was found in 2016-17. It was observed that Mn concentration in wheat grains was found significantly higher in ZTW_{R100} (14.8 mg kg^{-1}) treatment as compared to the ZTW_{R0} (13.8 mg kg^{-1}). Although non-significant effect was found to observe in the treatments during 2016-17, even then the Mn concentration in wheat grains was found higher in ZTW_{R100} (16.2 mg kg^{-1}) followed by CTW_{R0} (15.8 mg kg^{-1}) treatments and then in the ZTW_{R0} (14.7 mg kg^{-1}). The interaction between the wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was not significant.

4.10.2 Micronutrients (Zn, Cu, Fe and Mn) concentration in wheat straw

Zinc

A close examination of the data (Table 4.37) revealed that the Zn concentration in wheat straw ranged between 21.1 to 25.6 mg kg^{-1} and between 22.4 to 27.2 mg kg^{-1} during both the years of experimentation i.e. 2015-16 and 2016-17. Amongst the tillage and rice straw management practices in wheat irrespective of the wheat straw and green manure practices in rice, it was observed that the Zn concentration in wheat straw showed non significant difference among the treatments, even then the contents were higher in ZTW_{R100} (24.1 and 25.6 mg kg^{-1}) followed by CTW_{R0} (23.3 and 25.0 mg kg^{-1}) treatments and then in the ZTW_{R0} (22.8 and 24.0 mg kg^{-1}) during both the years (2015-16 and 2016-17). However, in wheat straw and green manure practices in rice showed significant differences among the treatments during both the years. Data showed that the Zn concentration in wheat straw was significantly higher in PTR_{W25}+GM (25.6 and 27.2 mg kg^{-1}) and PTR_{W0}+GM (24.6 and 26.6 mg kg^{-1}) with respect to the PTR_{W0} (21.1 and 22.4 mg kg^{-1}) and PTR_{W25} (22.2 and 23.6 mg kg^{-1}) treatments. In nutshell, the Zn concentration was found higher in treatments where green manure was incorporated before the rice crop as compared to the treatments where no green manure was incorporated. However, the interaction between the wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was not significant.

Copper

The data pertaining to the effect of wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat suggested that the Cu concentration showed non-significant effect within the treatments amongst tillage and rice straw management practices in wheat. The Cu concentration was higher in the ZTW_{R100} treatment as compared to the CTW_{R0} and ZTW_{R0}. It varied as 4.58 and 4.68 mg kg^{-1} in ZTW_{R100} followed by 4.47 and 4.52 mg kg^{-1} in CTW_{R0} and then 4.27 and 4.36 mg kg^{-1} in ZTW_{R0} in 2015-16 and

2016-17.However, Cu concentration showed significant effect among the wheat straw and green manure practices in rice, it was observed that the concentration was significantly higher in PTR_{W25}+GM (4.67 and 4.76 mg kg^{-1}) with respect to the PTR_{W0} (3.95 and 4.06 mg kg^{-1}). The interaction between the wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was not significant.

Table 4.37: Effect of tillage, green manuring and wheat straw management practices on micronutrients concentration (mg kg^{-1})in wheat straw

Treatment	Zn		Cu		Fe		Mn	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
Wheat straw and green manure practices in rice								
PTR_{W0}	21.1	22.4	3.95	4.06	170.3	175.9	18.7	20.0
PTR_{W25}	22.2	23.6	4.54	4.65	178.0	183.4	20.3	21.2
PTR_{W0}+GM	24.6	26.6	4.60	4.69	184.2	187.1	21.4	22.2
PTR_{W25}+GM	25.6	27.2	4.67	4.76	187.6	192.6	22.2	24.2
LSD (0.05)	2.13	1.42	0.45	0.44	7.45	4.45	1.01	1.06
Tillage and rice straw management practices in wheat								
CTW_{R0}	23.3	25.0	4.47	4.52	179.4	184.5	20.6	22.2
ZTW_{R0}	22.8	24.0	4.27	4.36	176.6	180.4	19.9	21.2
ZTW_{R100}	24.1	25.6	4.58	4.68	184.2	189.3	21.5	23.1
LSD (0.05)	NS	NS	NS	NS	3.89	4.55	1.21	NS
Interaction								
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Iron

The data (Table 4.37) pertaining to the effect of wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat on Fe concentration in wheat straw (2015-16 and 2016-17) showed that the concentration of Fe ranged from 170.3 to 187.6 mg kg^{-1} and 175.9 to 192.6 mg kg^{-1} in both the years of experimentation i.e. 2015-16 and 2016-17, respectively. Amongst the tillage and rice straw management practices in wheat irrespective of wheat straw and green manure practices in rice, significant difference in Fe concentration in wheat straw was found within the treatments during both the years (2015-16 and 2016-17). The Fe concentration in wheat straw was observed significantly higher in ZTW_{R100} (184.2 and 189.3 mg kg^{-1}) treatment as compared to the CTW_{R0} (179.4 and 184.5 mg kg^{-1}) and ZTW_{R0} (176.6 and 180.4 mg kg^{-1}) during both the years (2015-16 and 2016-17). However, in wheat straw and green manure practices in rice, Fe concentration in wheat straw was found significantly higher in PTR_{W25}+GM (187.6 and 192.6 mg kg^{-1}) with respect to the

PTR_{W0} (170.3 and 175.9 mg kg^{-1}) and PTR_{W25} (178.0 and 183.4 mg kg^{-1}) treatments in 2015-16 and 2016-17. The interaction between the wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was not significant.

Manganese

A persual of the data showed that the Mn concentration in wheat straw ranged from 18.7 to 22.2 mg kg^{-1} and from 20.0 to 24.2 mg kg^{-1} during both the years of experimentation i.e. 2015-16 and 2016-17 (Table 4.37). Amongst the wheat straw and green manure practices in rice irrespective of the tillage and rice straw management practices in wheat, data showed that the Mn concentration was significantly higher in PTR_{W25}+GM (22.2 and 24.2 mg kg^{-1}) with respect to the PTR_{W0} (18.7 and 20.0 mg kg^{-1}) and PTR_{W25} (20.3 and 21.2 mg kg^{-1}). Moreover, it was observed that the Mn concentration in wheat straw was higher in the treatments where green manure was incorporated (PTR_{W25}+GM and PTR_{W0}+GM) as compared to the treatments where no green manuring was done (PTR_{W0} and PTR_{W25}). Even the concentration was found significantly higher in PTR_{W0}+GM as compared to the PTR_{W0} treatment in 2015-16 and 2016-17. However, in case of tillage and rice straw management practices in wheat irrespective of the wheat straw and green manure practices in rice, significant difference was observed within the treatments in 2015-16 but no significant difference was found in 2016-17. It was observed that Mn concentration in wheat straw was found significantly higher in ZTW_{R100} (21.5 mg kg^{-1}) treatment as compared to the ZTW_{R0} (19.9 mg kg^{-1}). Although no significant difference was found to observe in the treatments during 2016-17, even then the Mn concentration in wheat straw was found higher in ZTW_{R100} (23.1 mg kg^{-1}) followed by CTW_{R0} (22.2 mg kg^{-1}) treatments and then in the ZTW_{R0} (21.2 mg kg^{-1}). The interaction between the wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was not significant.

4.10.3 Micronutrients (Zn, Cu, Fe and Mn) concentration in rice grains

Zinc

From the data, it was observed that Zn concentration in rice grains ranged from 19.8 to 23.7 mg kg^{-1} and from 15.3 to 18.5 mg kg^{-1} amongst the wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat (Table 4.38). The Zn concentration in rice grains was found significantly higher in the year 2017, the Zn concentration was found significantly higher in PTR_{W25}+GM (18.5 mg kg^{-1}) and PTR_{W0}+GM (18.3 mg kg^{-1}) as compared to the treatments where no green manuring was done i.e.PTR_{W0} (15.3 mg kg^{-1}) and PTR_{W25} (16.1 mg kg^{-1}). Moreover, Zn concentration in rice grains in 2016 was also higher in PTR_{W25}+GM (23.7 mg kg^{-1}) and PTR_{W0}+GM (22.2 mg kg^{-1}) as compared to the treatments where no green manuring was done i.e. PTR_{W0} (19.8 mg kg^{-1}) and PTR_{W25} (20.3 mg kg^{-1}), although no significant differences among the treatments were observed. However, in case of tillage and rice straw management practices in wheat irrespective of the wheat straw and green manure practices in rice, it was observed that the Zn concentration showed significantly higher content in rice grain in 2016 but not in 2017. Zn was significantly higher in ZTW_{R100} (22.6 mg kg^{-1}) as compared to the ZTW_{R0} (20.5 mg kg^{-1}) in 2016.

Rice grain analysis for nutrients viz. Fe, Zn, Mn and Cu showed a significant increase in Fe and Mn content in the treatments having 2 or more organic amendments over control. Zn and Cu content also increased but the increment was significant with combined application of 3 or 4 organic amendments (Singh *et al* 2008). Fulvic acid formed during organic matter decomposition and siderophores that are produced by microorganisms will also help to increase Fe solubility and its availability to plants. On the other hand, metals such as Cu is tightly bound by soil organic matter and become less available in organic matter amended soils (organic soils). Zn availability may be increased in soils under aerated conditions by complexation with fulvic acid (Tagwira *et al* 1992), or decreased in submerged soils where organic matter additions alter soil solution chemistry.

Table 4.38: Effect of tillage, green manuring and wheat straw management practices on micronutrients concentration (mg kg^{-1}) in rice grains

Treatment	Zn		Cu		Fe		Mn	
	2016	2017	2016	2017	2016	2017	2016	2017
Wheat straw and green manure practices in rice								
PTR_{W0}	19.8	15.3	3.37	3.38	41.3	32.6	11.5	12.9
PTR_{W25}	20.3	16.1	3.69	3.98	45.5	34.1	12.4	15.5
PTR_{W0}+GM	22.2	18.3	4.15	4.32	46.7	36.2	12.9	17.3
PTR_{W25}+GM	23.7	18.5	4.62	4.54	48.1	38.5	13.8	18.8
LSD (0.05)	NS	1.75	0.72	0.53	4.46	NS	NS	2.26
Tillage and rice straw management practices in wheat								
CTW_{R0}	21.4	17.1	3.93	4.02	45.3	35.2	12.7	15.9
ZTW_{R0}	20.5	16.1	3.74	3.87	44.2	34.1	12.1	15.2
ZTW_{R100}	22.6	18.3	4.21	4.26	46.8	36.7	13.2	17.3
LSD (0.05)	1.50	NS	NS	NS	NS	NS	NS	NS
Interaction LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Copper

The data pertaining to the effect of wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat suggested that the Cu concentration in rice grains showed non-significant effect within the treatments amongst tillage and rice straw management practices in wheat. The Cu concentration was higher in the ZTW_{R100} (4.21 and 4.26 mg kg^{-1}) treatment as compared to the CTW_{R0} (3.93 and 4.02 mg kg^{-1}) and ZTW_{R0} (3.74 and 3.87 mg kg^{-1}) during both the years (2016 and 2017). However, Cu concentration showed significant effect among the wheat straw and green manure practices in rice, it was observed that the Cu concentration was significantly higher in PTR_{W25}+GM (4.62 and 4.54 mg kg^{-1}) with respect to the PTR_{W0} (3.37 and 3.38 mg kg^{-1}) as well as PTR_{W25} (3.69 and 3.98 mg kg^{-1}). The interaction between the wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was not significant.

Iron

The data regarding the effect of wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat on Fe concentration in rice grains (2016 and 2017) showed that the concentration of Fe in rice grains ranged from 41.3 to 48.1 mg kg^{-1} and 32.6 to 38.5 mg kg^{-1} in both the years of experimentation i.e. 2016 and 2017, respectively (Table 4.38). Amongst the tillage and rice straw management practices in wheat irrespective of the wheat straw and green manure practices in rice, no significant differences in Fe concentration in rice grains were found within the treatments during both the years (2016 and 2017). But the concentration of Fe in rice grains was observed higher in ZTW_{R100} (46.8 and 36.7 mg kg^{-1}) treatment as compared to the CTW_{R0} (45.3 and 35.2 mg kg^{-1}) and ZTW_{R0} (44.2 and 34.1 mg kg^{-1}) during both the years (2016 and 2017). However, in wheat straw and green manure practices in rice, significant effects were observed for Fe concentration in rice grains in the first year (2016) but no significant difference was found in 2017. Fe concentration in rice grains was significantly higher in PTR_{W25}+GM (48.1 mg kg^{-1}) as compared to the PTR_{W0} (41.3 mg kg^{-1}) treatments in 2016. Even in 2017, Fe concentration was also higher in PTR_{W25}+GM and PTR_{W0}+GM as compared to the PTR_{W0} as well as $PTR_{W25.}$ The interaction between the wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was not significant.

Manganese

Mn concentration in rice grains ranged from 11.5 to 13.8 mg kg^{-1} and 12.9 to 18.8 mg kg^{-1} between the wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat (Table 4.38). Amongst the wheat straw and green manure practices in rice, Mn concentration in rice grains showed non-significant effect within the treatments in 2016 but the effect was significant in 2017. It was observed that Mn concentration was significantly higher in PTR_{W25}+GM (18.8 mg kg^{-1}) as compared to the PTR_{W0} (12.9 mg kg^{-1}) as well as PTR_{W25} (15.5 mg kg^{-1}) in 2017. The Mn concentration in rice grains was found higher in the treatments where green manure was incorporated in soil as compared to the treatments where no green manure was incorporated. However, tillage and rice straw management practices in wheat did not significantly affect the Mn concentration within the treatments. The Mn concentration was found higher in ZTW_{R100} (13.2 and 17.3 mg kg^{-1}) as compared to the CTW_{R0} (12.7 and 15.9 mg kg^{-1}) and ZTW_{R0} (12.1 and 15.2 mg kg^{-1}) during both the years (2016 and 2017).

4.10.4 Micronutrients (Zn, Cu, Fe and Mn) concentration in rice straw

Zinc

A close examination of the data revealed that the Zn concentration in rice straw ranged between 71.9 to 80.5 mg kg^{-1} and between 69.9 to 78.6 mg kg^{-1} during both the years of experimentation i.e. 2016 and 2017 (Table 4.39). Amongst the tillage and rice straw management practices in wheat irrespective of the wheat straw and green manure practices in rice, it was observed that the Zn concentration in rice straw showed significant differences among the treatments, the Zn concentration was found significantly higher in ZTW_{R100} (80.5 and 78.6 mg kg^{-1}) with respect to CTW_{R0} (76.5 and 74.5 mg kg^{-1}) and ZTW_{R0} (73.4 and 71.6 mg kg^{-1}) during both the years (2016 and 2017). However, in wheat straw and green manure practices in rice, the data showed significant differences among the treatments during both the years. Data showed that the Zn concentration in rice straw was significantly higher in PTR_{W25}+GM (80.2 and 78.0 mg kg^{-1}) with respect to the PTR_{W0} (71.9 and 69.9 mg kg^{-1}) and PTR_{W25} (76.9 and 75.6 mg kg^{-1}) treatments. Even the Zn content was also significantly higher in PTR_{W0}+GM (78.1 and 78.0 mg kg^{-1}) as compared to the PTR_{W0}. In nutshell, the Zn concentration in rice straw was found higher in treatments where green manure was incorporated before the rice crop as compared to the treatments where no green manure was incorporated. However, the interaction among the wheat straw and GM practices in rice and tillage and rice straw management practices in wheat was not significant.

Copper

The data (Table 4.39) suggested that the Cu concentration showed non-significant effect within the treatments amongst tillage and rice straw management practices in wheat, but the Cu concentration was significantly affected by the wheat straw and green manure practices in rice. The Cu concentration in rice straw was higher in the ZTW_{R100} treatment as compared to the CTW_{R0} and ZTW_{R0}. It varied as 6.80 and 6.72 mg kg^{-1} in ZTW_{R100} followed by 6.34 and 6.30 mg kg^{-1} in CTW_{R0} and then 6.24 and 6.15 mg kg^{-1} in ZTW_{R0} during both the years i.e. 2016 and 2017.However, Cu concentration showed significant effect among the wheat straw and green manure practices in rice irrespective of the tillage and rice straw management practices in wheat, it was observed that the Cu concentration was significantly higher in PTR_{W25}+GM (7.64 and 7.53 mg kg^{-1}) with respect to the PTR_{W0}+GM (6.61 and 6.64 mg kg^{-1}), PTR_{W25} (5.87 and 5.80 mg kg^{-1}) and PTR_{W0} (5.71 and 5.58 mg kg^{-1}) during both the years of experimentation (2016 and 2017). The interaction between the wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was not significant.

Table 4.39: Effect of tillage, green manuring and wheat straw management practices on micronutrients concentration (mg kg^{-1}) in rice straw

Treatment	Zn		Cu		Fe		Mn	
	2016	2017	2016	2017	2016	2017	2016	2017
Wheat straw and green manure practices in rice								
PTR_{W0}	71.9	69.9	5.71	5.58	276.4	272.9	251.4	248.6
PTR_{W25}	76.9	75.6	5.87	5.80	305.7	301.0	256.5	254.1
PTR_{W0}+GM	78.1	76.1	6.61	6.64	381.1	374.8	256.9	253.7
PTR_{W25}+GM	80.2	78.0	7.64	7.53	404.6	398.3	264.3	261.7
LSD (0.05)	3.67	4.69	0.65	0.58	17.1	17.3	NS	NS
Tillage and rice straw management practices in wheat								
CTW_{R0}	76.5	74.5	6.34	6.30	340.3	334.8	256.9	254.4
ZTW_{R0}	73.4	71.6	6.24	6.15	319.8	315.1	252.2	249.7
ZTW_{R100}	80.5	78.6	6.80	6.72	365.7	360.5	262.6	259.6
LSD (0.05)	3.43	2.60	NS	NS	31.6	32.4	NS	NS
Interaction LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Iron

The data pertaining to the effect of wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat on Fe concentration in rice straw (2016 and 2017) showed that the concentration of Fe in rice straw ranged from 276.4 to 404.6 mg kg^{-1} and from 272.9 to 398.3 mg kg^{-1}in both the years of experimentation i.e. 2016 and 2017, respectively. Amongst the tillage and rice straw management practices in wheat irrespective of wheat straw and green manure practices in rice, significant difference in Fe concentration in rice straw was found within the treatments during both the years (2016 and 2017). The Fe concentration in rice straw was observed significantly higher in ZTW_{R100} (365.7 and 360.5 mg kg^{-1}) treatment as compared to the ZTW_{R0} (319.8 and 315.1 mg kg^{-1}) during both the years (2016 and 2017). However, in wheat straw and green manure practices in rice, significant effects were observed for Fe concentration in rice straw in the first as well as second year of experimentation. Fe concentration in rice straw was significantly higher in PTR_{W25}+GM (404.6 and 398.3 mg kg^{-1}) with respect to the PTR_{W0}+GM (381.1 and 374.8 mg kg^{-1}), PTR_{W0} (276.4 and 272.9 mg kg^{-1}) and PTR_{W25} (305.7 and 301.0 mg kg^{-1}) treatments in 2016 and 2017. The interaction between the wheat straw and GM practices in rice and tillage and rice straw management practices in wheat was not significant.

Manganese

A persual of the data (Table 4.39) showed that the Mn concentration in rice straw ranged from 251.4 to 264.3 mg kg^{-1} and from 248.6 to 261.7 mg kg^{-1} during both the years of experimentation i.e. 2016 and 2017. Amongst the wheat straw and green manure practices in rice irrespective of the tillage and rice straw management practices in wheat, data showed that the Mn concentration was higher in PTR_{W25}+GM (264.3 and 261.7 mg kg^{-1}) and PTR_{W0}+GM (256.9 and 253.7 mg kg^{-1}) with respect to the PTR_{W0} (251.4 and 248.6 mg kg^{-1}) and PTR_{W25} (256.5 and 254.1 mg kg^{-1}) during both the years of experimentation (2016 and 2017). Moreover, it was observed that the Mn concentration in rice straw was higher in the treatments where green manure was incorporated (PTR_{W25}+GM and PTR_{W0}+GM) as compared to the treatments where no green manuring was done (PTR_{W0} and PTR_{W25}). However, in case of tillage and rice straw management practices in wheat irrespective of the wheat straw and green manure practices in rice, non- significant difference was found in 2016 as well as 2017. It was observed that Mn concentration in rice straw was found higher in ZTW_{R100} (262.6 and 259.6 mg kg^{-1}) treatment followed by CTW_{R0} (256.9 and 254.4 mg kg^{-1}) and ZTW_{R0} (252.2 and 249.7 mg kg^{-1}) during both the years (2016 and 2017). The interaction between the wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was not significant.

4.11 Effect of tillage, green manuring and wheat straw management practices on micronutrients uptake in wheat and rice

4.11.1 Micronutrients (Zn, Cu, Fe and Mn) uptake in wheat grains

Zinc

A persual of the data (Table 4.40) regarding the uptake of micronutrients as influenced by the wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat, it was observed that Zn uptake in wheat grains was significantly affected by the treatments during both the years of experimentation. Amongst the tillage and rice straw management practices in wheat, Zn uptake was significantly higher in ZTW_{R100} (150.8 and 190.2 g ha^{-1}) as compared to the CTW_{R0} (134.8 and 163.5 g ha^{-1}) and ZTW_{R0} (120.9 and 144.4 g ha^{-1}) during both the years (2015-16 and 2016-17). Even the Zn uptake was higher in CTW_{R0} as compared to the ZTW_{R0}. The trend for decrease in Zn uptake in wheat grains from ZTW_{R100} to the CTW_{R0} and then in ZTW_{R0} was same during both the years.

On the other hand, in case of wheat straw and green manure practices in rice, It was observed that Zn uptake was significantly higher in PTR_{W25}+GM (158.3 and 194.1 g ha^{-1}) with respect to the PTR_{W0}+GM (142.2 and 174.3 g ha^{-1}), PTR_{W25} (129.0 and 156.5 g ha^{-1}) and PTR_{W0} (112.6 and 139.2 g ha^{-1}) during 2015-16 and 2016-17. However, the interaction between the wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was not significant.

Copper

A close examination of the data showed that the uptake of copper in wheat grains varied from 16.4 to 25.6 g ha^{-1} and 20.2 to 28.7 g ha^{-1} in 2015-16 as well as 2016-17 amongst the wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat (Table 4.40). Cu uptake in wheat grains was significantly affected during both the years within the treatments among the wheat straw and GM practices in rice. It was observed that the Cu uptake was significantly higher in wheat grains under PTR_{W25}+GM (25.6 and 28.7 g ha^{-1}) as compared to the PTR_{W0}+GM (22.3 and 26.0 g ha^{-1}) as well as PTR_{W25} (18.5 and 23.4 g ha^{-1}) and PTR_{W0} (16.4 and 20.2 g ha^{-1}) during first and second year of experimentation. However, in case of tillage and rice straw management practices in wheat, data showed significant effect on Cu uptake in wheat grains within the treatments in 2016-17 but not in 2015-16. Moreover, the Cu uptake was found higher in ZTW_{R100} (23.1 and 27.8 g ha^{-1}) as compared to the CTW_{R0} (20.5 and 24.4 g ha^{-1}) and ZTW_{R0} (18.2 and 21.6 g ha^{-1}) during both the years (2015-16 and 2016-17). The interaction between the wheat straw and GM practices in rice and tillage and rice straw management practices in wheat was not significant.

Table 4.40: Effect of tillage, green manuring and wheat straw management practices on uptake (g ha^{-1}) of micronutrients in wheat grains

Treatment	Zn		Cu		Fe		Mn	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
Wheat straw and green manure practices in rice								
PTR_{W0}	112.6	139.2	16.4	20.2	116.4	162.9	61.6	69.8
PTR_{W25}	123.0	156.5	18.5	23.4	127.7	188.2	75.0	84.4
PTR_{W0}+GM	142.2	174.3	22.3	26.0	156.5	209.1	87.3	101.9
PTR_{W25}+GM	158.3	194.1	25.6	28.7	178.9	227.0	96.3	116.1
LSD (0.05)	13.9	16.6	5.61	3.60	15.1	16.4	9.27	10.2
Tillage and rice straw management practices in wheat								
CTW_{R0}	134.8	163.5	20.5	24.4	143.2	191.8	78.6	93.1
ZTW_{R0}	120.9	144.4	18.2	21.6	129.9	178.3	70.8	82.4
ZTW_{R100}	150.8	190.2	23.1	27.8	165.3	220.7	90.7	103.6
LSD (0.05)	8.12	22.6	NS	1.80	17.0	19.4	6.69	11.8
Interaction								
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Iron

From the data, it was observed that Fe uptake ranged from 116.4 to 178.9 g ha^{-1} and from 162.9 to 227.0 g ha^{-1} during both the years of experimentation i.e. 2015-16 and 2016-17 among the wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat. It was observed that Fe uptake in wheat grains was significantly higher under ZTW_{R100} (165.3 and 220.7 g ha^{-1}) as compared to the CTW_{R0} (143.2 and 191.8 g ha^{-1}) and ZTW_{R0} (129.9 and 178.3 g ha^{-1}) during both the years (2015-16 and 2016-17). However, in case of the wheat straw and green manure practices in rice, significant differences were found among the treatments, it was observed that the Fe uptake was found significantly higher under PTR_{W25}+GM (178.9 and 227.0 g ha^{-1}) and PTR_{W0}+GM (156.5 and 209.1 g ha^{-1}) as compared to PTR_{W25} (127.7 and 188.2 g ha^{-1}) and PTR_{W0} (116.4 and 162.9 g ha^{-1}) during first and second year of experimentation. It was observed that the Fe uptake in wheat grain was higher in the treatments where green manure was incorporated as compared to the treatments where no green manure was incorporated. However, the interaction among the wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was not significant.

Manganese

A persual of the data (Table 4.40) showed that the Mn uptake in wheat grains ranged from 61.6 to 96.3 mg kg^{-1} and from 69.8 to 116.1 mg kg^{-1} during both the years of experimentation i.e. 2015-16 and 2016-17. Amongst the wheat straw and green manure practices in rice irrespective of the tillage and rice straw management practices in wheat, data showed that the Mn uptake was higher in PTR_{W25}+GM (96.3 and 116.1 g ha^{-1}) with respect to the PTR_{W25}+GM (87.3 and 101.9 g ha^{-1}), PTR $_{W25}$ (75.0 and 84.4 g ha^{-1}) and PTR_{W0} (61.6 and 69.8 g ha^{-1}). In conclusion, it was observed that the Mn uptake in wheat grain was higher in the treatments where green manure was incorporated (PTR_{W25}+GM and PTR_{W0}+GM) as compared to the treatments where no green manuring was done (PTR_{W0} and PTR_{W25}). Even the uptake was found significantly higher in PTR_{W0}+GM as compared to the PTR_{W25} and PTR_{W0} treatment in 2015-16 and 2016-17. However, in case of tillage and rice straw management practices in wheat irrespective of the wheat straw and green manure practices in rice, significant difference was observed within the treatments in 2015-16 and 2016-17. It was observed that Mn uptake in wheat grains was found significantly higher in ZTW_{R100} (90.7 and 103.6 g ha^{-1}) treatment as compared to the ZTW_{R0} (70.8 and 82.4 g ha^{-1}). The interaction between the wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was not significant.

4.11.2 Micronutrients (Zn, Cu, Fe and Mn) uptake in wheat straw

Zinc

Zn uptake (Table 4.41) in wheat straw ranged from 141.4 to 178.4 g ha^{-1} in 2015-16. Similarly, in 2016-17, Zn uptake in wheat straw ranged from 152.7 to 193.7 g ha^{-1} among the wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat. It was observed that the Zn uptake in wheat straw was found significantly higher in ZTW_{R100} i.e. 170.7 g ha^{-1} as compared to the CTW_{R0} i.e. 158.0 g ha^{-1} and ZTW_{R0} i.e. 152.3 g ha^{-1} in 2015-16. Similarly, in 2016-17, Zn uptake was found higher in ZTW_{R100} i.e. 185.1 g ha^{-1} as compared to the CTW_{R0} i.e. 173.8 g ha^{-1} and ZTW_{R0} i.e. 163.6 g ha^{-1} in 2016-17. However, in case of wheat straw and green manure practices in rice, Zn uptake in wheat straw was found significantly higher in PTR_{W25}+GM (178.4 and 193.7 g ha^{-1}) with respect to the PTR_{W25} (150.5 and 163.1 g ha^{-1}) and PTR_{W0} (141.4 and 152.7 g ha^{-1}) during both the years of experimentation. Even the Zn uptake was also higher in PTR_{W0}+GM with respect to the PTR_{W25} and $PTR_{W0.}$ It could be concluded that the Zn uptake was much higher in the treatments where green manure was incorporated in comparison to the treatments where no green manure was incorporated in the soil.

Table 4.41: Effect of tillage, green manuring and wheat straw management practices on uptake (g ha^{-1}) of micronutrients in wheat straw

Treatment	Zn		Cu		Fe		Mn	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
Wheat straw and green manure practices in rice								
PTR_{W0}	141.4	152.7	26.5	27.8	1142.7	1201.4	125.3	136.9
PTR_{W25}	150.5	163.1	30.9	32.1	1208.6	1265.5	138.0	153.2
PTR_{W0}+GM	171.2	187.1	32.1	33.3	1280.2	1330.3	149.0	158.1
PTR_{W25}+GM	178.4	193.7	32.6	33.9	1307.6	1373.2	154.5	172.5
LSD (0.05)	10.2	12.4	3.04	2.63	80.3	NS	14.2	15.3
Tillage and rice straw management practices in wheat								
CTW_{R0}	158.0	173.8	30.3	31.7	1218.1	1280.4	139.6	154.3
ZTW_{R0}	152.3	163.6	28.6	29.8	1181.5	1232.1	133.0	144.5
ZTW_{R100}	170.7	185.1	32.6	33.9	1306.0	1366.7	152.3	166.6
LSD (0.05)	13.2	11.9	NS	2.42	73.9	NS	11.3	10.6
Interaction								
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Copper

Data pertaining to the effect ofwheat straw and green manure practices in rice and tillage and rice straw management practices in wheat (Table 4.41), showed that the Cu uptake in wheat straw ranged from 26.5 to 32.6 g ha^{-1} and from 27.8 to 33.9 g ha^{-1} in 2015-16 as well as 2016-17. Cu uptake in wheat straw was significantly affected during both the years among the wheat straw and green manure practices in rice. It was observed that the Cu uptake was significantly higher in wheat straw under PTR_{W25}+GM (32.6 and 33.9 g ha^{-1}) as compared to PTR_{W0} (26.5 and 27.8 g ha^{-1}) during first and second year of experimentation. Moreover, the Cu uptake was found higher under PTR_{W0}+GM as compared to the PTR_{W25} and $PTR_{W0.}$ However, in case of tillage and rice straw management practices in wheat, data revealed significant effect on Cu uptake in wheat straw within the treatments in 2016-17 but not in 2015-16. The Cu uptake was found higher in ZTW_{R100} (32.6 and 33.9 g ha^{-1}) as compared to the CTW_{R0} (30.3 and 31.7 g ha^{-1}) and ZTW_{R0} (28.6 and 29.8 g ha^{-1}) during both the years (2015-16 and 2016-17). The interaction between the wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was not significant.

Iron

The data concerning the effect of wheat straw and GM practices in rice and tillage and rice straw management practices in wheat on Fe uptake in wheat straw (2015-16 and 2016-17) showed that the uptake of Fe in wheat straw ranged from 1142.7 to 1307.6 mg kg^{-1}and 1201.4 to 1373.2 mg kg^{-1} in both the years of experimentation i.e.2015-16 and 2016-17, respectively. Amongst the tillage and rice straw management practices in wheat irrespective of the wheat straw and green manure practices in rice, significant differences in Fe uptake in wheat straw were found within the treatments during 2015-16 but not in 2016-17. The Fe uptake in wheat straw was observed significantly higher in ZTW_{R100} (1306.0 and 1366.7 mg kg^{-1}) treatment as compared to the CTW_{R0} (1218.1 and 1280.4 mg kg^{-1}) and ZTW_{R0} (1181.5 and 1232.1 mg kg^{-1}) during both the years (2015-16 and 2016-17).

However, in wheat straw and green manure practices in rice, significant effects were observed for Fe uptake in wheat straw in the first year (2015-16) but no significant difference was found in 2016-17. Fe uptake in wheat straw was significantly higher in PTR_{W25}+GM (1307.6 mg kg^{-1}) as compared to the PTR_{W0} (1142.7 mg kg^{-1}) treatments in 2015-16. Even in 2016-17, Fe uptake was also higher in PTR_{W25}+GM and PTR_{W0}+GM as compared to the PTR_{W0} as well as $PTR_{W25.}$ The interaction between the wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was not significant.

Manganese

Mn uptake (Table 4.41) in wheat straw showed significant difference within wheat straw and green manure practices in rice irrespective of the tillage and rice straw management practices in wheat. It was observed that the Mn uptake in wheat straw ranged between 125.3

to 154.5 mg kg^{-1} and between 136.9 to 172.5 mg kg^{-1} during both the years of experimentation i.e. 2015-16 and 2016-17. Amongst the wheat straw and green manure practices in rice irrespective of the tillage and rice straw management practices in wheat, data showed that the Mn uptake was significantly higher in PTR_{W25}+GM (154.5 and 172.5 mg kg^{-1}) with respect to the PTR_{W0} (125.3 and 136.9 mg kg^{-1}) and PTR_{W25} (138.0 and 153.2 mg kg^{-1}) during both the years of experimentation (2015-16 and 2016-17). Moreover, it was observed that the Mn uptake in wheat straw was higher in the treatments where green manure was incorporated (PTR_{W25}+GM and PTR_{W0}+GM) as compared to the treatments where no green manuring was done (PTR_{W0} and PTR_{W25}). However, it was observed that Mn uptake in wheat straw was significantly higher in ZTW_{R100} (152.3 and 166.6 mg kg^{-1}) treatment as compared to CTW_{R0} (139.6 and 154.3 mg kg^{-1}) and ZTW_{R0} (133.0 and 144.5 mg kg^{-1}) during both the years (2015-16 and 2016-17). The interaction between the wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was not significant.

4.11.3 Micronutrients (Zn, Cu, Fe and Mn) uptake in rice grains

Zinc

A close examination of the data (Table 4.42) revealed that the uptake of Zn in rice grains varied from 124.4 to 182.9 g ha^{-1} and from 97.4 to 144.2 g ha^{-1} between wheat straw and green manure practices in rice as well as tillage and rice straw management practices in wheat. Zn uptake was significantly higher in ZTW_{R100} i.e. 166.1 and 132.6 g ha^{-1} as compared to the ZTW_{R0} i.e. 131.9 and 106.9 g ha^{-1} during both the years of experimentation i.e. 2016 and 2017. Even the Zn uptake was higher in CTW_{R0} (149.8 and 120.3 g ha^{-1}) as compared to the ZTW_{R0} (131.9 and 106.9 g ha^{-1}) treatments in 2016 and 2017. However, in case of wheat straw and GM practices in rice, the data revealed that the Zn uptake was significantly higher in PTR_{W25}+GM (182.9 and 144.2 g ha^{-1}) as compared to the PTR_{W25} (130.1 and 104.7 g ha^{-1}) and PTR_{W0} (124.4 and 97.4 g ha^{-1}). Even the Zn uptake in rice grains was significantly higher in PTR_{W0}+GM as compared to the PTR_{W25} and PTR_{W0} among the wheat straw and GM practices in rice crop. However, the interaction between wheat straw and GM practices in rice as well as tillage and rice straw management practices in wheat on Zn uptake in rice grains was found non-significant. Behera *et al* (2011) reported that during the decomposition of organic matter, Zn forms labile organic mineral complexes which resulted in the increase in Zn content of soil.

Copper

A review of the data in the Table 4.42 indicated that the uptake of Cu in rice grains showed significant effect within the different treatments regarding the effect of wheat straw and green manure practices in rice as well as tillage and rice straw management practices in wheat. It was recorded that the Cu uptake in rice grains varied from 21.3 to 35.6 g ha^{-1} and from 21.5 to 35.5 g ha^{-1} between wheat straw and green manure practices in rice as well as tillage and rice straw management practices in wheat. In case of wheat straw and green manure practices in rice, the data revealed that the Cu uptake was significantly higher in PTR_{W25}+GM (35.6 and 35.5 g ha^{-1}) as compared to the PTR_{W25} (23.5 and 25.7 g ha^{-1}) and PTR_{W0} (21.3 and 21.5 g ha^{-1}). Even the Cu uptake in rice grains was also significantly higher in PTR_{W0}+GM (29.8 and 31.4 g ha^{-1}) as compared to the PTR_{W25} and PTR_{W0} among the wheat straw and green manure practices in rice crop during both the years of experimentation i.e. 2016 and 2017. Amongst the wheat straw and green manure practices in rice, Cu uptake was significantly higher in ZTW_{R100} i.e. 31.0 and 31.8 g ha^{-1} as compared to the ZTW_{R0} i.e. 24.2 and 25.3 g ha^{-1} during both the years of experimentation i.e. 2016 and 2017. Even the Cu uptake was higher in CTW_{R0} (27.4 and 28.5 g ha^{-1}) as compared to the ZTW_{R0} treatments in 2016 and 2017. However, the interaction between wheat straw and green manure practices in rice as well as tillage and rice straw management practices in wheat on Cu uptake in rice grains was found non-significant. Earlier authors have reported that inorganic fertilization with crop residue not only increases grain yield and maintains soil nutrient balance, but also accelerates rice nutrient uptake (Mann *et al* 2006, Li *et al* 2007, Xue *et al* 2014). Similar findings were reported by Aulakh and Malhi (2005) who enumerated that the interaction of other soil macronutrients and micronutrients also affected micronutrient uptake by crops.

Table 4.42: Effect of tillage, green manuring and wheat straw management practices on uptake (g ha^{-1}) of micronutrients in rice grains

Treatment	Zn		Cu		Fe		Mn	
	2016	2017	2016	2017	2016	2017	2016	2017
Wheat straw and green manure practices in rice								
PTR_{W0}	124.4	97.4	21.3	21.5	260.7	208.5	72.5	82.9
PTR_{W25}	130.1	104.7	23.5	25.7	292.5	221.2	78.4	99.8
PTR_{W0}+GM	159.6	133.4	29.8	31.4	334.5	262.9	93.1	125.7
PTR_{W25}+GM	182.9	144.2	35.6	35.5	371.6	299.3	106.2	146.8
LSD (0.05)	27.3	7.86	4.36	4.84	37.4	64.9	16.9	19.0
Tillage and rice straw management practices in wheat								
CTW_{R0}	149.8	120.3	27.4	28.5	315.8	248.0	88.9	112.9
ZTW_{R0}	131.9	106.9	24.2	25.3	284.1	222.8	77.6	100.1
ZTW_{R100}	166.1	132.6	31.0	31.8	344.6	273.1	96.2	128.4
LSD (0.05)	18.5	16.1	3.62	4.85	42.9	37.5	13.4	12.8
Interaction								
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Iron

The data from the Table 4.42 exhibited significant results for Fe uptake in rice grains in case of wheat straw and green manure practices in rice as well as tillage and rice straw management practices in wheat. Amongst the wheat straw and green manure practices in rice, the data showed significant difference within the treatments, as the Fe uptake was significantly higher in PTR_{W25}+GM (371.6 and 299.3 g ha^{-1}) as compared to the PTR_{W25} (292.5 and 221.2 g ha^{-1}) and PTR_{W0} (260.7 and 208.5 g ha^{-1}) during both the years i.e. 2016 and 2017. Even the Fe uptake in rice grains was higher in PTR_{W0}+GM as compared to the PTR_{W25} and PTR_{W0} treatments. However, in case of the tillage and rice straw management practices in wheat, Fe uptake was significantly higher in ZTW_{R100} as compared to the ZTW_{R0}. Even the Fe uptake was also higher in CTW_{R0} as compared to the ZTW_{R0} treatment. The trend was found similar during both the years. The interaction between wheat straw and green manure practices in rice as well as tillage and rice straw management practices in wheat on Cu uptake in rice grains was found non-significant. Earlier studies have shown that crop residues contain considerable amount of Fe, which, when applied to the soil, results in higher availability of this micronutrient (Walia *et al* 2010), and thus, the crop uptake of this micronutrient significantly increases (Mann *et al* 2006).

Manganese

The data in respect of Mn uptake in rice grains is presented in Table 4.42. A close examination of the data regarding the effect of wheat straw and green manure practices in rice as well as tillage and rice straw management practices in wheat on Mn uptake in rice grains, revealed that the Mn uptake in rice grains varied from 72.5 to 106.2 g ha^{-1} and from 82.9 to 146.8 g ha^{-1}. Mn uptake was significantly higher in ZTW_{R100} i.e. 96.2 and 128.4 g ha^{-1} as compared to the ZTW_{R0} i.e. 77.6 and 100.1 g ha^{-1} during both the years of experimentation i.e. 2016 and 2017. Even the Mn uptake was higher in CTW_{R0} (88.9 and 112.9 g ha^{-1}) as compared to the ZTW_{R0} treatment in 2016 and 2017. However, in case of wheat straw and green manure practices in rice, the data revealed that the Mn uptake was significantly higher in PTR_{W25}+GM (106.2 and 146.8 g ha^{-1}) as compared to the PTR_{W25} (78.4 and 99.8 g ha^{-1}) and PTR_{W0} (72.5 and 82.9 g ha^{-1}). Even the Mn uptake in rice grains was higher in PTR_{W0}+GM as compared to the PTR_{W25} and PTR_{W0} among the wheat straw and green manure practices in rice crop. In conclusion, it was recorded from the data that the treatments where green manure was incorporated, they showed higher Mn uptake in rice grains as compared to the treatments where no green manure was incorporated in soil. However, the interaction between wheat straw and green manure practices in rice as well as tillage and rice straw management practices in wheat was found non-significant.

4.11.4 Micronutrients (Zn, Cu, Fe and Mn) uptake in rice straw

Zinc

It is evident from the data (Table 4.43) that the Zn uptake in rice straw ranged from 596.6 to 782.3 g ha^{-1} and from 583.0 to 764.7 g ha^{-1} between the wheat straw and green manure practices in rice as well as tillage and rice straw management practices in wheat during both the years of experimentation. Zn uptake in rice straw was found higher in ZTW_{R100} followed by CTW_{R0} and then in ZTW_{R0} during both the years. Zn uptake in rice straw was found significantly higher under ZTW_{R100} i.e. 759.8 and 746.7 g ha^{-1} as compared to the ZTW_{R0} i.e. 620.0 and 610.9 g ha^{-1} during both the years of experimentation i.e. 2016 and 2017. However, in wheat straw and green manure practices in rice, Zn uptake was found significantly higher in PTR_{W25}+GM (782.3g ha^{-1}) as compared to the PTR_{W25} (648.8g ha^{-1}) and PTR_{W0} (596.6g ha^{-1}) in 2016. Similarly, Zn uptake was found higher in PTR_{W25}+GM as compared to the PTR_{W25} and PTR_{W0} in 2017. Zn uptake was higher in both the treatments where green manure was incorporated as compared to the treatments where no green manure was incorporated. The beneficial effect of organic manure in improving the Zn uptake may be due to its higher availability from the unavailable forms through higher chelating capacity of organic manure (Nayyar *et al* 1990).

Copper

The data pertaining to the effect of wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat, showed that the Cu uptake in rice straw ranged from 47.3 to 74.1 g ha^{-1} and from 46.6 to 73.7 g ha^{-1} in 2016 as well as 2017. Cu uptake in rice straw was significantly affected during both the years within the treatments among the wheat straw and green manure practices in rice. It was observed that the Cu uptake was significantly higher in wheat straw under PTR_{W25}+GM (74.1 and 73.7 g ha^{-1}) as compared to PTR_{W0} (47.3 and 46.6 g ha^{-1}) during first and second year of experimentation. Moreover, the Cu uptake was found higher under PTR_{W0}+GM as compared to the PTR_{W25} and $PTR_{W0.}$ However, in case of tillage and rice straw management practices in wheat, data revealed significant effect on Cu uptake in rice straw. The Cu uptake was found higher in ZTW_{R100} (64.7 and 64.1 g ha^{-1}) as compared to the CTW_{R0} (57.4 and 58.2 g ha^{-1}) and ZTW_{R0} (53.3 and 52.9 g ha^{-1}) during both the years (2016 and 2017). The interaction between the wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was not significant. Increased Cu uptake by rice grain with green manure may be ascribed to increased availability of Cu under reduced conditions caused by green manure incorporation, thereby resulting in higher uptake of Cu.

Table 4.43: Effect of tillage, green manuring and wheat straw management practices on uptake (g ha^{-1}) of micronutrients in rice straw

Treatment	Zn		Cu		Fe		Mn	
	2016	2017	2016	2017	2016	2017	2016	2017
Wheat straw and green manure practices in rice								
PTR_{W0}	596.6	583.0	47.3	46.6	2294.0	2267.6	2084.0	2075.8
PTR_{W25}	648.8	639.9	49.3	49.3	2576.0	2554.1	2148.9	2158.0
PTR_{W0}+GM	739.3	734.2	63.2	63.9	3634.7	3625.5	2433.9	2440.2
PTR_{W25}+GM	782.3	764.7	74.1	73.7	3948.1	3890.2	2573.0	2553.8
LSD (0.05)	90.9	NS	8.86	15.3	504.3	489.3	NS	NS
Tillage and rice straw management practices in wheat								
CTW_{R0}	695.5	683.8	57.4	58.2	3133.4	3110.6	2325.2	2333.2
ZTW_{R0}	620.0	610.9	53.3	52.9	2734.7	2702.2	2124.9	2127.7
ZTW_{R100}	759.8	746.7	64.7	64.1	3471.5	3440.3	2479.9	2460.0
LSD (0.05)	76.8	69.3	8.83	7.52	507.8	470.5	235.9	NS
Interaction								
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Iron

The data (Table 4.43) regarding the effect of wheat straw and GM practices in rice and tillage and rice straw management practices in wheat on Fe uptake in rice straw (2016 and 2017) showed that the uptake of Fe in rice straw ranged from 2294.0 to 3948.1 g ha^{-1} and from 2267.6 to 3890.2 g ha^{-1} in both the years of experimentation i.e. 2016 and 2017, respectively. Amongst the tillage and rice straw management practices in wheat irrespective of the wheat straw and GM practices in rice, significant differences in Fe uptake in rice straw were found within the treatments during 2016 as well as 2017. The Fe uptake in rice straw was observed significantly higher in ZTW_{R100} (3471.5 and 3440.3 g ha^{-1}) treatment as compared to the ZTW_{R0} (2734.7 and 2702.2 g ha^{-1}) during both the years (2016 and 2017). However, in wheat straw and green manure practices in rice, significant effects were observed for Fe uptake in rice straw in 2016 as well as in 2017. Fe uptake in rice straw was significantly higher in PTR_{W25}+GM (3948.1 and 3890.2 g ha^{-1}) as compared to the PTR_{W25} (2576.0 and 2554.1 g ha^{-1}) and PTR_{W0} (2576.0 and 2554.1 g ha^{-1}) treatments in 2016 and 2017. The interaction between the wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was not significant. Higher uptake of Fe with manurestreated plots may be ascribed to increased availability of Fe due to their favourable impact on oxidation-reduction regime and higher chelation.

Manganese

Mn uptake in rice straw showed significant differences within wheat straw and green manure practices in rice irrespective of the tillage and rice straw management practices in wheat. It was observed that the Mn uptake in wheat straw ranged between 313.5 to 386.9 mg kg^{-1} and between 342.5 to 431.9 mg kg^{-1} during both the years of experimentation i.e. 2015-16 and 2016-17. Amongst the wheat straw and GM practices in rice irrespective of the tillage and rice straw management practices in wheat, data showed that the Mn uptake was significantly higher in PTR_{W25}+GM (386.9 and 431.9 mg kg^{-1}) with respect to the PTR_{W0} (313.5 and 342.5 mg kg^{-1}) and PTR_{W25} (345.2 and 383.8 mg kg^{-1}) during both the years of experimentation (2015-16 and 2016-17). Moreover, it was observed that the Mn uptake in wheat straw was higher in the treatments where green manure was incorporated (PTR_{W25}+GM and PTR_{W0}+GM) as compared to the treatments where no green manuring was done (PTR_{W0} and PTR_{W25}). However, in case of tillage and rice straw management practices in wheat irrespective of the wheat straw and green manure practices in rice, significant difference was found in 2016 as well as 2017. It was observed that Mn uptake in wheat straw was found significantly higher in ZTW_{R100} (381.1and 417.4 mg kg^{-1}) treatment as compared to CTW_{R0} (349.7 and 385.9 mg kg^{-1}) and ZTW_{R0} (332.8 and 361.9 mg kg^{-1}) during both the years (2015-16 and 2016-17). The interaction between the wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was not significant.

4.12 Effect of tillage, green manuring and wheat straw management practices on soil chemical properties

4.12.1 Distribution of soil pH in profile

A persual of the data in Table 4.44 regarding the effect of wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat did not significantly affected the soil pH in profile (0- 7.5cm, 7.5-15 cm, 15-30 cm, 30-45 cm and 45-60 cm). The pH value ranged from 7.10 to 7.18, 7.20 to 7.29, 7.50 to 7.63, 7.48 to 7.58 and 7.47 to 7.55 in 0-7.5cm, 7.5-15 cm, 15-30 cm, 30-45 cm and 45-60 cm soil depths in 2015. Similarly, the soil pH varied from 7.08 to 7.17, 7.18 to 7.28, 7.59 to 7.65, 7.58 to 7.65 and 7.50 to 7.55 in 0-7.5cm, 7.5-15 cm, 15-30 cm, 30-45 cm and 45-60 cm soil depths in 2017. Among the wheat straw and green manure practices in rice, non-significant difference among the treatments was found on soil pH during both the years of experimentation (2015 and 2017). The soil pH was found higher in CTW_{R0} than ZTW_{R0} and at the last in ZTW_{R100}. The pH value was found lower in the treatments where residue was retained or green manure was incorporated in the soil before rice. The trend was similar during both the years. It was observed from the data that soil pH increases with increase in depth (7.5-15 cm and 15-30 cm) and then again it start decreases (30-45 cm and 45-60 cm).

Table 4.44: Effect of tillage, green manuring and wheat straw management practices on soil pH in profile

Treatment	Soil depth (cm)				
	0 - 7.5	7.5 – 15	15 – 30	30 – 45	45 – 60
Wheat straw and green manure practices in rice (2015)					
PTR_{W0}	7.18	7.27	7.54	7.49	7.48
PTR_{W25}	7.15	7.26	7.54	7.50	7.49
PTR_{W0}+GM	7.14	7.23	7.63	7.58	7.55
PTR_{W25}+GM	7.10	7.20	7.56	7.51	7.50
LSD (0.05)	NS	NS	NS	NS	NS
Tillage and rice straw management practices in wheat					
CTW_{R0}	7.17	7.29	7.50	7.48	7.47
ZTW_{R0}	7.15	7.27	7.60	7.55	7.49
ZTW_{R100}	7.14	7.24	7.60	7.54	7.53
LSD (0.05)	NS	NS	NS	NS	NS
Interaction LSD (0.05)	NS	NS	NS	NS	NS
Wheat straw and green manure practices in rice (2017)					
PTR_{W0}	7.17	7.24	7.65	7.65	7.55
PTR_{W25}	7.14	7.23	7.63	7.65	7.55
PTR_{W0}+GM	7.11	7.21	7.62	7.62	7.54
PTR_{W25}+GM	7.08	7.18	7.59	7.58	7.50
LSD (0.05)	NS	NS	NS	NS	NS
Tillage and rice straw management practices in wheat					
CTW_{R0}	7.16	7.28	7.64	7.60	7.53
ZTW_{R0}	7.12	7.26	7.62	7.64	7.52
ZTW_{R100}	7.11	7.21	7.61	7.63	7.54
LSD (0.05)	NS	NS	NS	NS	NS
Interaction LSD (0.05)	NS	NS	NS	NS	NS

Amongst the wheat straw and green manure practices in wheat, it was observed from the data that pH was found lower in the treatments where green manure was incorporated (PTR_{W25}+GM and PTR_{W0}+GM) as compared to the treatments where no green manuring was done (PTR_{W0} and PTR_{W25}). However, the interaction between the tillage and rice straw management practices in wheat as well as the wheat straw and green manure practices in rice was found non-significant in 2015 as well as 2017.

Decrease in pH in manured plots may be attributed to release of organic acids during decomposition of these organic manures (Sadana and Bajwa 1985). The decline in soil pH may also attributes to decrease in buffer power of the soil with continuous addition of urea because upon hydrolysis of urea, there was release of H^+ ions (Brar *et al* 2004). Antil *et al* (2011) also reported that the decrease in soil pH may be attributed to the production of organic acids during decomposition of organic materials.

4.12.2 Distribution of electrical conductivity (EC) in profile

A close examination of the data (Table 4.45) related to the effect of wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat on electrical conductivity (EC) in soil profile, revealed that the EC showed non-significant difference among the different treatments. The EC value ranged from 0.165 to 0.183 dS m^{-1}, 0.151 to 0.178 dS m^{-1}, 0.143 to 0.158 dS m^{-1}, 0.116 to 0.144 dS m^{-1} and 0.103 to 0.129 dS m^{-1} in 0-7.5cm, 7.5-15 cm, 15-30 cm, 30-45 cm and 45-60 cm soil depths in 2015. Similarly, the soil EC varied from 0.167 to 0.184 dS m^{-1}, 0.142 to 0.153 dS m^{-1}, 0.128 to 0.144 dS m^{-1}, 0.127 to 0.137 dS m^{-1} and 0.109 to 0.122 dS m^{-1} in 0-7.5cm, 7.5-15 cm, 15-30 cm, 30-45 cm and 45-60 cm soil depths in 2017. The EC of the surface layer (0-7.5 cm) of soil was found lower in comparison to the lower layer viz.7.5-15 cm, 15-30 cm, 30-45 cm and 45-60 cm.

Among the wheat straw and green manure practices in rice, the EC was found higher in treatments where green manure was incorporated (PTR_{W25}+GM and PTR_{W0}+GM) as compared to the treatments where no green manure was incorporated (PTR_{W0} and PTR_{W25}). On the other hand, the EC was found higher in ZTW_{R100} as compared to CTW_{R0} and ZTW_{R0}. The trend was found similar during both the years among the different treatments. However, the interaction between the tillage and rice straw management practices in wheat as well as the wheat straw and green manure practices in rice was found non-significant in 2015 as well as 2017. Reddy *et al* (1986) reported that the reduction in soil pH due to green manure incorporation or crop residues retention along with chemical fertilizers application was attributed to the formation of organic acids by the reaction between inorganic fertilizers and manure, the release of organic acids on decomposition of added organic manure caused conversion of nutrient elements in the available form due to the activity of microorganisms.

Table 4.45: Effect of tillage, green manuring and wheat straw management practices on soil EC (dS m^{-1}) in profile

Treatment	Soil depth (cm)				
	0 - 7.5	**7.5 – 15**	**15 – 30**	**30 – 45**	**45 – 60**
Wheat straw and green manure practices in rice (2015)					
PTR_{W0}	0.176	0.164	0.158	0.135	0.123
PTR_{W25}	0.165	0.162	0.143	0.143	0.123
PTR_{W0}+GM	0.183	0.178	0.153	0.116	0.103
PTR_{W25}+GM	0.182	0.175	0.151	0.136	0.128
LSD (0.05)	NS	NS	NS	NS	NS
Tillage and rice straw management practices in wheat					
CTW_{R0}	0.175	0.151	0.158	0.144	0.129
ZTW_{R0}	0.175	0.166	0.149	0.131	0.114
ZTW_{R100}	0.179	0.169	0.146	0.123	0.114
LSD (0.05)	NS	NS	NS	NS	NS
Interaction LSD (0.05)	NS	NS	NS	NS	NS
Wheat straw and green manure practices in rice (2017)					
PTR_{W0}	0.167	0.142	0.128	0.127	0.109
PTR_{W25}	0.171	0.144	0.137	0.133	0.122
PTR_{W0}+GM	0.179	0.150	0.142	0.134	0.117
PTR_{W25}+GM	0.184	0.153	0.144	0.137	0.117
LSD (0.05)	NS	NS	NS	NS	NS
Tillage and rice straw management practices in wheat					
CTW_{R0}	0.173	0.145	0.136	0.130	0.119
ZTW_{R0}	0.176	0.148	0.138	0.134	0.114
ZTW_{R100}	0.177	0.149	0.139	0.134	0.116
LSD (0.05)	NS	NS	NS	NS	NS
Interaction LSD (0.05)	NS	NS	NS	NS	NS

4.11.3 Distribution of soil organic carbon (SOC) in profile

It is evident from the data in Table 4.46 concerning to the effect of tillage and rice straw management practices in wheat as well as the wheat straw and green manure practices in rice, the SOC was found significantly higher in surface layers (0-7.5 cm and 7.5-15 cm) as compared to the lower layers (15-30 cm, 30-45 cm and 45-60 cm). The SOC ranged from 0.542 to 0.753, 0.393 to 0.568, 0.209 to 0.298, 0.135 to 0.173 and 0.126 to 0.159 percent in 0-7.5cm, 7.5-15 cm, 15-30 cm, 30-45 cm and 45-60 cm soil depths in 2015. Similarly, the soil SOC varied from 0.547 to 0.754, 0.394 to 0.570, 0.224 to 0.303, 0.149 to 0.161and 0.133 to 0.150 percent in 0-7.5 cm, 7.5-15 cm, 15-30 cm, 30-45 cm and 45-60 cm soil depths in 2017. Amongst the wheat straw and green manure practices in rice, the data revealed that the SOC was significantly higher in PTR_{W25}+GM (0.753 percent) as compared to the PTR_{W0}+GM (0.664 percent), PTR_{W25} (0.575 percent) and PTR_{W0} (0.542 percent) in surface soil layer (0-7.5 cm) in 2015. Moreover, the SOC was found higher in ZTW_{R100} (0.679 percent) followed by ZTW_{R0} (0.627 percent) and then in CTW_{R0} (0.595 percent) in 2015.

Likewise, in 2017, the SOC in case of wheat straw and green manure treatment practices in rice, varied as 0.754 percent in PTR_{W25}+GM, 0.671 percent in PTR_{W0}+GM, 0.583 percent in PTR_{W25} and 0.547 percent in $PTR_{W0.}$ However, in case of tillage and rice straw management practices in rice, the SOC was found significantly higher in ZTW_{R100} (0.681 percent) followed by ZTW_{R0} (0.632 percent) and then in CTW_{R0} (0.602 percent). In nutshell, the SOC was found higher in the treatments where crop residue was retained as well as the treatments where green manure was incorporated in soil before rice crop as compared to the treatments where no crop residue was retained as well as no green manure was incorporated in the soil. The interaction was found non-significant between tillage and rice straw management practices in wheat as well as the wheat straw and green manure practices in rice.

The increase in soil organic carbon content in crop residue retained plots may be due to the addition of organic carbon through organic manure. Built up of organic manure may be due to the continuous addition of crop residues and fertilizers and also proliferation of more roots due to higher biomass production. Bhardwaj *et al* (2010) reported that maximum organic carbon content was observed under conjoint use of organic sources or crop residues followed by fertilizers plus organic combinations. Increase in soil organic carbon with application of an organic manure and crop residue has been reported by (Ghuman and Sur 2001).

Table 4.46: Effect of tillage, green manuring and wheat straw management practices on SOC (%) in profile

Treatment	Soil depth (cm)				
	0 - 7.5	**7.5 – 15**	**15 - 30**	**30 – 45**	**45 – 60**
Wheat straw and green manure practices in rice (2015)					
PTR_{W0}	0.542	0.393	0.209	0.135	0.126
PTR_{W25}	0.575	0.433	0.262	0.159	0.139
PTR_{W0}+GM	0.664	0.508	0.267	0.173	0.148
PTR_{W25}+GM	0.753	0.568	0.271	0.170	0.159
LSD (0.05)	0.03	0.03	NS	NS	NS
Tillage and rice straw management practices in wheat					
CTW_{R0}	0.595	0.453	0.244	0.170	0.151
ZTW_{R0}	0.627	0.476	0.215	0.152	0.136
ZTW_{R100}	0.679	0.497	0.298	0.156	0.144
LSD (0.05)	0.02	0.03	NS	NS	NS
Interaction LSD (0.05)	NS	NS	NS	NS	NS
Wheat straw and green manure practices in rice (2017)					
PTR_{W0}	0.547	0.394	0.224	0.149	0.133
PTR_{W25}	0.583	0.435	0.268	0.154	0.140
PTR_{W0}+GM	0.671	0.518	0.274	0.159	0.150
PTR_{W25}+GM	0.754	0.570	0.276	0.161	0.147
LSD (0.05)	0.03	0.05	NS	NS	NS
Tillage and rice straw management practices in wheat					
CTW_{R0}	0.602	0.457	0.253	0.156	0.145
ZTW_{R0}	0.632	0.480	0.225	0.155	0.142
ZTW_{R100}	0.681	0.500	0.303	0.156	0.141
LSD (0.05)	0.02	0.01	NS	NS	NS
Interaction LSD (0.05)	NS	NS	NS	NS	NS

Moreover, on incorporation of green manure into soil, it decompose rapidly due to their high moisture content, low C: N ratio and low lignin content (Singh *et al* 1992), and only a small quantity of carbon is left for conversion into stable soil organic matter. The increase in soil organic carbon content with the long term use of manure in rice-wheat system has also been reported by Yadvinder-Singh *et al* (2004). Lal and Mathur (1989) reported higher production of root biomass of crops leading to more organic residue addition to the soil.

4.13Effect of tillage, green manuring and wheat straw management practices on DTPA-extractable micronutrients (Zn, Cu, Fe and Mn)

4.13.1 Distribution of DTPA-extractable Zn in profile

The data (Table 4.47) regarding the effect of wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat on DTPA-extractable Zn in soil profile (0-60 cm), showed that the DTPA-extractable Zn varied from 3.94 to 6.14 mg kg^{-1}, 2.22 to 3.13 mg kg^{-1}, 0.51 to 0.77 mg kg^{-1}, 0.38 to 0.48 mg kg^{-1} and 0.24 to 0.39 mg kg^{-1} in 0-7.5 cm, 7.5-15 cm, 15-30 cm, 30-45 cm and 45-60 cm soil depths in the first year of experimentation (2015). Likewise, in 2017, the DTPA-extractable Zn ranged from 3.32 to 5.38 mg kg^{-1}, 1.67 to 2.37 mg kg^{-1}, 0.43 to 0.57 mg kg^{-1}, 0.17 to 0.27 mg kg^{-1} and 0.16 to 0.25 mg kg^{-1} in 0-7.5 cm, 7.5-15 cm, 15-30 cm, 30-45 cm and 45-60 cm soil depths. From the data, it was revealed that the DTPA-extractable Zn was significantly higher at the 0-7.5 cm and 7.5-15 cm as compared to the deeper soil layers in case of wheat straw and green manure practices in rice as well as tillage and rice straw management practices in wheat.

It was observed that the DTPA-Zn content was significantly higher in PTR_{W25}+GM (6.14 and 5.38 mg kg^{-1}) and PTR_{W0}+GM (5.68 and 5.00 mg kg^{-1}) as compared to the PTR_{W25} (4.55 and 4.24 mg kg^{-1}) and PTR_{W0} (3.94 and 3.32 mg kg^{-1}) treatments during both the years of experimentation (2015 and 2017) among the wheat straw and green manure management practices in rice. It can be concluded that the DTPA-extractable Zn content was found higher in the treatments where green manure was incorporated in the soil before rice as compared to the treatments where no green manure was incorporated in soil. However, in case of tillage and rice straw management practices in wheat, DTPA-extractable Zn was significantly higher in ZTW_{R100} (5.53 and 4.75 mg kg^{-1}) as compared to the CTW_{R0} (5.05 and 4.51 mg kg^{-1}) and ZTW_{R0} (4.65 and 4.20 mg kg^{-1}) during both the years (2015 and 2017). This may be ascribed to the better supply of Zn from organic materials or crop residues. The organic materials, besides being the source of organic C, available N, P and K played an important role in release of Zn, Cu, Fe and Mn in rice-wheat system because these provide the favourable environment for oxidation and reduction regime and lowering of soil pH. Zn availability in soils is influenced by soil pH (Anderson and Christensen 1988). Application of green manure not only promotes biological and chemical reactions that result in the dissolution of non-available Zn, but also supplies large amounts of Zn to the soil (Moharana *et al* 2017).

Table 4.47: Effect of tillage, green manuring and wheat straw management practices on DTPA – Zn (mg kg^{-1}) in profile

Treatment	Soil depth (cm)				
	0 - 7.5	**7.5 – 15**	**15 – 30**	**30 – 45**	**45 – 60**
Wheat straw and green manure practices in rice (2015)					
PTR_{W0}	3.94	2.22	0.51	0.38	0.24
PTR_{W25}	4.55	2.60	0.58	0.40	0.34
PTR_{W0}+GM	5.68	2.96	0.74	0.44	0.36
PTR_{W25}+GM	6.14	3.13	0.77	0.48	0.39
LSD (0.05)	0.87	0.24	0.06	NS	NS
Tillage and rice straw management practices in wheat					
CTW_{R0}	5.05	2.68	0.64	0.46	0.38
ZTW_{R0}	4.65	2.49	0.60	0.39	0.29
ZTW_{R100}	5.53	3.03	0.71	0.43	0.33
LSD (0.05)	0.64	0.36	0.04	NS	NS
Interaction LSD (0.05)	NS	NS	NS	NS	NS
Wheat straw and green manure practices in rice (2017)					
PTR_{W0}	3.32	1.67	0.43	0.17	0.16
PTR_{W25}	4.24	2.23	0.44	0.21	0.18
PTR_{W0}+GM	5.00	2.32	0.52	0.24	0.20
PTR_{W25}+GM	5.38	2.37	0.57	0.27	0.25
LSD (0.05)	0.31	0.09	0.06	NS	NS
Tillage and rice straw management practices in wheat					
CTW_{R0}	4.51	2.13	0.49	0.26	0.23
ZTW_{R0}	4.20	2.05	0.47	0.20	0.17
ZTW_{R100}	4.75	2.27	0.51	0.22	0.20
LSD (0.05)	0.28	0.08	NS	NS	NS
Interaction LSD (0.05)	NS	NS	NS	NS	NS

Hargrove *et al* (1982) have observed redistribution of Zn to the surface layer of soil by no-tillage and attributed due to accumulation of crop residues and possible association with soil organic fractions (Shuman and Hargrove 1985). The interaction between wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat during both the years was found non-significant. DTPA-extractable Zn was positively correlated with DTPA Cu, Mn, and Fe. The deficiency of Zn is mainly associated with soils having coarse texture, high pH, low organic C, and high calcium carbonate contents (Katyal and Sharma 1991).

4.13.2 Distribution of DTPA-extractable Cu in profile

The effect of wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat on DTPA-extractable Cu in soil profile (0-60 cm), presented that the DTPA-extractable Cu (Table 4.48) ranged from 0.69 to 0.81 mg kg^{-1}, 0.57 to 0.68 mg kg^{-1}, 0.25 to 0.32 mg kg^{-1}, 0.22 to 0.29 mg kg^{-1} and 0.10 to 0.14 mg kg^{-1} in 0-7.5 cm, 7.5-15 cm, 15-30 cm, 30-45 cm and 45-60 cm soil depths in the first year of experimentation (2015). Similarly, in 2017, the DTPA-extractable Cu varied from 0.68 to 0.76 mg kg^{-1}, 0.26 to 0.36 mg kg^{-1}, 0.22 to 0.26 mg kg^{-1}, 0.20 to 0.24 mg kg^{-1} and 0.11 to 0.13 mg kg^{-1} in 0-7.5 cm, 7.5-15 cm, 15-30 cm, 30-45 cm and 45-60 cm soil depths. From the data, it was revealed that the DTPA-extractable Cu was significantly higher at the surface soil layers (0-7.5 cm and 7.5-15 cm) as compared to the lower depths in case of wheat straw and green manure practices in rice as well as tillage and rice straw management practices in wheat. This increase in availability of DTPA-extractable Cu in the plots where crop residue was retained over the surface as well as where green manure was incorporated in soil may be ascribed to reduction in the redox - potential of the soil with the addition of organic manures which lead to more release of micronutrients in available form in the soil as compared with the application of chemical fertilizer alone. The increase in DTPA-extractable Cu may be attributed to the chelating action of organic compounds released during decomposition of organic materials, which increased the availability of micronutrients by preventing fixation, oxidation, precipitation and leaching. Hao and Chang (2002) reported the effect of 25 annual cattle manure applications on soluble and exchangeable Cu in soil. In an acid soil Lal and Mathur (1989) reported higher levels of DTPA-Cu under combined use of crop residue or green manure and fertilizer treatments.

Table 4.48: Effect of tillage, green manuring and wheat straw management practices on DTPA-Cu (mg kg^{-1}) in profile

Treatment	Soil depth (cm)				
	0 - 7.5	**7.5 – 15**	**15 – 30**	**30 – 45**	**45 – 60**
Wheat straw and green manure practices in rice (2015)					
PTR_{W0}	0.70	0.57	0.25	0.22	0.10
PTR_{W25}	0.73	0.60	0.29	0.25	0.13
PTR_{W0}+GM	0.76	0.64	0.31	0.29	0.14
PTR_{W25}+GM	0.80	0.68	0.32	0.29	0.14
LSD (0.05)	NS	NS	NS	NS	NS
Tillage and rice straw management practices in wheat					
CTW_{R0}	0.75	0.61	0.29	0.26	0.13
ZTW_{R0}	0.69	0.59	0.27	0.25	0.12
ZTW_{R100}	0.81	0.66	0.31	0.28	0.14
LSD (0.05)	0.04	NS	NS	NS	NS
Interaction LSD (0.05)	NS	NS	NS	NS	NS
Wheat straw and green manure practices in rice (2017)					
PTR_{W0}	0.68	0.26	0.22	0.20	0.11
PTR_{W25}	0.69	0.32	0.25	0.20	0.12
PTR_{W0}+GM	0.73	0.35	0.26	0.22	0.13
PTR_{W25}+GM	0.76	0.36	0.23	0.24	0.13
LSD (0.05)	0.05	NS	NS	NS	NS
Tillage and rice straw management practices in wheat					
CTW_{R0}	0.74	0.35	0.24	0.23	0.12
ZTW_{R0}	0.69	0.29	0.24	0.21	0.11
ZTW_{R100}	0.71	0.32	0.23	0.20	0.12
LSD (0.05)	NS	NS	NS	NS	NS
Interaction LSD (0.05)	NS	NS	NS	NS	NS

DTPA-Cu was found higher in PTR_{W25}+GM (0.80 and 0.76 mg kg^{-1}) and PTR_{W0}+GM (0.76 and 0.73 mg kg^{-1}) as compared to the PTR_{W25} (0.73 and 0.69 mg kg^{-1}) and PTR_{W0} (0.70 and 0.68 mg kg^{-1}) treatments during both the years of experimentation (2015 and 2017). The DTPA-Cu decreases with increase in soil depths, at the lower depths the DTPA-Cu content was more or less the same. However, in case of tillage and rice straw management practices in wheat, DTPA-Cu content was more in ZTW_{R100} (0.81 and 0.71 mg kg^{-1}) as compared to the CTW_{R0} (0.75 and 0.74 mg kg^{-1}) and ZTW_{R0} (0.69 and 0.69 mg kg^{-1}) during both the years (2015 and 2017). Significantly higher content of DTPA-Cu was observed in ZTW_{R100} with respect to CTW_{R0} and ZTW_{R0} in surface layers during both the years in case of treatments within tillage and rice straw management practices. The interaction between wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat on DTPA-extractable Cu was found non-significant. In an acid soil Lal and Mathur (1989) reported higher levels of DTPA-Cu under combined use of crop residues or organic materials and fertilizer treatments.

4.13.3 Distribution of DTPA-extractable Fe in profile

A persual of the data in Table 4.49 revealed that the DTPA-extractable Fe content ranged from 31.4 to 43.4 mg kg^{-1}, 19.3 to 28.8 mg kg^{-1}, 6.81 to 10.4 mg kg^{-1}, 3.99 to 5.90 mg kg^{-1} and 3.78 to 4.34 mg kg^{-1} in in 0-7.5 cm, 7.5-15 cm, 15-30 cm, 30-45 cm and 45-60 cm soil depths in the first year of experimentation (2015). Similarly, in 2017, the DTPA-extractable Fe ranged from 29.5 to 36.5 mg kg^{-1}, 18.6 to 26.9 mg kg^{-1}, 6.87 to 9.04 mg kg^{-1}, 3.95 to 5.86 mg kg^{-1} and 3.18 to 4.09 mg kg^{-1} in 0-7.5 cm, 7.5-15 cm, 15-30 cm, 30-45 cm and 45-60 cm soil depths. The data among the wheat straw and green manure practices in rice, revealed that the DTPA-extractable Fe showed significantly higher content in surface soil layer (0-7.5 cm) in PTR_{W25}+GM (43.4 mg kg^{-1}) with respect to the PTR_{W0}+GM (40.8 mg kg^{-1}), PTR_{W25} (35.1 mg kg^{-1}) and PTR_{W0} (31.4 mg kg^{-1}) treatments in 2015. However, DTPA-extractable Cu was also found significantly higher in ZTW_{R100} (40.6 mg kg^{-1}) with respect to CTW_{R0} (37.8 mg kg^{-1}) and ZTW_{R0} (34.6 mg kg^{-1}) in 2015.

Similarly, in 2017, DTPA-extractable Fe was found significantly higher in PTR_{W25}+GM (36.5 mg kg^{-1}) with respect to the PTR_{W25} (32.4 mg kg^{-1}) and PTR_{W0} (29.5 mg kg^{-1}) within wheat straw and green manure practices in rice. It was observed that the DTPA-Fe content was higher in the treatments where crop residue was retained as well as green manure was incorporated in soil before rice crop. Moreover, in case of tillage and rice straw management practices in wheat, it was observed that the DTPA-extractable Fe was significantly higher in ZTW_{R100} (34.3 mg kg^{-1}) with respect to CTW_{R0} (32.9 mg kg^{-1}) and ZTW_{R0} (31.3 mg kg^{-1}). It was observed that the DTPA-Fe was higher in surface soil layers and it decreases with increase in soil depths. The interaction between wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat on DTPA-extractable Fe was found non-significant.

Table 4.49: Effect of tillage, green manuring and wheat straw management practices on DTPA-Fe (mg kg^{-1}) in profile

Treatment	Soil depth (cm)				
	0 - 7.5	7.5 – 15	15 – 30	30 – 45	45 – 60
Wheat straw and green manure practices in rice (2015)					
PTR_{W0}	31.4	19.3	6.81	3.99	3.78
PTR_{W25}	35.1	23.9	8.84	4.63	3.89
PTR_{W0}+GM	40.8	24.8	9.37	5.18	4.09
PTR_{W25}+GM	43.4	28.8	10.4	5.90	4.13
LSD (0.05)	1.73	2.94	0.59	NS	NS
Tillage and rice straw management practices in wheat					
CTW_{R0}	37.8	23.9	8.95	4.94	4.34
ZTW_{R0}	34.6	23.0	8.27	4.69	3.63
ZTW_{R100}	40.6	25.7	9.32	5.13	3.96
LSD (0.05)	2.14	1.88	0.72	NS	NS
Interaction LSD (0.05)	NS	NS	NS	NS	NS
Wheat straw and green manure practices in rice (2017)					
PTR_{W0}	29.5	18.6	6.87	3.95	3.18
PTR_{W25}	32.4	23.2	7.41	4.52	3.76
PTR_{W0}+GM	32.9	24.9	8.41	5.86	3.93
PTR_{W25}+GM	36.5	26.9	9.04	5.23	4.09
LSD (0.05)	4.00	5.18	1.44	NS	NS
Tillage and rice straw management practices in wheat					
CTW_{R0}	32.9	22.9	8.73	4.92	3.85
ZTW_{R0}	31.3	22.4	7.18	4.43	3.52
ZTW_{R100}	34.3	24.8	7.88	4.57	3.87
LSD (0.05)	2.29	NS	1.01	NS	NS
Interaction LSD (0.05)	NS	NS	NS	NS	NS

An increase in the availability of Fe in soil with the application of organic manure or crop residues in rice-wheat cropping system has been reported by Yadvinder-Singh *et al* 2000, Yadav and Kumar 2000). However, crop residue management increased the micronutrients supply to a reasonable extent. Mann *et al* (1978) reported an increase in DTPA-Fe by green manure application in maize-wheat cropping system. Similarly, in a 2-year old experiment at Ludhiana, India, Fe deficiency was effectively corrected by manuring with Sesbania (Takkar and Nayyar 1986).

The Fe solubility is pH dependent, so decrease in pH may increase the concentration of available Fe (Aulakh and Malhi 2005). Higher content of DTPA-Fe was found in plot treated with green manure along with crop residues and chemical fertilizers as compared to inorganically treated plots and control, which was attributed to the amounts of Fe in the manure (Li *et al* 2010).

4.13.4 Distribution of DTPA-extractable Mn in profile

The data (Table 4.50) related to the effect of wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat on DTPA-extractable Mn in soil profile (0-60 cm), showed that the DTPA-extractable Mn varied from 4.53 to 5.42 mg kg^{-1}, 4.83 to 6.17 mg kg^{-1}, 4.48 to 5.55 mg kg^{-1}, 4.15 to 4.99 mg kg^{-1} and 4.17 to 4.48 mg kg^{-1} in 0-7.5 cm, 7.5-15 cm, 15-30 cm, 30-45 cm and 45-60 cm soil depths in the first year of experimentation (2015). Likewise, in 2017, the DTPA-extractable Mn ranged from 4.33 to 5.92 mg kg^{-1}, 4.40 to 6.42 mg kg^{-1}, 5.16 to 6.54 mg kg^{-1}, 5.79 to 6.61 mg kg^{-1} and 5.11 to 5.53 mg kg^{-1} in 0-7.5 cm, 7.5-15 cm, 15-30 cm, 30-45 cm and 45-60 cm soil depths. From the data, it was revealed that the DTPA-extractable Mn was significantly higher at the 0-7.5 cm and 7.5-15 cm soil layers as compared to the lower depths viz. 15-30 cm, 30-45 cm and 45-60 cm in case of wheat straw and green manure practices in rice as well as tillage and rice straw management practices in wheat. The DTPA-extractable Mn was found significantly higher in PTR_{W25}+GM (5.42 and 5.59 mg kg^{-1}) with respect to the PTR_{W25} (4.85 and 5.14 mg kg^{-1}) and PTR_{W0} (4.53 and 4.33 mg kg^{-1}) within wheat straw and green manure practices in rice during both the years of experimentation (2015 and 2017).

It was observed that the DTPA-extractable Mn content was higher in the treatments where crop residue was retained as well as green manure was incorporated in soil before rice crop. Moreover, in case of tillage and rice straw management practices in wheat, it was observed that the DTPA-extractable Mn was significantly higher in ZTW_{R100} (5.15 and 5.59 mg kg^{-1}) with respect to CTW_{R0} (5.03 and 5.34 mg kg^{-1}) and ZTW_{R0} (4.85 and 5.04 mg kg^{-1}) during 2015 as well as 2017. It was observed that the DTPA-Mn content increase with increase in soil depths but it again decreases in 45-60 cm soil layer in 2017. On the contrary, in 2015, no particular trend of increase or decrease was found to observe with increase in soil depths, it first increase then again it decreases with increase in soil depths. However, the interaction between the wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat.

Table 4.50: Effect of tillage, green manuring and wheat straw management practices on DTPA - Mn (mg kg^{-1}) in profile

Treatment	Soil depth (cm)				
	0 - 7.5	**7.5 – 15**	**15 – 30**	**30 – 45**	**45 - 60**
Wheat straw and green manure practices in rice (2015)					
PTR$_{W0}$	4.53	4.83	4.48	4.15	4.17
PTR$_{W25}$	4.85	4.98	4.98	4.20	4.21
PTR$_{W0}$+GM	5.23	5.75	5.41	4.59	4.48
PTR$_{W25}$+GM	5.42	6.17	5.51	4.99	4.36
LSD (0.05)	0.38	0.69	0.34	NS	NS
Tillage and rice straw management practices in wheat					
CTW$_{R0}$	5.03	5.48	5.06	4.36	4.31
ZTW$_{R0}$	4.85	5.13	4.67	4.16	4.19
ZTW$_{R100}$	5.15	5.68	5.55	4.92	4.41
LSD (0.05)	NS	0.29	0.26	NS	NS
Interaction LSD (0.05)	NS	NS	NS	NS	NS
Wheat straw and green manure practices in rice (2017)					
PTR$_{W0}$	4.33	4.40	5.16	5.79	5.23
PTR$_{W25}$	5.14	5.36	5.60	5.86	5.11
PTR$_{W0}$+GM	5.72	5.91	5.98	6.48	5.44
PTR$_{W25}$+GM	5.92	6.42	6.54	6.61	5.53
LSD (0.05)	0.33	0.28	0.16	NS	NS
Tillage and rice straw management practices in wheat					
CTW$_{R0}$	5.34	5.66	5.82	6.17	5.48
ZTW$_{R0}$	5.04	5.07	5.46	6.09	5.16
ZTW$_{R100}$	5.59	5.82	5.85	6.27	5.35
LSD (0.05)	0.43	0.28	0.18	NS	NS
Interaction LSD (0.05)	NS	NS	NS	NS	NS

An increase in DTPA-extractable Mn may be attributed to the reduction of Mn^{+4} to Mn^{+2} accompanied by an increase in its solubility under submerged conditions and the chelating action of organic manures or crop residues. Lal and Mathur (1989) reported long term application of crop residues or organic manure and fertilizer increased DTPA-extractable Mn in an acid soil. Hargrove *et al* (1982) investigated the influence of 5 yr of various tillage practices on the fertility status of an acid soil in Georgia. They found accumulations of Mn and Zn in the surface soil (7.5 cm) with no-tillage compared to conventional-tillage (plowed) treatments. In general, no-tillage resulted in increased nutrient concentrations in the surface soil and a decrease with depth, while conventional tillage resulted in more homogeneous soil with respect to soil fertility status. Organic C has a positive effect on available Zn, Cu, Mn, and Fe (Katyal and Sharma 1991).

4.14 Effect of tillage, green manuring and wheat straw management practices on chemical fractions of micronutrients (Zn, Cu, Fe and Mn) in surface soil

4.14.1 Water soluble plus exchangeable fraction (WSEX) of Zn, Cu, Fe and Mn

Water soluble plus exchangeable fraction zinc (WSEX-Zn)

A persual of the data (Table 4.51) regarding the effect of tillage, green manuring and wheat straw management practices on water soluble and exchangeable fraction (WSEX) of micronutrients (Zn, Cu, Fe and Mn) in surface soil (0-7.5 cm), states that the WSEX-Zn showed significant effect in case of treatments where green manure was incorporated in soil before rice crop i.e. PTR_{W25}+GM (1.84 and 1.94 mg kg^{-1}) with respect to the PTR_{W25} (1.72 and 1.82 mg kg^{-1})and PTR_{W0} (1.68 and 1.64 mg kg^{-1}) within wheat straw and green manure practices in rice in 2015 and 2017. Even the PTR_{W0}+GM treatment also showed higher WSEX-Zn content as compared to the PTR_{W25} and $PTR_{W0.}$ However, in case of tillage and rice straw management practices in wheat, data showed that the WSEX-Zn was significantly higher in the treatment where zero tillage was done plus crop residue was retained i.e. ZTW_{R100} (1.81 and 1.87 mg kg^{-1}) as compared to the CTW_{R0} (1.75 and 1.82 mg kg^{-1}) and ZTW_{R0} (1.71 and 1.76 mg kg^{-1}) during both the years of experimentation (2015 and 2017). Similar results were observed by Maskina *et al* (1998), who reported the increase in the WSEX fraction of Zn with organic manure amended plots at the end of 5 cycle of rice-wheat rotation. However, the interaction between wheat straw and green manure practices in rice as well as tillage and rice straw management practices in wheat found non-significant.

Water soluble plus exchangeable copper (WSEX-Cu)

The WSEX-Cu content showed significant effect among the treatments within wheat straw and green manure practices in rice, but it showed non-significant effect among the treatments in tillage and rice straw management practices in wheat in 2015. WSEX-Cu content ranged from 0.20 to 0.27 mg kg^{-1} and from 0.23 to 0.27 mg kg^{-1} within wheat straw and green manure practices in rice as well as tillage and rice straw management practices in wheat during 2015 and 2017. Amongst the treatments, PTR_{W25}+GM and PTR_{W0}+GM treatments showed higher WSEX-Cu content as compared to the PTR_{W25} and PTR_{W0}. The trend was similar among the different treatments during both the years. However, in case of tillage and rice straw management practices in wheat, data showed that the WSEX-Cu content was higher in the treatments where zero tillage was done plus crop residue was retained i.e. ZTW_{R100} (0.25 and 0.27 mg kg^{-1}) as compared to the CTW_{R0} (0.23 and 0.24 mg kg^{-1}) and ZTW_{R0} (0.23 and 0.25 mg kg^{-1}) during both the years of experimentation (2015 and 2017).

Table 4.51: Effect of tillage, green manuring and wheat straw management practices on WSEX fraction of micronutrients (mg kg^{-1}) in soil

Treatment	Zn	Cu	Fe	Mn
Wheat straw and green manure practices in rice (2015)				
PTR_{W0}	1.68	0.20	1.60	0.46
PTR_{W25}	1.72	0.22	1.70	0.51
PTR_{W0}+GM	1.79	0.25	1.80	0.57
PTR_{W25}+GM	1.84	0.27	1.84	0.62
LSD (0.05)	0.07	0.02	0.03	0.03
Tillage and rice straw management practices in wheat				
CTW_{R0}	1.75	0.23	1.74	0.54
ZTW_{R0}	1.71	0.23	1.67	0.49
ZTW_{R100}	1.81	0.25	1.80	0.59
LSD (0.05)	0.05	NS	0.05	0.06
Interaction LSD (0.05)	NS	NS	NS	NS
Wheat straw and green manure practices in rice (2017)				
PTR_{W0}	1.64	0.23	1.60	0.60
PTR_{W25}	1.82	0.25	1.75	0.62
PTR_{W0}+GM	1.88	0.27	1.75	0.67
PTR_{W25}+GM	1.94	0.26	1.80	0.72
LSD (0.05)	0.10	NS	0.04	0.05
Tillage and rice straw management practices in wheat				
CTW_{R0}	1.82	0.24	1.72	0.65
ZTW_{R0}	1.76	0.25	1.68	0.62
ZTW_{R100}	1.87	0.27	1.77	0.70
LSD (0.05)	NS	NS	0.05	0.05
Interaction LSD (0.05)	NS	NS	NS	NS

Water soluble plus exchangeable iron (WSEX-Fe)

The data in Table 4.51 showed that the WSEX-Fe content varied from 1.60 to 1.84 mg kg^{-1} and from 1.60 to 1.80 mg kg^{-1} among the treatments within wheat straw and green manure practices in rice as well as tillage and rice straw management practices in wheat. The WSEX-Fe was significantly higher in PTR_{W25}+GM, where it was 1.84 and 1.80 mg kg^{-1}, as compared to PTR_{W25} (1.70 and 1.75 mg kg^{-1}) and PTR_{W0} (1.60 and 1.60 mg kg^{-1}). It was observed that WSEX-Fe was higher in the treatments where residue was retained on soil surface as well as where green manure was incorporated in soil before rice crop. Similar trend was found to observe among the wheat straw and green manure practices in rice as well as tillage and rice straw management practices in wheat in 2017. However, in case of tillage and rice straw management practices in wheat, WSEX-Fe content was found higher in ZTW_{R100} (1.80 and 1.77 mg kg^{-1}) as compared to the CTW_{R0} (1.74 and 1.72 mg kg^{-1}) and ZTW_{R0} (1.67 and 1.68 mg kg^{-1}) during both the years of experimentation (2015 and 2017).

Water soluble plus exchangeable manganese (WSEX-Mn)

A close examination of the data (Table 4.51) showed that WSEX-Mn content ranged from 0.46 to 0.62 mg kg^{-1} and 0.60 to 0.72 mg kg^{-1} during both the years i.e. 2015 and 2017. Data showed significant difference within the treatments among the wheat straw and green manure practices in rice, it was observed that WSEX-Mn was significantly higher in PTR_{W25}+GM (0.62 and 0.72 mg kg^{-1}) as compared to PTR_{W25} (0.51 and 0.62 mg kg^{-1}) and PTR_{W0} (0.46 and 0.60 mg kg^{-1}) during both the years (2015 and 2017). Moreover, in case of tillage and rice straw management practices in wheat, data showed significant higher content in ZTW_{R100} i.e. 0.59 and 0.70 mg kg^{-1} with respect to ZTW_{R0} i.e. 0.49 and 0.62 mg kg^{-1} during 2015 and 2017. However, the interaction between wheat straw and green manure practices in rice as well as tillage and rice straw management practices in wheat found non-significant.

4.14.2 Specifically adsorbed fraction (SpAd) of Zn, Cu, Fe and Mn

Specifically adsorbed zinc (SpAd-Zn)

The data (Table 4.52) pertaining to the effect of tillage, green manuring and wheat straw management practices on specifically adsorbed fraction (SpAd) of micronutrients (Zn, Cu, Fe and Mn) in surface soil (0-7.5 cm), states that the SpAd-Zn showed higher content in case of treatments where green manure was incorporated in soil before rice crop i.e. PTR_{W25}+GM (4.04 and 4.25 mg kg^{-1}) with respect to the PTR_{W25} (2.91 and 3.48 mg kg^{-1})and PTR_{W0} (2.46 and 3.30 mg kg^{-1}) within wheat straw and green manure practices in rice in 2015 and 2017. Moreover, the PTR_{W0}+GM treatment also showed higher SpAd-Zn content as compared to the PTR_{W25} and $PTR_{W0.}$ However, in case of tillage and rice straw management practices in wheat, data showed that the SpAd-Zn was higher in ZTW_{R100} (3.54 and 4.11 mg kg^{-1}) as compared to the CTW_{R0} (3.29 and 3.67 mg kg^{-1}) and ZTW_{R0} (3.17 and 3.30 mg kg^{-1}) during both the years of experimentation (2015 and 2017).

Table 4.52: Effect of tillage, green manuring and wheat straw management practices on SpAd fraction of micronutrients (mg kg^{-1}) in soil

Treatment	Zn	Cu	Fe	Mn
Wheat straw and green manure practices in rice (2015)				
PTR_{W0}	2.46	0.05	0.22	1.91
PTR_{W25}	2.91	0.05	0.25	2.17
PTR_{W0}+GM	3.91	0.03	0.27	2.45
PTR_{W25}+GM	4.04	0.04	0.33	2.57
LSD (0.05)	0.65	NS	0.02	NS
Tillage and rice straw management practices in wheat				
CTW_{R0}	3.29	0.05	0.27	2.31
ZTW_{R0}	3.17	0.04	0.25	2.09
ZTW_{R100}	3.54	0.04	0.29	2.42
LSD (0.05)	NS	NS	0.02	NS
Interaction LSD (0.05)	NS	NS	NS	NS
Wheat straw and green manure practices in rice (2017)				
PTR_{W0}	3.30	0.05	0.31	0.56
PTR_{W25}	3.48	0.06	0.36	0.62
PTR_{W0}+GM	3.75	0.06	0.39	0.67
PTR_{W25}+GM	4.25	0.06	0.44	0.74
LSD (0.05)	0.44	NS	0.04	0.08
Tillage and rice straw management practices in wheat				
CTW_{R0}	3.67	0.06	0.38	0.65
ZTW_{R0}	3.30	0.05	0.35	0.60
ZTW_{R100}	4.11	0.06	0.40	0.69
LSD (0.05)	0.35	NS	NS	0.05
Interaction LSD (0.05)	NS	NS	NS	NS

Specifically adsorbed copper (SpAd-Cu)

The SpAd-Cu content showed non-significant effect among the treatments within wheat straw and green manure practices in rice as well as in case of tillage and rice straw management practices in wheat in 2015 and 2017 (Table 4.51). SpAd-Cu content varied from 0.03 to 0.05 mg kg^{-1} and from 0.05 to 0.06 mg kg^{-1} within wheat straw and green manure practices in rice as well as tillage and rice straw management practices in wheat during 2015 and 2017. It was observed from the data that the values for SpAd-Cu did not differ much among the treatments. However, in case of tillage and rice straw management practices in wheat, data showed that the SpAd-Cu content was nearly same among the treatments. It was observed that the values differ as, ZTW_{R100} (0.04 and 0.06 mg kg^{-1}), CTW_{R0} (0.05 and 0.06 mg kg^{-1}) and ZTW_{R0} (0.04 and 0.05 mg kg^{-1}) during both the years of experimentation (2015 and 2017). However, the interaction between wheat straw and green manure practices in rice as well as tillage and rice straw management practices in wheat found non-significant.

Specifically adsorbed iron (SpAd-Fe)

A persual of data regarding the effect of tillage and rice straw management practices in wheat as well as wheat straw and green manure practices in rice on SpAd-Fe content of surface soil (0-7.5 cm) ranged between 0.22 to 0.33 mg kg^{-1} and from 0.31 to 0.44 mg kg^{-1} during 2015 and 2017, respectively. The wheat straw and green manure practices in rice as well as the tillage and rice straw management practices in wheat indicated significant differences among the different treatments in the tear 2015, but on the other hand, the results showed non-significant differences in 2017 among tillage and rice straw management practices in wheat. The SpAd-Fe in PTR_{W25}+GM treatment (0.33 and 0.44 mg kg^{-1}) was significantly more as compared the PTR_{W25} (0.25 and 0.36 mg kg^{-1}) and PTR_{W0} (0.22 and 0.31 mg kg^{-1}). It was revealed that the SpAd-Fe was more in the treatments where green manure was incorporated in soil before rice plus crop residue was retained on soil surface. In case of tillage and rice straw management practices in wheat, SpAd-Fe was found higher in ZTW_{R100} (0.29 and 0.40 mg kg^{-1}) as compared to the ZTW_{R0} (0.25 and 0.35 mg kg^{-1}) and CTW_{R0} (0.27 and 0.38 mg kg^{-1}) which might be due to the higher organic matter and lower pH under these treatments which resulted in dissolution of iron from other fractions. The interaction between tillage and rice straw management practices in wheat as well as the wheat straw and green manure practices in rice was found non-significant. Iu *et al* (1981) reported increase in amount of SpAd-Fe with thw addition of organic manure. These results are also in agreement with the results obtained by Chatterjee *et al* (1992) who reported increase in this form with addition of organic manure.

Specifically adsorbed manganese (SpAd-Mn)

The data (Table 4.52) pertaining to the effect of tillage and rice straw management practices in wheat as well as wheat straw and green manure practices in rice on SpAd-Mn revealed that the SpAd-Mn content varied from 1.91 to 2.57 mg kg^{-1} and from 0.56 to 0.74 mg kg^{-1} during the year 2015 and 2017 respectively, in the surface soil samples (0-7.5 cm) and it was found that SpAd-Mn was higher under ZTW_{R100} as compared to the ZTW_{R0} and CTW_{R0} within tillage and rice straw management practices in wheat during both the years. Among the wheat straw and green manure practices in rice during 2017, PTR_{W25}+GM (0.74 mg kg^{-1}) showed significantly higher content with respect to PTR_{W25} (0.62 mg kg^{-1}) and PTR_{W0} (0.56 mg kg^{-1}). The interaction between tillage and rice straw management practices in wheat as well as wheat straw and green manure practices in rice was found non-significant. The SpAd-Mn (specifically adsorbed manganese) fraction was observed to higher in residue retained plots under tillage and rice straw management practices in wheat might be due to the lower pH under these treatments which might have increased surface area and adsorption sites provided by the presence of higher amounts of organic matter and at the same time low pH facilitated the dissolution of Mn from other fractions particularly oxide bound and residual fraction of mineral. This form of Mn is generally held on soil surfaces by forces ranging from weak electrostatic to strong ligand-exchange bonds.

4.14.3 Mn-oxide bound fraction (MnOx) of Zn, Cu, Fe and Mn

Mn-oxide bound zinc (MnOx-Zn)

The data in Table 4.53 showed that manganese oxide bound zinc (MnOx-Zn) in surface layer (0-7.5 cm) ranged from 2.65 to 3.89 mg kg^{-1} and from 2.32 to 3.38 mg kg^{-1} in the year 2015 and 2017. Amongst tillage and rice straw management practices in wheat, the value for MnOx-Zn content was significantly higher in PTR_{W25}+GM (3.89 and 3.38 mg kg-1) with respect to PTR_{W25} (2.79 and 2.60 mg kg^{-1}) and PTR_{W0} (2.65 and 2.32 mg kg^{-1}). The MnOx-Zn content was higher in CTW_{R0} (3.16 and 2.93 mg kg^{-1}) as compared to the ZTW_{R0} (2.86 and 2.67 mg kg^{-1}) during both the years of experimentation (2015 and 2017). It was concluded that among the wheat straw and green manure management practices in rice, the MnOx-Zn was found higher in the treatments where crop residue was retained plus green manure was incorporated in soil before rice. Similarly, in case of tillage and rice straw management practices in wheat, the MnOx-Zn content was found higher in the plots where ZT wheat was sown with happy seeder or where crop residue was retained over the soil surface. Shuman (1985) also found an increase in Zn in manganese fractions due to organic amendments. The interaction between tillage and rice straw management practices in wheat as well as the wheat straw and green manure practices in rice was found non-significant.

Table 4.53: Effect of tillage, green manuring and wheat straw management practices on MnOx bound fraction of micronutrients (mg kg^{-1}) in soil

Treatment	Zn	Cu	Fe	Mn
Wheat straw and green manure practices in rice (2015)				
PTR_{W0}	2.65	0.36	24.3	36.4
PTR_{W25}	2.79	0.34	28.4	39.2
PTR_{W0}+GM	3.78	0.24	28.6	42.9
PTR_{W25}+GM	3.89	0.23	29.9	45.1
LSD (0.05)	0.92	0.03	2.10	2.49
Tillage and rice straw management practices in wheat				
CTW_{R0}	3.16	0.31	29.8	40.8
ZTW_{R0}	2.86	0.29	26.8	37.3
ZTW_{R100}	3.82	0.29	26.9	44.6
LSD (0.05)	0.58	NS	2.21	2.12
Interaction LSD (0.05)	NS	NS	NS	NS
Wheat straw and green manure practices in rice (2017)				
PTR_{W0}	2.32	0.16	23.6	25.6
PTR_{W25}	2.60	0.18	26.2	25.5
PTR_{W0}+GM	3.19	0.21	27.7	28.0
PTR_{W25}+GM	3.38	0.23	29.1	29.9
LSD (0.05)	0.15	0.03	2.35	2.91
Tillage and rice straw management practices in wheat				
CTW_{R0}	2.93	0.19	28.6	27.3
ZTW_{R0}	2.67	0.18	25.2	26.4
ZTW_{R100}	3.02	0.20	26.1	28.1
LSD (0.05)	0.24	NS	2.65	NS
Interaction LSD (0.05)	NS	NS	NS	NS

Mn-oxide bound copper (MnOx-Cu)

A persual of the data presented in Table 4.53 indicated that that MnOx-Cu content varied from 0.23 to 0.36 mg kg^{-1} and from 0.16 to 0.23 mg kg^{-1} in the surface soil samples (0-7.5 cm) during the year 2015 and 2017, respectively. It was found that MnOx-Cu showed non-significant effect among the treatments within tillage and rice straw management practices in wheat during both the years. Although, the difference among the treatments was found non-significant, still the MnOx-Cu content was found higher under ZTW_{R100} (0.29 and 0.20 mg kg^{-1}) with respect to CTW_{R0} (0.31 and 0.19 mg kg^{-1}) and ZTW_{R0} (0.29 and 0.18 mg kg^{-1}) during 2015 as well as 2017. Amongst the wheat straw and green manure practices in rice, significant difference was found among the treatments, it was observed that the MnOx-Cu was significantly higher in PTR_{W25}+GM as compared to the PTR_{W25} and PTR_{W0} during 2015 and 2017. However, the interaction between tillage and rice straw management practices in wheat and wheat straw and green manure practices in rice was found non-significant.

Mn-oxide bound iron (MnOx-Fe)

The data related to the effect of tillage and rice straw management practices in wheat and wheat straw and green manure practices in rice on MnOx-Fe showed significant difference among the different treatments. The data in the Table revealed that the MnOx-Fe content ranged from 24.3 to 29.9 mg kg^{-1} and from 23.6 to 29.1 mg kg^{-1} during both the years of experimentation. Amongst the wheat straw and green manure practices in rice, the treatments where green manure plus residue was retained over the surface i.e. PTR_{W25}+GM showed significantly higher content of MnOx-Fe with respect to the PTR_{W25} and $PTR_{W0.}$ However, in case of tillage and rice straw management practices in wheat, data showed the significant increase in CTW_{R0} (29.8 and 28.6 mg kg^{-1}) with respect to ZTW_{R0} (26.8 and 25.2 mg kg^{-1}). Even the MnOx-Fe content was also found higher in CTW_{R0} (29.8 and 28.6 mg kg^{-1}) with respect to the ZTW_{R100} (26.9 and 26.1 mg kg^{-1}) during both the years i.e. 2015 and 2017. Here, in case of manganese oxide bound fraction, the trend became reverse with respect to the water soluble and exchangeable fraction and specifically adsorbed fraction in case of ZT and CT treatments. The interaction between tillage and rice straw management practices in wheat and wheat straw and green manure practices in rice was found non-significant.

Mn-oxide bound manganese (MnOx-Mn)

The MnOx-Mn content (Table 4.53) varied from 36.4 to 45.1 mg kg^{-1} and from 25.6 to 29.9 mg kg^{-1} among the tillage and rice straw management practices in wheat and wheat straw and green manure practices in rice during both the years. It was observed from the data, the MnOx-Mn content was significantly higher in PTR_{W25}+GM (45.1 and 29.9 mg kg^{-1}) as compared to the PTR_{W25} (39.2 and 25.5 mg kg^{-1}) and PTR_{W0} (36.4 and 25.6 mg kg^{-1}) in 2015 and 2017. In case of PTR_{W0}+GM treatment, the MnOx-Mn was also found higher with respect to the PTR_{W25} and PTR_{W0} but the content was lower than PTR_{W25}+GM. Moreover, in case of tillage and rice straw management practices in wheat, the data showed that the MnOx-Mn content was significantly higher under ZTW_{R100} (44.6 mg kg^{-1}) as compared to the CTW_{R0} (40.8 mg kg^{-1}) and ZTW_{R0} (37.3 mg kg^{-1}) in 2015. On the other hand, in 2017, no significant difference was found among the treatments, but the MnOx-Mn content was found higher under ZTW_{R100} (28.1 mg kg^{-1}) as compared to the CTW_{R0} (27.3 mg kg^{-1}) and ZTW_{R0} (26.4 mg kg^{-1}) in 2017. The interaction between tillage and rice straw management practices in wheat and wheat straw and green manure practices in rice was found non-significant.

4.14.4 Amorphous Fe-oxide bound fraction (AFeOx) of Zn, Cu, Fe and Mn

Amorphous iron oxide bound zinc (AFeOx-Zn)

A close examination of data indicated that tillage and rice straw management practices in wheat and wheat straw and green manure practices in rice, significantly affected the amorphous iron oxide bound zinc (AFeOx-Zn) fraction during 2015 and 2017 (Table 4.53). The content for AFeOx-Zn varied from 12.5 to 15.5 mg kg^{-1} and from 6.54 to 8.57 mg kg^{-1} during the year 2015 and 2017, respectively. Among the wheat straw and green manure practices in rice, the content for AFeOx-Zn was found significantly higher in PTR_{W25}+GM (15.5 and 8.57 mg kg^{-1}) as compared to the PTR_{W25} (13.5 and 6.99 mg kg^{-1}) and PTR_{W0} (12.5 and 6.54 mg kg^{-1}) in 2015 and 2017. Even the content for AFeOx-Zn was found higher in PTR_{W0}+GM as compared to the PTR_{W25} and $PTR_{W0.}$ However, in 2015 and 2017, among the tillage and rice straw management practices in wheat, the AFeOx-Zn showed reverse trend as compared to the previous fractions by indicating higher content of AFeOx-Zn under CTW_{R0} (15.2 and 7.86 mg kg^{-1}) instead of ZTW_{R100} (14.1 and 7.48 mg kg^{-1}) and ZTW_{R0} (12.7 and 7.01 mg kg^{-1}). The interaction between tillage and rice straw management practices in wheat as well as wheat straw and green manure practices in rice showed non-significant differences. In contrast to WSEX-Zn, the fraction of Zn associated with AFeOx was significantly higher for conventional tillage (CT) treatments than no tillage (NT). Sims (1986) found the dominant form of soil-Zn to be AFeOx at pH > 6.9. "The increase in amorphous iron oxide bound fraction might be due to the mechanical effects of these two tillage systems (DS and MB) may have changed other forms of the Zn fraction to the AFeOx fraction, which has a greater surface area and may have adsorbed a greater amount of Zn; and the DS and MB treatments may have transported this Zn fraction from subsoil". Studies by Shuman (1976, 1977) also indicated that the Fe oxide fraction contained substantial amounts of Zn.

Amorphous iron oxide bound copper (AFeOx-Cu)

A persual of the data in Table 4.54revealed that AFeOX-Cu ranged between 2.31 to 2.72 mg kg^{-1} and from 2.39 to 2.57 mg kg^{-1} during first and second year of the experimentation i.e. in 2015 and 2017, respectively. The wheat straw and green manure practices in rice, showed non-significant difference among the treatments during both the years. It was observed that the AFeOx-Cu was found higher in PTR_{W25}+GM (2.72 and 2.53 mg kg^{-1}) and PTR_{W0}+GM (2.62 and 2.48 mg kg^{-1}) as compared to the PTR_{W25} (2.55 and 2.41 mg kg^{-1}) and PTR_{W0} (2.31 and 2.39 mg kg^{-1}) treatments. On the other hand, tillage and rice straw management practices in wheat irrespective of the wheat straw and green manure practices in rice, showed significant difference amongst the treatments in 2017 but no such significant difference was observed in 2015. The content for AFeOx-Cu followed the reverse trend as compared to the other fractions, as it was found higher under CTW_{R0} instead of ZTW_{R0} and ZTW_{R100}. The interaction between tillage and rice straw management practices in wheat as well as wheat straw and green manure practices in rice showed non-significant differences.

Amorphous iron oxide bound iron (AFeOx-Fe)

The data pertaining to the effect of tillage and rice straw management practices in wheat as well as wheat straw and green manure practices in rice in Table 4.54 revealed that the AFeOx-Fe content indicated significant differences among the different treatments in 2015. No such significant difference was found to observe in 2017 among tillage and rice straw management practices in wheat. Moreover, the content for AFeOx-Fe was found higher in ZTW_{R100} (140.8 mg kg^{-1}) treatment as compared to the ZTW_{R0} (139.5 mg kg^{-1}) as well as CTW_{R0} (139.7 mg kg^{-1}) in 2017. Similar trend was observed in 2015, where AFeOx-Fe showed significantly higher content in ZTW_{R100} (544.5 mg kg^{-1}) treatment as compared to the ZTW_{R0} (489.2 mg kg^{-1}) as well as CTW_{R0} (513.2 mg kg^{-1}). On the other hand, in case of wheat straw and green manure practices in rice, significant differences amongst the treatments were observed during 2015 but not in 2017. The AFeOx-Fe content was found significantly higher under PTR_{W25}+GM (615.2 mg kg^{-1}) as compared to PTR_{W0}+GM (554.9 mg kg^{-1}), PTR_{W25} (494.5 mg kg^{-1}) and PTR_{W0} (397.9 mg kg^{-1}) treatments in 2015. Similarly, AFeOx-Fe content was found higher in PTR_{W25}+GM (142.2 mg kg^{-1}) and PTR_{W0}+GM (140.9 mg kg^{-1}) with respect to PTR_{W25} (139.1 mg kg^{-1}) and PTR_{W0} (137.7 mg kg^{-1}) treatments in 2017.

Table 4.54: Effect of tillage, green manuring andwheat straw management practices on AFeOx bound fraction of micronutrients (mg kg^{-1}) in soil

Treatment	Zn	Cu	Fe	Mn
Wheat straw and green manure practices in rice (2015)				
PTR_{W0}	12.5	2.31	397.9	17.7
PTR_{W25}	13.5	2.55	494.5	18.1
PTR_{W0}+GM	14.3	2.62	554.9	20.0
PTR_{W25}+GM	15.5	2.72	615.2	21.8
LSD (0.05)	NS	NS	57.6	NS
Tillage and rice straw management practices in wheat				
CTW_{R0}	15.2	2.69	513.2	21.3
ZTW_{R0}	12.7	2.42	489.2	17.9
ZTW_{R100}	14.1	2.54	544.5	18.9
LSD (0.05)	1.88	NS	34.13	2.16
Interaction LSD (0.05)	NS	NS	NS	NS
Wheat straw and green manure practices in rice (2017)				
PTR_{W0}	6.54	2.39	137.7	19.7
PTR_{W25}	6.99	2.41	139.1	22.4
PTR_{W0}+GM	7.69	2.48	140.9	22.9
PTR_{W25}+GM	8.57	2.53	142.2	24.2
LSD (0.05)	0.95	NS	NS	2.78
Tillage and rice straw management practices in wheat				
CTW_{R0}	7.86	2.57	139.7	23.3
ZTW_{R0}	7.01	2.37	139.5	21.4
ZTW_{R100}	7.48	2.42	140.8	22.2
LSD (0.05)	0.44	0.15	NS	NS
Interaction LSD (0.05)	NS	NS	NS	NS

Amorphous iron oxide bound manganese (AFeOx-Mn)

The values in the data in Table 4.54indicated that AFeOx-Mn content varied from 17.7 to 21.8 mg kg^{-1} and from 19.7 to 24.2 mg kg^{-1} in the surface soil samples (0-7.5 cm) during the year 2015 and 2017, respectively, and it was observed that AFeOx-Mn was higher under CTW_{R0} instead of ZTW_{R100} as well as ZTW_{R0} within tillage and rice straw management practices in wheat during both the years. Wheat straw and green manure practices in rice irrespective of the tillage and rice straw management practices in wheat also indicated significant increase in AFeOx-Mn during 2017. The AFeOx-Mn content was higher under PTR_{W25}+GM (21.8 and 24.2 mg kg^{-1}) as compared to PTR_{W0}+GM (20.0 and 22.9 mg kg^{-1}), PTR_{W25} (18.1 and 22.4 mg kg^{-1}) and PTR_{W0} (17.7 and 19.7 mg kg^{-1}) during both the years i.e. 2015 and 2017. The interaction between tillage and rice straw management practices in wheat as wel as wheat straw and green manure practices in rice showed non-significant differences. Organic, occulted (AFeOx), and residual Mn were significantly affected by the various tillage systems (Falatah 2009). The extractant of Mn from the AFeOx and RES (residual) fractions were significantly higher for DS and MB treatments than for the NT, HR, and CH treatments.

4.14.5 Crystalline Fe-oxide bound fraction (CFeOx) of Zn, Cu, Fe and Mn

Crystalline iron oxide bound zinc (CFeOx-Zn)

A glance at data in Table 4.55 below showed that CFeOx-Zn content ranged between 20.8 to 28.3 mg kg^{-1} and from 10.4 to 10.8 mg kg^{-1} respectively amongst the tillage and rice straw management practices in wheat as well as wheat straw and green manure practices in rice in the surface soil samples (0-7.5 cm) during the year 2015 and 2017. It was observed that among the tillage and rice straw management practices in wheat, CFeOx-Zn was found significantly higher under CTW_{R0} (27.1 mg kg^{-1}) as compared to the ZTW_{R100} (23.0 mg kg^{-1}), even the CFeOx-Zn was higher in CTW_{R0} as compared to the ZTW_{R0} (25.9 mg kg^{-1}) in 2015. Whereas, it also varied significantly in 2017, it was found higher in CTW_{R0} (10.8 mg kg^{-1}) as compared to ZTW_{R100} (10.3 mg kg^{-1}), even CFeOx-Zn was also found higher in CTW_{R0} with respect to ZTW_{R0}. On the other hand, in wheat straw and green manure practices in rice, irrespective of the tillage and rice straw management practices in wheat, failed to cause significant effect on the CFeOx-Zn content in 2017 but significant effect among the treatments was found in 2015. It was observed that, CFeOx-Zn was higher in treatments where crop residue was retained over the soil surface as well as where the green manure was incorporated in soil before rice crop i.e. CFeOx-Zn was found higher in PTR_{W25}+GM (28.3 and 10.8 mg kg^{-1}) and PTR_{W0}+GM (27.4 and 10.6 mg kg^{-1}) as compared to the PTR_{W25} (24.9 and 10.5 mg kg^{-1}) and PTR_{W0} (20.8 and 10.4 mg kg^{-1}) during both the years of experimentation (2015 and 2017). The interaction between tillage and rice straw management practices in wheat as well as wheat straw and green manure practices in rice showed non-significant differences. The decrease in Zn in crystalline and amorphous iron oxide bound fractions was accompanied by a concomitant increase in the water-soluble plus exchangeable, specifically absorbed, organic and manganese oxide. It denotes that a large part of the Zn released from crystalline and amorphous iron oxide bound was mobilized in to the organic fraction, manganese oxide fraction, water soluble plus exchangeable fraction and specifically adsorbed fractions (Sekhon *et al* 2006).

Crystalline iron oxide bound copper (CFeOx-Cu)

A close examination of the data in Table 4.55 revealed that CFeOx-Cu ranged between 2.81 to 3.54 mg kg^{-1} and from 1.57 to 1.80 mg kg^{-1} during first and second year of the experimentation i.e. in 2015 and 2017, respectively. The wheat straw and green manure practices in rice irrespective of tillage and rice straw management practices in wheat, the CFeOx-Cu differ significantly among the treatments during both the years. The content for CFeOx-Cu was found higher in PTR_{W25}+GM (3.54 and 1.80 mg kg^{-1}) and PTR_{W0}+GM (3.44 and 1.76 mg kg^{-1}) as compared to the PTR_{W25} (3.29 and 1.70 mg kg^{-1}) and PTR_{W0} (2.81 and 1.57 mg kg^{-1}) treatments during both the years (2015 and 2017). On the other hand, tillage and rice straw management practices in wheat irrespective of the wheat straw and green manure practices in rice, showed significant difference amongst the treatments in 2015 but no such significant difference was observed in 2017. The content for CFeOx-Cu was found higher under ZTW_{R0} and CTW_{R0} instead of ZTW_{R100}. The interaction between tillage and rice straw management practices in wheat as well as wheat straw and green manure practices in rice showed non-significant differences. Agbenin and Henningsen (2004) reported the increasing Cryst-Cu fractions in the cultivated field. Because of cultivation, it causes the loss of organic matter which inhibits Fe crystallization and facilitates the transformation of Amor-Cu to Cryst-Cu because Cryst-Cu is occluded in CFeOx. Similarly, Manchanda *et al* (2002) observed the higher content of Cu in CFeOx fraction in soil under rice-wheat cropping system.

Crystalline iron oxide bound iron (CFeOx-Fe)

The data concerning to CFeOx-Fe fraction as affected by the tillage and rice straw management practices in wheat and wheat straw and green manure practices in rice indicated that CFeOx-Fe content varied from 834 to 1073.8 mg kg^{-1} and from 229.8 to 236.6 mg kg^{-1} in the surface soil samples (0-7.5 cm) during the year 2015 and 2017, respectively. It was observed that CFeOx-Fe was higher under CTW_{R0} instead of ZTW_{R100} and ZTW_{R0} within tillage and rice straw management practices in wheat during both the years (2015 and 2017). The wheat straw and green manure practices in rice irrespective of the tillage and rice straw management practices in wheat indicated significant effect on the CFeOx-Fe content under PTR_{W25}+GM (1073.8 and 236.6 mg kg^{-1}) as compared to PTR_{W25} (956.8 and 231.2 mg kg^{-1}) and PTR_{W0} (834.3 and 229.8 mg kg^{-1}) treatment in 2015 as well as in 2017. Even the CFeOx-

Table 4.55: Effect of tillage, green manuring andwheat straw management practices on CFeOx bound fraction of micronutrients (mg kg^{-1}) in soil

Treatment	Zn	Cu	Fe	Mn
Wheat straw and green manure practices in rice (2015)				
PTR_{W0}	20.8	2.81	834.3	27.1
PTR_{W25}	24.9	3.29	956.8	29.7
PTR_{W0}+GM	27.4	3.44	1056.4	33.8
PTR_{W25}+GM	28.3	3.54	1073.8	35.1
LSD (0.05)	3.24	0.30	109.7	4.45
Tillage and rice straw management practices in wheat				
CTW_{R0}	27.1	3.47	1025.7	31.8
ZTW_{R0}	25.9	3.23	925.5	28.8
ZTW_{R100}	23.0	3.11	989.8	33.7
LSD (0.05)	2.47	0.22	NS	3.69
Interaction LSD (0.05)	NS	NS	NS	NS
Wheat straw and green manure practices in rice (2017)				
PTR_{W0}	10.4	1.57	229.8	37.3
PTR_{W25}	10.5	1.70	231.2	37.4
PTR_{W0}+GM	10.6	1.76	234.8	39.3
PTR_{W25}+GM	10.8	1.80	236.6	43.2
LSD (0.05)	NS	0.14	4.79	1.46
Tillage and rice straw management practices in wheat				
CTW_{R0}	10.8	1.77	235.6	39.0
ZTW_{R0}	10.5	1.69	230.6	37.7
ZTW_{R100}	10.3	1.65	233.2	41.1
LSD (0.05)	0.03	NS	NS	NS
Interaction LSD (0.05)	NS	NS	NS	NS

Fe content was found higher in PTR_{W0}+GM (1056.4 and 234.8 mg kg^{-1}) as compared to PTR_{W25} (956.8 and 231.2 mg kg^{-1}) and PTR_{W0} (834.3 and 229.8 mg kg^{-1}) treatments. The interaction between tillage and rice straw management practices in wheat and wheat straw and green manure practices in rice was also found non-significant. CFeOx-Fe fraction is the second most dominant fraction of iron after residual Fe. The hydroxides or oxides might have provided the sites for adsorption of the cations on the broken edges therefore increasing the amount of AFeOx-Fe and CFeOx-Fe bound fraction of Fe. The differences in the contents of amorphous and crystalline iron oxide bound Fe under different treatments might be due to the effect of soil pH and soil organic matter.

Crystalline iron oxide bound manganese (CFeOx-Mn)

A glance at data in Table 4.55showed that CFeOx-Mn content ranged between 27.1 to 35.1 mg kg^{-1} and from 37.3 to 43.2 mg kg^{-1} respectively amongst the tillage and rice straw management practices in wheat as well as wheat straw and green manure practices in rice crop, in the surface soil samples (0-7.5 cm) during the year 2015 and 2017. It was observed that amongst the tillage and rice straw management practices in wheat, CFeOx-Mn was found significantly higher under ZTW_{R100} (33.7 mg kg^{-1}) as compared to the ZTW_{R0} (28.8 mg kg^{-1}), even CFeOx-Mn content was also higher in CTW_{R0} (31.8 mg kg^{-1}) as compared to ZTW_{R0} in 2015, whereas it varied as non-significantly in 2017 among the treatments.

On the other hand, wheat straw and green manure practices in rice irrespective of the tillage and rice straw management practices in wheat cause significant effect on the CFeOx-Mn content in 2015 and 2017, significant increase was observed in PTR_{W25}+GM (35.1 and 43.2 mg kg^{-1}) as compared to PTR_{W25} (29.7 and 37.4 mg kg^{-1}) and PTR_{W0} (27.1 and 37.3 mg kg^{-1}) treatments in 2015 as well as in 2017. Lowest content for CFeOx-Mn was observed in PTR_{W0} treatment amongst all the treatments. The interaction between tillage and rice straw management practices in wheat and wheat straw and green manure practices in rice was also found non-significant. As it was observed from the data that contents for CFeOx-Mn was higher in ZTW_{R100} treatments, it seems that crop residue mobilize non-labile Mn sources into labile forms of Mn. Several mechanisms could be proposed for this phenomenon, which include surface complexation of Mn by organic ligands produced from the decomposition of the crop residue; improved the CEC conferred on the soil by crop residues probably induced by sorption of organic ligands to oxide surfaces; and the inhibition of Fe crystallization by crop residue. Either of these mechanisms could lead to decreasing Cryst Fe-Mn, and the increasing AFeOx-Mn, MnOx-Mn, OM-Mn, and SpAd-Mn and WSEX-Mn fractions in residue retained plots.

4.14.6 Organically bound fraction (OM) of Zn, Cu, Fe and Mn

Organically bound zinc (OM-Zn)

A persual of the data in Table 4.56 revealed that the content for OM-Zn ranged from 0.87 to 1.57 mg kg^{-1} and from 4.51 to 5.41 mg kg^{-1} within all the treatment combinations (tillage and rice straw management practices in wheat and wheat straw and green manure practices in rice) during 2015 and 2017, respectively. It was observed that tillage and rice straw management practices in wheat irrespective of the wheat straw and green manure practices in rice crop non-significantly influenced the organic matter bound zinc (OM-Zn) during 2015 and 2017. Whereas, the wheat straw and green manure practices in rice, vary significantly during both the years, and it was observed that among the wheat straw and green manure practices in rice, the content for OM-Zn was found higher in PTR_{W25}+GM (1.57 and 5.41 mg kg^{-1}) as compared to PTR_{W25} (1.01 and 4.70 mg kg^{-1}) and PTR_{W0} (0.87 and 4.51 mg kg^{-1}) treatments in 2015 as well as in 2017. However, among the tillage and rice straw management practices in wheat, the OM-Zn was highest for ZTW_{R100} (1.26 and 5.13 mg kg^{-1}) followed by CTW_{R0} (1.19 and 4.96 mg kg^{-1}) then in ZTW_{R0} (1.14 and 4.81 mg kg^{-1}), respectively in both the years. The increase in OM-Zn content in ZTW_{R100} treatments might be due to the higher soil organic carbon content in these treatments. Zinc forms strong complexes with soil organic matter (Sharad and Verma 2001, Umesh *et al* 2013). The interaction between tillage and rice straw management practices in wheat and wheat straw and green manure practices in rice was also found non-significant. Zn is often associated with the organic bound fraction (Mandal and Mandal 1986), so because of more organic matter content in the NT treatments. (Falatah 2009) might have expected to upturn Zn in that fraction.

Organically bound copper (OM-Cu)

A close examination of the contents of data in Table 4.56 revealed that OM-Cu content amongst the tillage and rice straw management practices in wheat as well as wheat straw and green manure practices in rice ranged between 0.14 to 0.18 mg kg^{-1} and from 0.14 to 0.19 mg kg^{-1} in the surface soil samples (0-7.5 cm) during the year 2015 and 2017, respectively. Amongst the wheat straw and green manure practices in rice, OM-Cu content was found to have significant effect between the treatments during both the years. It was revealed that OM-Cu content was varied in 2015 as 0.14 mg kg^{-1}, 0.16 mg kg^{-1}, 0.17 mg kg^{-1} and 0.20 mg kg^{-1} in PTR_{W25}+GM, PTR_{W0}+GM , PTR_{W25} and PTR_{W0} respectively. In the next year, OM-Cu content was ranged as 0.14 mg kg^{-1}, 0.19 mg kg^{-1}, 0.16 mg kg^{-1} and 0.15 mg kg^{-1} in PTR_{W25}+GM, PTR_{W0}+GM, PTR_{W25} and PTR_{W0} respectively.

Table 4.56: Effect of tillage, green manuring andwheat straw management practices on OM bound fraction of micronutrients (mg kg^{-1}) in soil

Treatment	Zn	Cu	Fe	Mn
Wheat straw and green manure practices in rice (2015)				
PTR_{W0}	0.87	0.20	151.1	2.78
PTR_{W25}	1.01	0.17	155.4	3.36
PTR_{W0}+GM	1.35	0.16	160.9	4.91
PTR_{W25}+GM	1.57	0.14	162.6	4.38
LSD (0.05)	0.37	0.02	4.68	0.81
Tillage and rice straw management practices in wheat				
CTW_{R0}	1.19	0.18	157.8	3.82
ZTW_{R0}	1.14	0.17	154.4	3.33
ZTW_{R100}	1.26	0.15	160.6	4.42
LSD (0.05)	NS	0.02	2.87	0.59
Interaction LSD (0.05)	NS	NS	NS	NS
Wheat straw and green manure practices in rice (2017)				
PTR_{W0}	4.51	0.15	144.2	2.84
PTR_{W25}	4.70	0.16	147.1	2.82
PTR_{W0}+GM	5.25	0.19	157.9	3.53
PTR_{W25}+GM	5.41	0.14	163.6	3.48
LSD (0.05)	0.27	0.02	14.3	0.61
Tillage and rice straw management practices in wheat				
CTW_{R0}	4.96	0.16	153.2	3.14
ZTW_{R0}	4.81	0.16	150.4	2.92
ZTW_{R100}	5.13	0.17	156.1	3.44
LSD (0.05)	NS	NS	NS	0.32
Interaction LSD (0.05)	NS	NS	NS	NS

Tillage and rice straw management practices in wheat irrespective of the wheat straw and green manure practices in rice indicated significant effect on OM-Cu content in soil in 2015 but not in 2017. The content was found higher in case of ZTW_{R100} as compared to ZTW_{R0} and CTW_{R0} in 2017. This increase might be because of increase in organic matter on the surface layer. The organic matter content in soil is one of the key factor which plays an important role not only in the distribution of the Cu among different fractions but it also supply the additional nutrients to the growing plants. Due to presence of more organic matter, it influences the forms and availability of Cu due to release of organic acids and other microbial products during decomposition (Verma and Bhagat 1992). However, the interaction between tillage and rice straw management practices in wheat as well as the wheat straw and green manure practices in rice was observed as non-significant.

Organically bound iron (OM-Fe)

The data pertaining to the effect of tillage and rice straw management practices in wheat as well as the wheat straw and green manure practices in rice in Table 4.56 revealed that the OM-Fe content indicated significant differences among the different treatments between wheat straw and green manure practices in rice in surface soil (0-7.5 cm) in 2015 and 2017. The content for OM-Fe was found significantly higher in in PTR_{W25}+GM (162.6 and 163.6 mg kg^{-1}) as compared to PTR_{W25} (155.4 and 147.1 mg kg^{-1}) and PTR_{W0} (151.1 and 144.2 mg kg^{-1}) respectively, in 2015 and 2017. However, in case of tillage and rice straw management practices in wheat irrespective of the wheat straw and green manure practices in rice, it was observed from the data that OM-Fe content was found higher in ZTW_{R100} (160.6 and 156.1 mg kg^{-1}) as compared to the ZTW_{R0} (154.4 and 150.4 mg kg^{-1}) and CTW_{R0} (157.8 and 153.2 mg kg^{-1}) respectively, in 2015 and 2017. It was concluded from the data that the OM-Fe content was found higher in the treatments where crop residue was retained over the surface as well as where the green manure was incorporated in soil before rice. A persual of the data suggested that higher organic matter content in these treatments might have resulted in higher OM-Fe content. Soil organic matter plays a major role in influencing organically bound fraction micronutrients. Similar results have been reported by Sharma *et al* (2008) in different parts of country. The interaction between tillage and rice straw management practices in wheat as well as the wheat straw and green manure practices in rice was observed as non-significant.

Organically bound manganese (OM-Mn)

A glance at data in Table 4.56 showed that OM-Mn content ranged between 2.78 to 4.38 mg kg^{-1} and from 2.82 to 3.53 mg kg^{-1} respectively amongst the tillage and rice straw management practices as well as wheat straw and green manure practices in rice in the surface soil samples (0-7.5 cm) during the year 2015 and 2017. It was observed that amongst the tillage and rice straw management practices in wheat, OM-Mn was found higher under ZTW_{R100} (4.42 and 3.44 mg kg^{-1}) as compared to the ZTW_{R0} (3.33 and 2.92 mg kg^{-1}) and CTW_{R0} (3.82 and 3.14 mg kg^{-1}) in 2015 as well in 2017. The increase in organic fraction in residue retained plots can probably be ascribed to the formation of organic complexes of Mn with organic acids produced during decomposition of the organic materials (Sekhon *et al* 2007). Wheat straw and green manure practices in rice irrespective of the tillage and rice straw management practices in wheat, cause significantly affected the OM-Mn content in 2015 and 2017. Significantly higher content for OM-Mn was observed in PTR_{W25}+GM (4.38 and 3.48 mg kg^{-1}) with respect to PTR_{W25} (3.36 and 2.82 mg kg^{-1}) and PTR_{W0} (2.78 and 2.84 mg kg^{-1}) amongst all the treatments during 2015 as well as 2017. Even the OM-Mn content was higher in PTR_{W0}+GM as compared to the PTR_{W25} and PTR_{W0}. The interaction between tillage and rice straw management practices in wheat as well as the wheat straw and green manure practices in rice was observed as non-significant.

4.14.7 Residual fraction (RES) of Zn, Cu, Fe and Mn

Residual zinc (RES-Zn)

A persual of the data in Table 4.57 revealed that the content for RES-Zn ranged from 68.8 to 80.1 mg kg^{-1} and from 85.6 to 98.9 mg kg^{-1} within all the treatment combinations (tillage and rice straw management practices in wheat and wheat straw and green manure practices in rice) during 2015 and 2017, respectively. It was observed that tillage and rice straw management practices in wheat irrespective of the wheat straw and green manure practices in rice crop non-significantly influenced the residual zinc (RES-Zn) during 2015 but it showed significant effect in 2017. It was observed that among the wheat straw and green manure practices in rice, the content for RES-Zn was found higher in PTR_{W25}+GM (79.2 and 98.9 mg kg^{-1}) as compared to PTR_{W25} (68.8 and 85.6 mg kg^{-1}) and PTR_{W0} (73.8and 86.1 mg kg^{-1}) treatments in 2015 as well as in 2017. However, among the tillage and rice straw management practices in wheat, the RES-Zn was highest for ZTW_{R100} (80.1 and 98.5 mg kg^{-1}) followed by CTW_{R0} (71.6 and 90.4 mg kg^{-1}) then in ZTW_{R0} (71.9 and 86.6 mg kg^{-1}), respectively in both the years. The increase in RES-Zn content in ZTW_{R100} treatments might be due to the higher soil organic carbon content in these treatments. The interaction between tillage and rice straw management practices in wheat and wheat straw and green manure practices in rice was also found non-significant.

Table 4.57: Effect of tillage, green manuring andwheat straw management practices on RES fraction of micronutrients (mg kg^{-1}) in soil

Treatment	Zn	Cu	Fe	Mn
Wheat straw and green manure practices in rice (2015)				
PTR$_{W0}$	73.8	10.8	1.41	90.6
PTR$_{W25}$	68.8	11.2	1.42	87.1
PTR$_{W0}$+GM	76.5	12.1	1.44	85.6
PTR$_{W25}$+GM	79.2	12.5	1.47	87.4
LSD (0.05)	NS	NS	NS	NS
Tillage and rice straw management practices in wheat				
CTW$_{R0}$	71.6	11.4	1.43	85.5
ZTW$_{R0}$	71.9	11.1	1.41	90.5
ZTW$_{R100}$	80.1	12.4	1.47	87.0
LSD (0.05)	4.67	NS	0.05	NS
Interaction				
LSD (0.05)	NS	NS	NS	NS
Wheat straw and green manure practices in rice (2017)				
PTR$_{W0}$	86.1	14.8	1.52	96.7
PTR$_{W25}$	85.6	15.5	1.55	105.4
PTR$_{W0}$+GM	96.8	16.1	1.62	108.1
PTR$_{W25}$+GM	98.9	16.7	1.63	108.2
LSD (0.05)	2.85	NS	0.06	NS
Tillage and rice straw management practices in wheat				
CTW$_{R0}$	90.4	15.4	1.58	103.2
ZTW$_{R0}$	86.6	15.3	1.54	98.4
ZTW$_{R100}$	98.5	16.6	1.63	112.2
LSD (0.05)	3.32	NS	0.04	6.93
Interaction				
LSD (0.05)	NS	NS	NS	NS

Residual copper (RES-Cu)

A close examination of the contents of data in Table 4.57 revealed that RES-Cu content amongst the tillage and rice straw management practices in wheat as well as wheat straw and green manure practices in rice ranged between 10.8 to 12.5 mg kg^{-1} and from 14.8 to 16.7 mg kg^{-1} in the surface soil samples (0-7.5 cm) during the year 2015 and 2017, respectively. Amongst the wheat straw and green manure practices in rice, RES-Cu content was found to have non-significant effect between the treatments during both the years. It was revealed that RES-Cu content was varied in 2015 as 12.5 mg kg^{-1}, 12.1 mg kg^{-1}, 11.2 mg kg^{-1} and 10.8 mg kg^{-1} in PTR_{W25}+GM, PTR_{W0}+GM , PTR_{W25} and PTR_{W0} respectively. In the next year, RES-Cu content was ranged as 16.7 mg kg^{-1}, 16.1 mg kg^{-1}, 15.5 mg kg^{-1} and 14.8 mg kg^{-1} in PTR_{W25}+GM, PTR_{W0}+GM, PTR_{W25} and PTR_{W0} respectively. Tillage and rice straw management practices in wheat irrespective of the wheat straw and green manure practices in rice indicated non-significant effect on RES-Cu content in soil in 2015 as well as in 2017. The interaction between tillage and rice straw management practices in wheat and wheat straw and green manure practices in rice was also found non-significant.

Residual iron (RES-Fe)

The data concerning to RES-Fe fraction as affected by the tillage and rice straw management practices in wheat and wheat straw and green manure practices in rice indicated that RES-Fe content varied from 1.41 to 1.47percent and from 1.52 to 1.63percent in the surface soil samples (0-7.5 cm) during the year 2015 and 2017, respectively. It was observed that RES-Fe was significantly higher under ZTW_{R100} (1.47 and 1.63 percent) as compared to ZTW_{R0}(1.41 and 1.54 percent) and CTW_{R0} (1.43 and 1.58 percent) within tillage and rice straw management practices in wheat during both the years (2015 and 2017). The wheat straw and green manure practices in rice irrespective of the tillage and rice straw management practices in wheat indicated significant effect on the RES-Fe content under PTR_{W25}+GM (1.63 percent) as compared to PTR_{W25} (1.55 percent) and PTR_{W0} (1.52 percent) treatment in 2017 only. Even the RES-Fe content was found higher in PTR_{W0}+GM (1.62 percent) as compared to PTR_{W25} (1.55 percent) and PTR_{W0} (1.52 percent) treatments. The interaction between tillage and rice straw management practices in wheat and wheat straw and green manure practices in rice was also found non-significant.

Residual manganese (RES-Mn)

A glance at data in Table 4.57 showed that RES-Mn content ranged between 85.5 to 90.6 mg kg^{-1} and from 96.7 to 112.2 mg kg^{-1} respectively amongst the tillage and rice straw management practices as well as wheat straw and green manure practices in rice in the surface soil samples (0-7.5 cm) during the year 2015 and 2017. It was observed that amongst the tillage and rice straw management practices in wheat, RES-Mn was found higher under

ZTW_{R100} (87.0 and 112.2 mg kg^{-1}) as compared to the ZTW_{R0} (90.5 and 98.4 mg kg^{-1}) and CTW_{R0} (85.5 and 103.2 mg kg^{-1}) in 2015 as well in 2017. Wheat straw and green manure practices in rice irrespective of the tillage and rice straw management practices in wheat, non-significantly affected the RES-Mn content in 2015 and 2017. Higher content for RES-Mn was observed in PTR_{W25}+GM (87.4 and 108.1 mg kg^{-1}) with respect to PTR_{W25} (87.1 and 105.4 mg kg^{-1}) and PTR_{W0} (90.6 and 96.7 mg kg^{-1}) amongst all the treatments during 2015 as well as 2017. The interaction between tillage and rice straw management practices in wheat as well as the wheat straw and green manure practices in rice was observed as non-significant.

4.14.7 Total fraction (Total) of Zn, Cu, Fe and Mn

Total zinc (Total-Zn)

A close examination of data in Table 4.58revealed that the content for total-Zn varied from 105.1 to 118.8 mg kg^{-1} and from 114.8 to 134.4 mg kg^{-1} within all the treatments combinations during 2015 and 2017, respectively. It was observed that tillage and rice straw management practices in wheat as well as wheat straw and green manure practices in ricesignificantly influenced the total-Zn content during 2015 as well in 2017. It was observed that among the wheat straw and green manure practices in rice, the content for total-Zn was found significantly higher in PTR_{W25}+GM (118.8and 134.4 mg kg^{-1}) as compared to PTR_{W25} (109.7 and 115.6 mg kg^{-1}) and PTR_{W0} (105.1 and 114.8 mg kg^{-1}) in 2015 and 2017. Even the total-Zn content was also found higher in PTR_{W0}+GM with respect to PTR_{W25} and PTR_{W0}. However, among the tillage and rice straw management practices in wheat, the total-Zn content was highest for ZTW_{R100} (116.1 mg kg^{-1}) followed by CTW_{R0} (112.5 mg kg^{-1}) and then in ZTW_{R0}(107.5 mg kg^{-1}), respectively in 2015. Likewise, in 2017, total-Zn was higher in ZTW_{R100} (131.8 mg kg^{-1}) followed by CTW_{R0} (122.1 mg kg^{-1}) and then in ZTW_{R0} (116.5 mg kg^{-1}). The increase in ZTW_{R100} treatments might be due to the higher soil organic carbon content in these treatments. The interaction between tillage and rice straw management practices in wheat as well as the wheat straw and green manure practices in rice showed non-significant differences.

Total copper (Total-Cu)

The data in Table 4.58 regarding the effect tillage and rice straw management practices in wheat as well as the wheat straw and green manure practices in rice revealed thattotal-Cu content ranged between 16.7 to 19.5 mg kg^{-1} and from 19.3 to 21.7 mg kg^{-1} in the surface soil samples (0-7.5 cm) during the year 2015 and 2017, respectively. Amongst the wheat straw and green manure practices in rice, total-Cu content was found to have non-significant effect between the treatments during both the years. It was revealed that total-Cu content varied in 2015 as 19.5 mg kg^{-1}, 18.9 mg kg^{-1}, 17.8 mg kg^{-1} and 16.7 mg kg^{-1} in, PTR_{W25}+GM, PTR_{W0}+GM, PTR_{W25} and $PTR_{W0,}$ respectively. In the next year, total-Cu content was ranged as 21.7 mg kg^{-1}, 21.1 mg kg^{-1}, 20.3 mg kg^{-1} and 19.3 mg kg^{-1} in PTR_{W25}+GM, PTR_{W0}+GM,

PTR_{W25} and $PTR_{W0,}$ respectively. Tillage and rice straw management practices in wheat irrespective of the wheat straw and green manure practices in rice also indicated non-significant effect on total-Cu content in soil in 2015 as well as 2017. Even then the content was found higher in case of ZTW_{R100} (19.2 and 21.5 mg kg^{-1}) and CTW_{R0} (18.1 and 20.3 mg kg^{-1}) as compared to ZTW_{R0} (17.4 and 19.9 mg kg^{-1}) during 2015 and 2017. High total-Cu content in FYM treated plots might be due to build-up of organic matter under continuous manuring possibly results in higher total micronutrients content in soil (Chaudhary and Narwal 2005).

Total iron (Total-Fe)

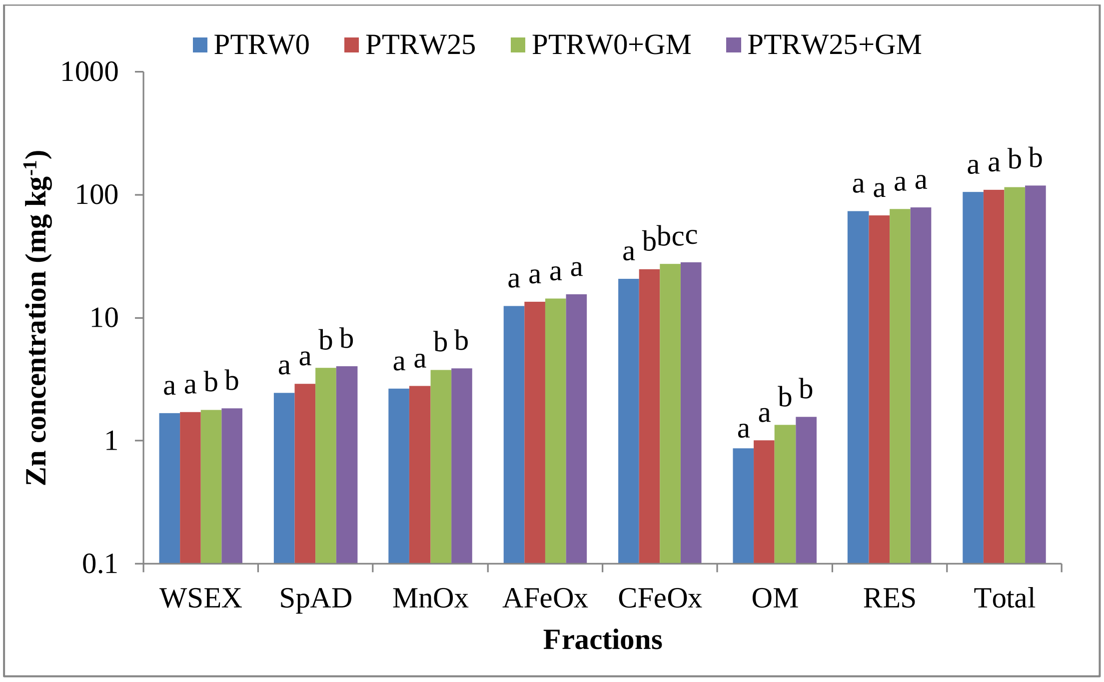
An examination of the data in Table 4.58 indicated that the that total-Fe content varied from 1.55 to 1.66 percentand from 1.58 to 1.69 percent in the surface soil samples (0-7.5 cm) during the year 2015 and 2017, respectively, and it was observed that total-Fe content was significantly higher under ZTW_{R100} (1.64 and 1.69 percent) as compared to the CTW_{R0} (1.61 and 1.64 percent) within tillage and rice straw management practices in wheat during both the years of experimentation (2015 and 2017). The tillage and rice straw management practices in wheat indicated significant effect on the total-Fe content, the content was higher under ZTW_{R100} treatment compared to the ZTW_{R0} and CTW_{R0} treatments during both the years. Wheat straw and green manure practices in rice irrespective of the tillage and rice straw management practices in wheat indicated significant higher content for the total-Fe in PTR_{W25}+GM (1.66 and 1.69 percent) with respect to PTR_{W25} (1.58 and 1.61 percent) and PTR_{W0} (1.55 and 1.58 percent), respectively, during both the years. The interaction between tillage and rice straw management practices in wheat as well as the wheat straw and green manure practices in rice also found non-significant.

Total manganese (Total-Mn)

A close examination of data indicated that wheat straw and green manure practices in rice significantly affected the total-Mn content during 2015 as well as 2017. The content for total-Mn varied from 176.9 to 196.9 mg kg^{-1} and from 183.3 to 210.5 mg kg^{-1} during the year 2015 and 2017, respectively. Among wheat straw and green manure practices in rice, the content for total-Mn was found higher in PTR_{W25}+GM (196.9 and 210.5 mg kg^{-1}) with respect to PTR_{W25} (180.0 and 194.8mg kg^{-1}) and PTR_{W0} (176.9 and 183.3 mg kg^{-1}) during both the years of experimentation i.e. 2015 and 2017. However, among the tillage and rice straw management practices in wheat irrespective of the wheat straw and green manure practices in rice, the total-Mn indicated higher content under ZTW_{R100} (191.7 and 208.4 mg kg^{-1}) as compared to ZTW_{R0} (180.4 and 188.1 mg kg^{-1}) and CTW_{R0} (186.1 and 197.3 mg kg^{-1}) during both the years. The interaction between tillage and rice straw management practices in wheat as well as wheat straw and green manure practices in rice showed non-significant differences.

Table 4.58: Effect of tillage, green manuring andwheat straw management practices on total fraction of micronutrients (mg kg^{-1}) in soil

Treatment	Zn	Cu	Fe	Mn
Wheat straw and green manure practices in rice (2015)				
PTR_{W0}	105.1	16.7	1.55	176.9
PTR_{W25}	109.7	17.8	1.58	180.0
PTR_{W0}+GM	115.9	18.9	1.62	190.3
PTR_{W25}+GM	118.8	19.5	1.66	196.9
LSD (0.05)	5.42	NS	0.05	5.10
Tillage and rice straw management practices in wheat				
CTW_{R0}	112.5	18.1	1.61	186.1
ZTW_{R0}	107.5	17.4	1.57	180.4
ZTW_{R100}	116.1	19.2	1.64	191.7
LSD (0.05)	5.19	NS	0.04	6.86
Interaction LSD (0.05)	NS	NS	NS	NS
Wheat straw and green manure practices in rice (2017)				
PTR_{W0}	114.8	19.3	1.58	183.3
PTR_{W25}	115.6	20.3	1.61	194.8
PTR_{W0}+GM	129.1	21.1	1.68	203.1
PTR_{W25}+GM	134.4	21.7	1.69	210.5
LSD (0.05)	13.6	NS	0.06	9.47
Tillage and rice straw management practices in wheat				
CTW_{R0}	122.1	20.3	1.64	197.3
ZTW_{R0}	116.5	19.9	1.59	188.1
ZTW_{R100}	131.8	21.5	1.69	208.4
LSD (0.05)	10.4	NS	0.04	4.91
Interaction LSD (0.05)	NS	NS	NS	NS



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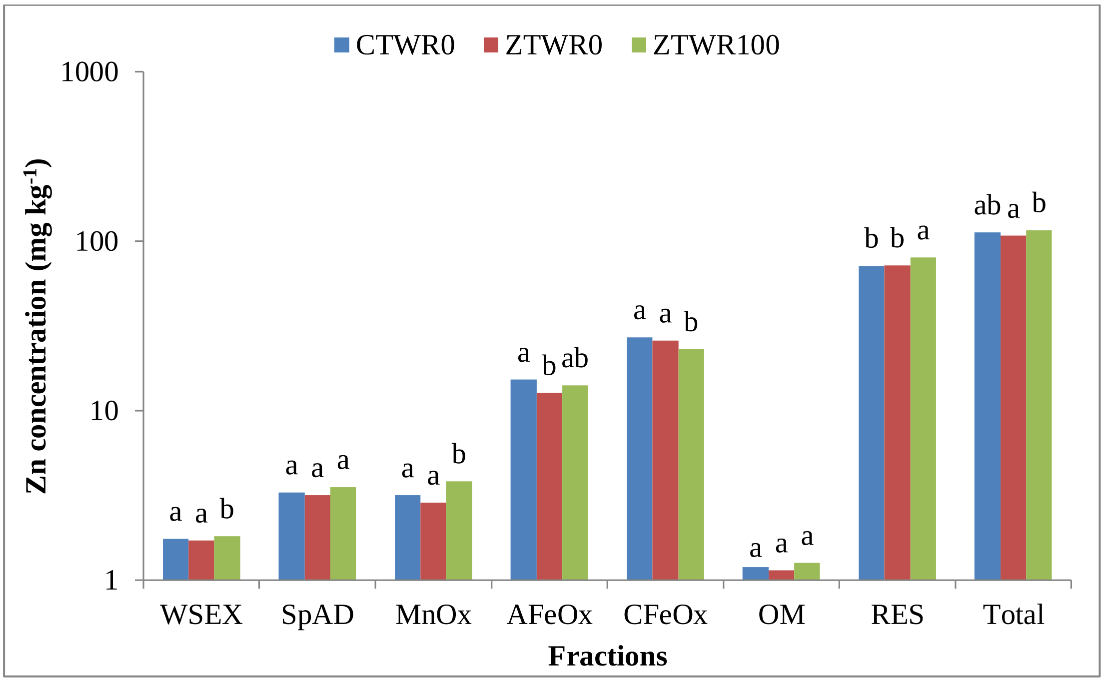
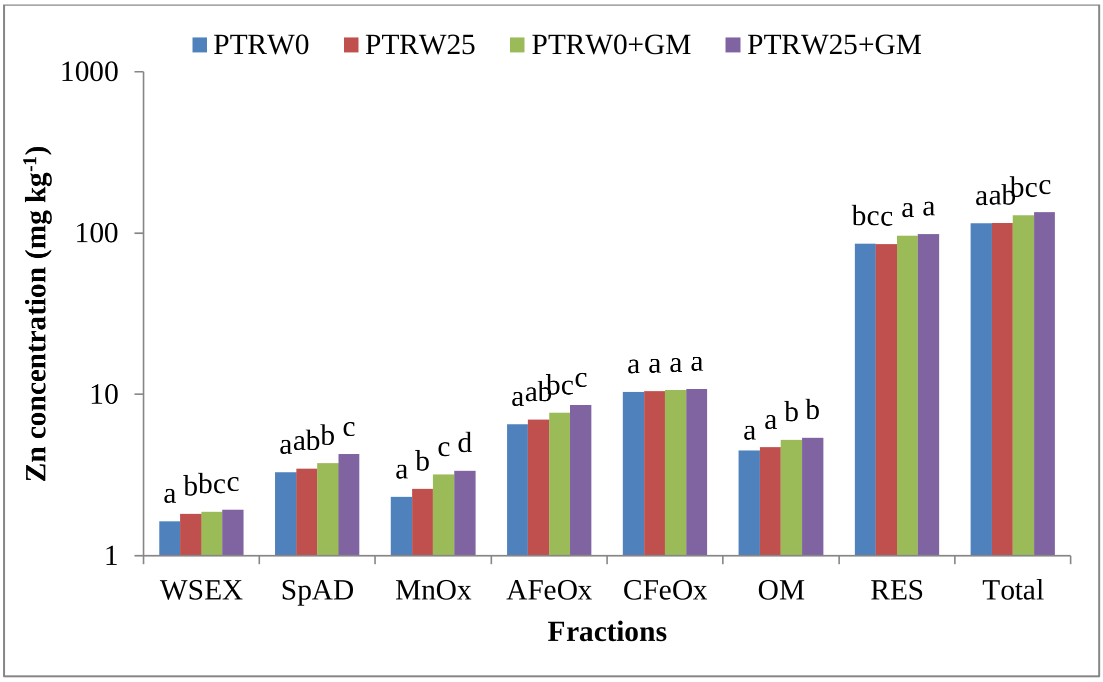


(b)

Fig. 4.9: Effect of tillage, green manuring and wheat straw management practices on different fractions of Zn during 2015 (a) main plots and (b) sub plots



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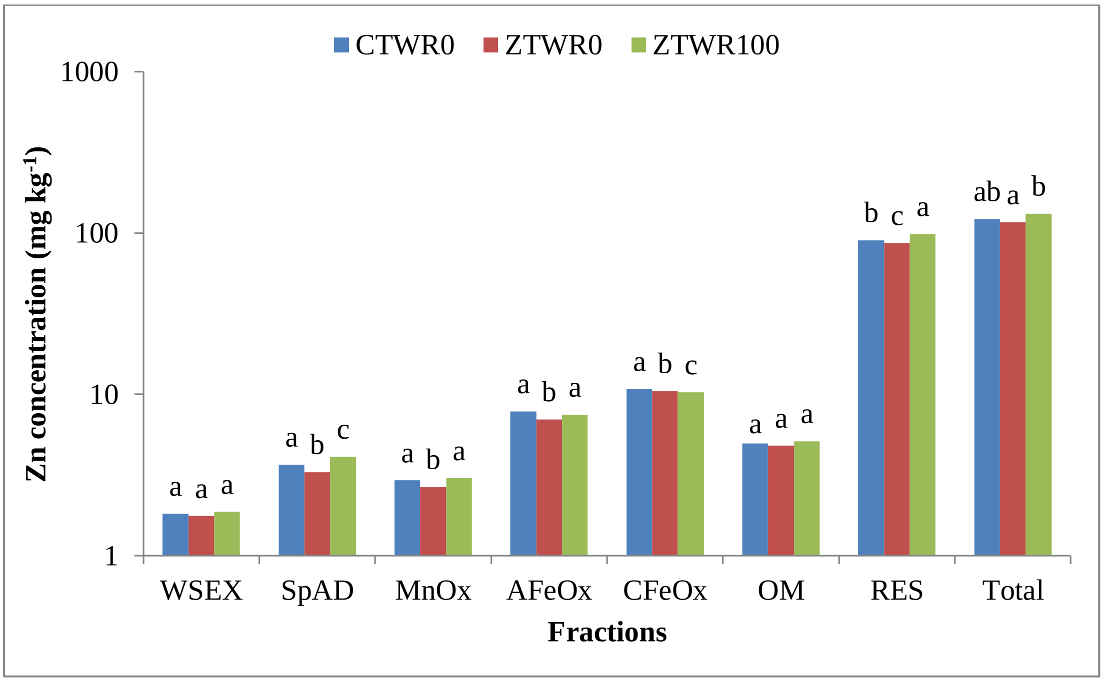
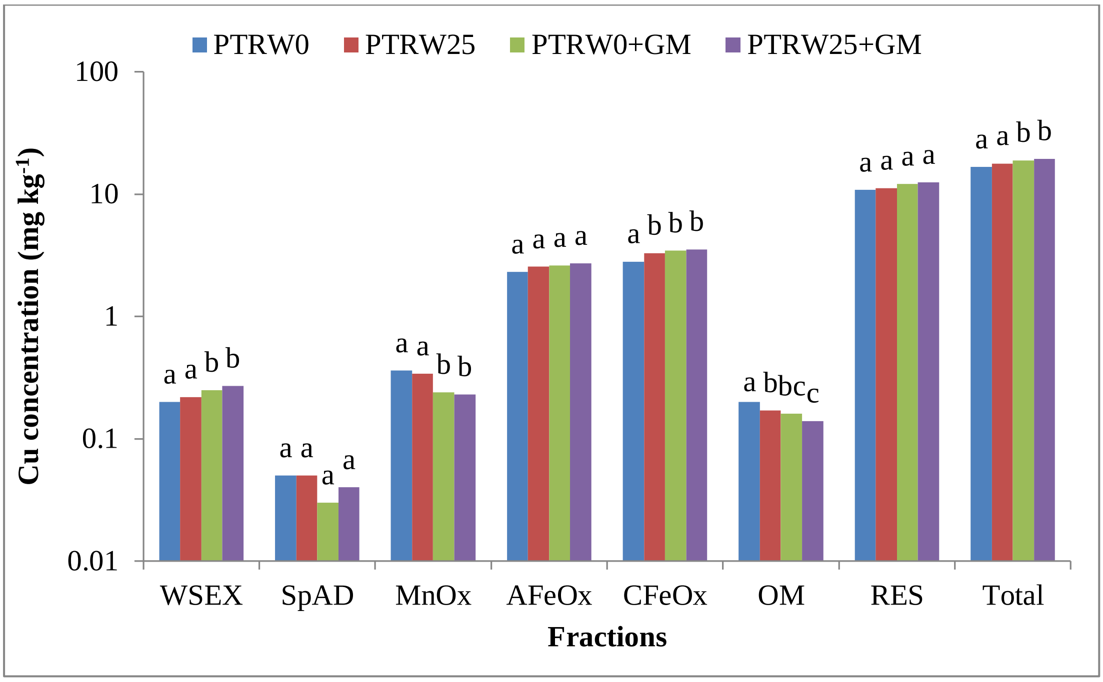
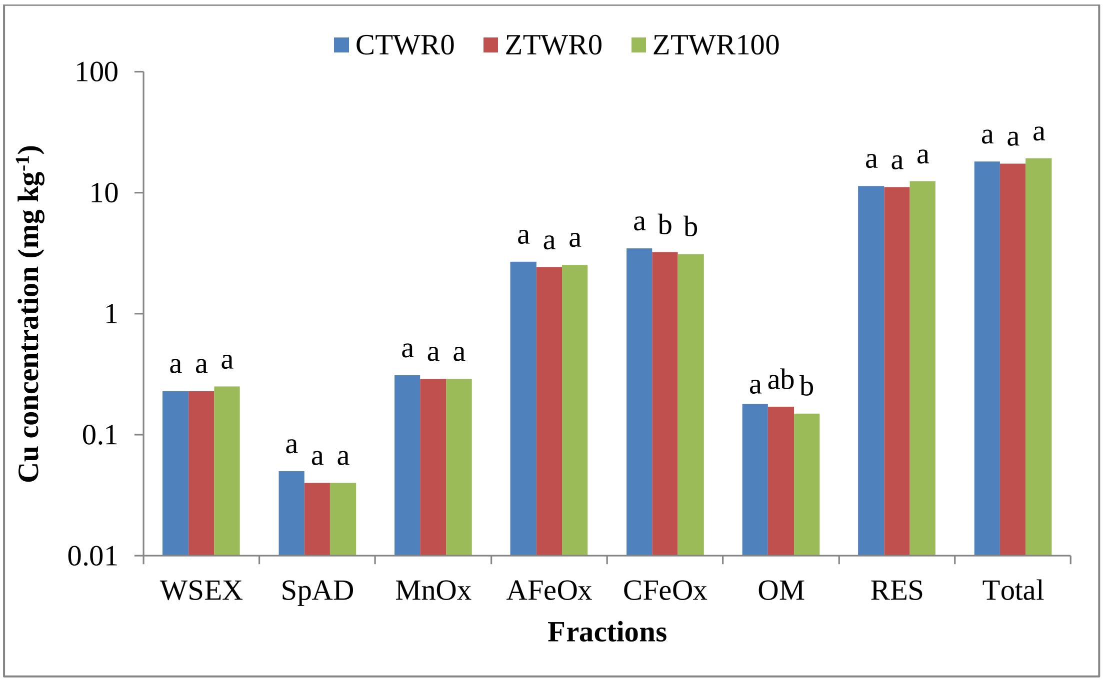


(b)

Fig. 4.10: Effect of tillage, green manuring and wheat straw management practices on different fractions of Zn during 2017 (a) main plots and (b) sub plots

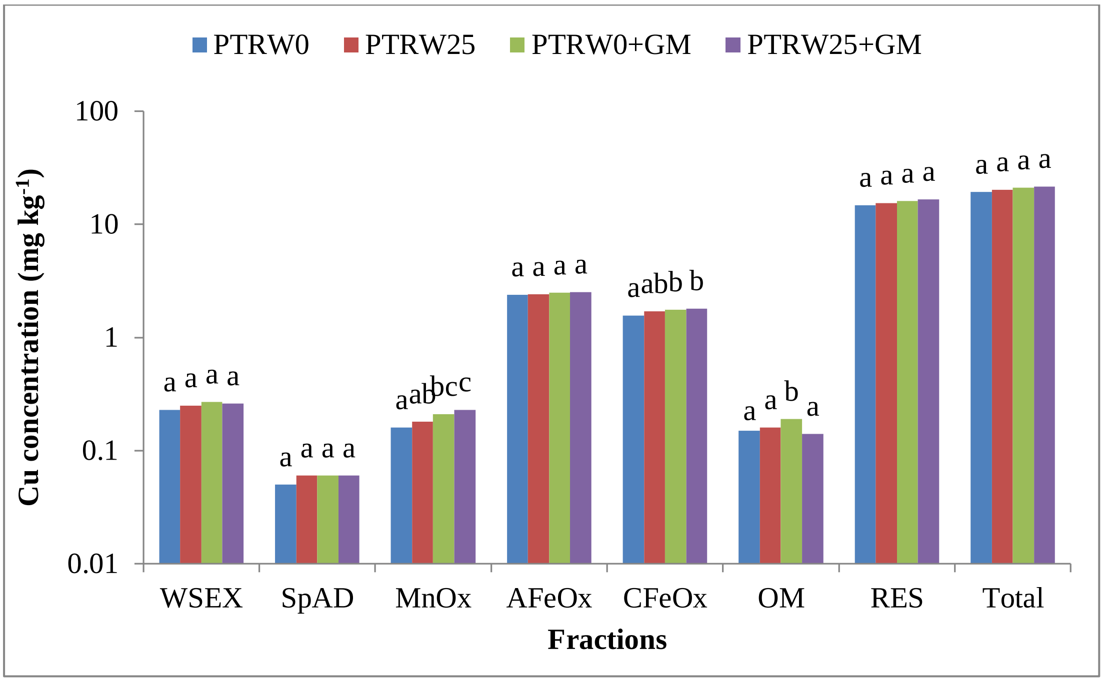


(a)

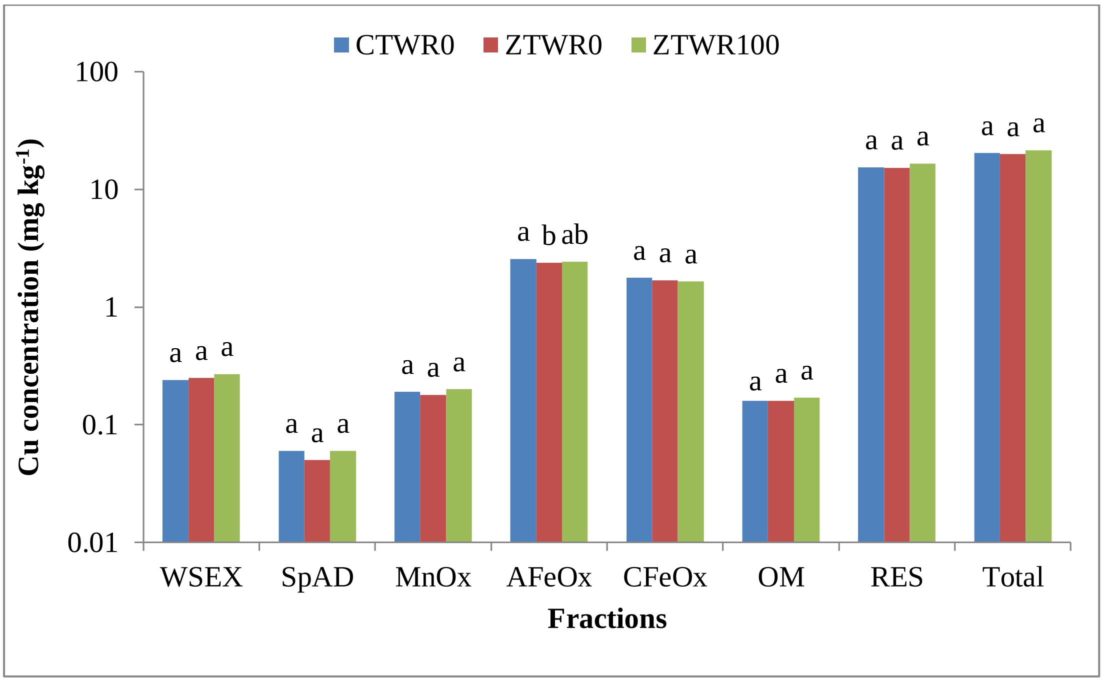


(b)

Fig. 4.11: **Effect of tillage, green manuring and wheat straw management practices on different fractions of Cu during 2015 (a) main plots and (b) sub plots**

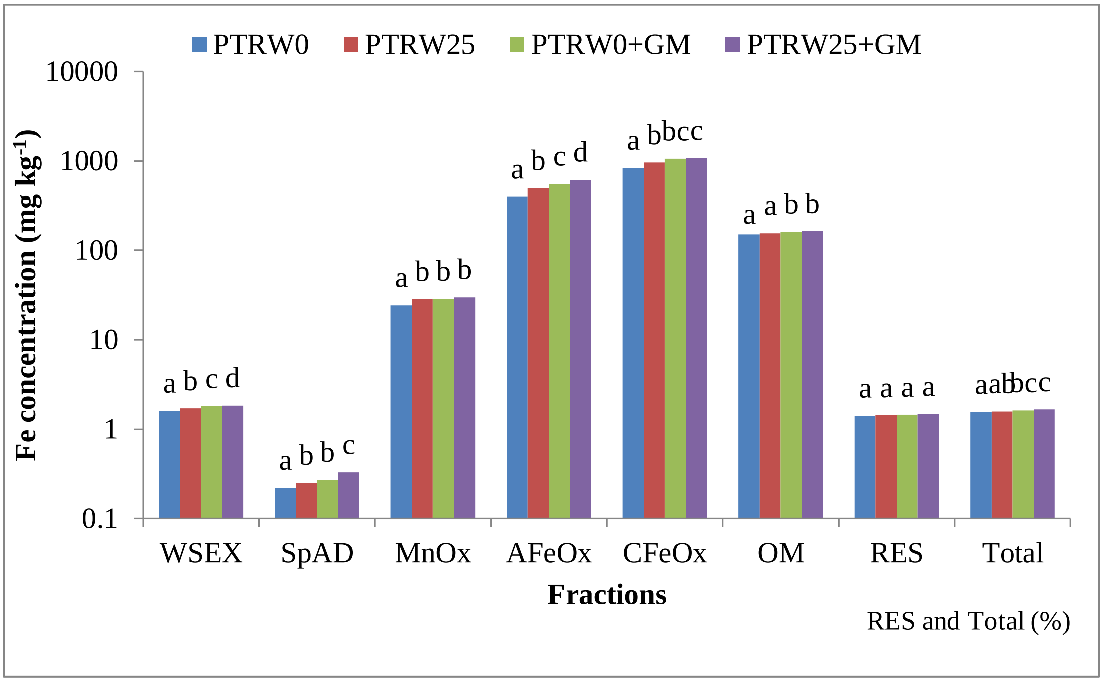


(a)

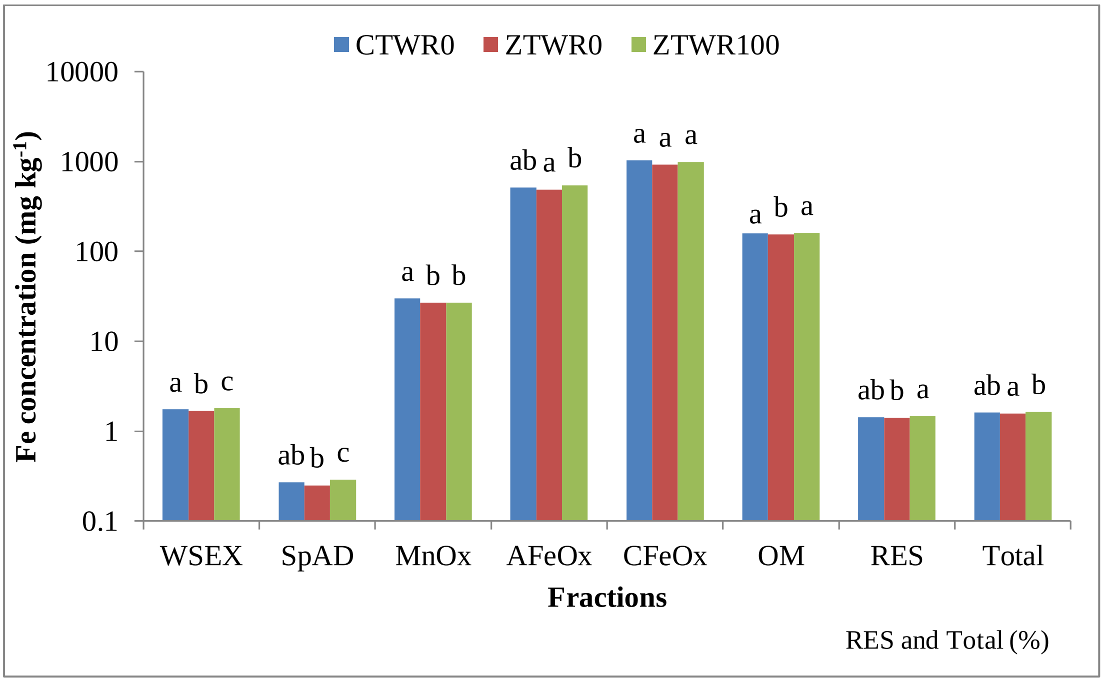


(b)

Fig. 4.12: Effect of tillage, green manuring and wheat straw management practices on different fractions of Cu during 2017 (a) main plots and (b) sub plots

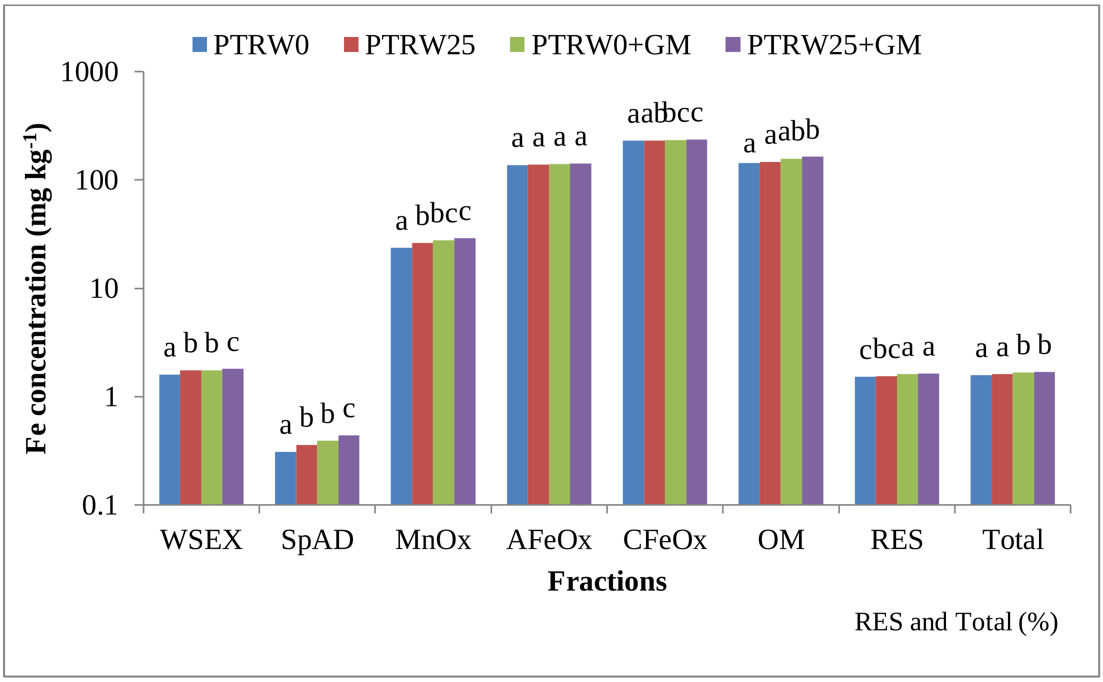


(a)

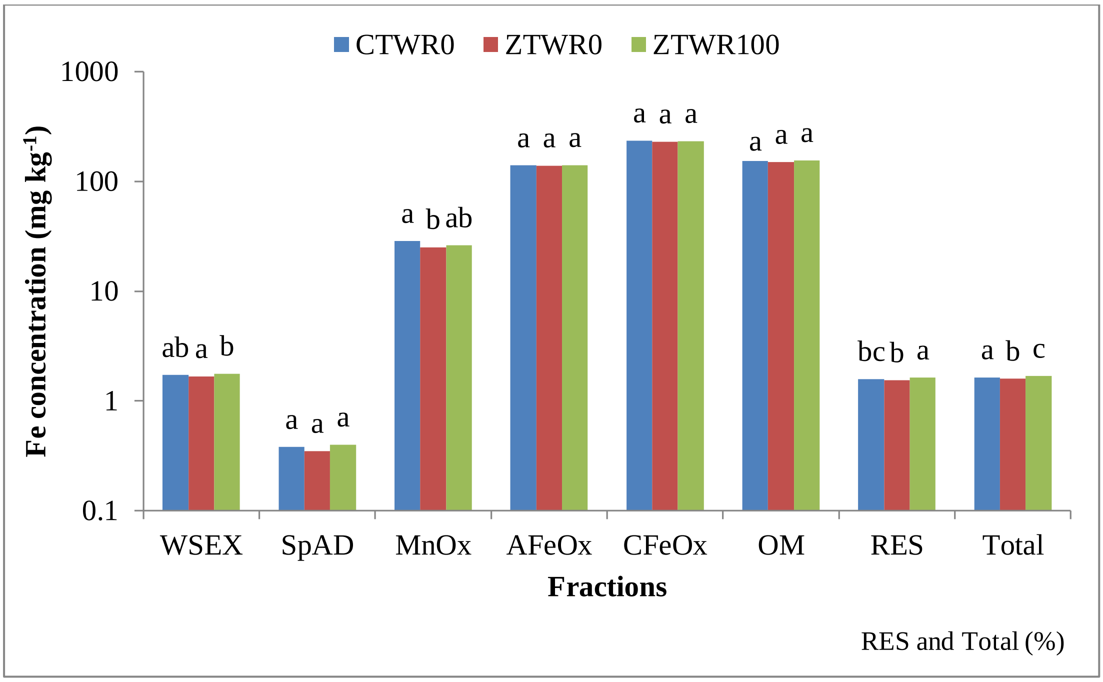


(b)

Fig. 4.13: Effect of tillage, green manuring and wheat straw management practices on different fractions of Fe during 2015 (a) main plots and (b) sub plots

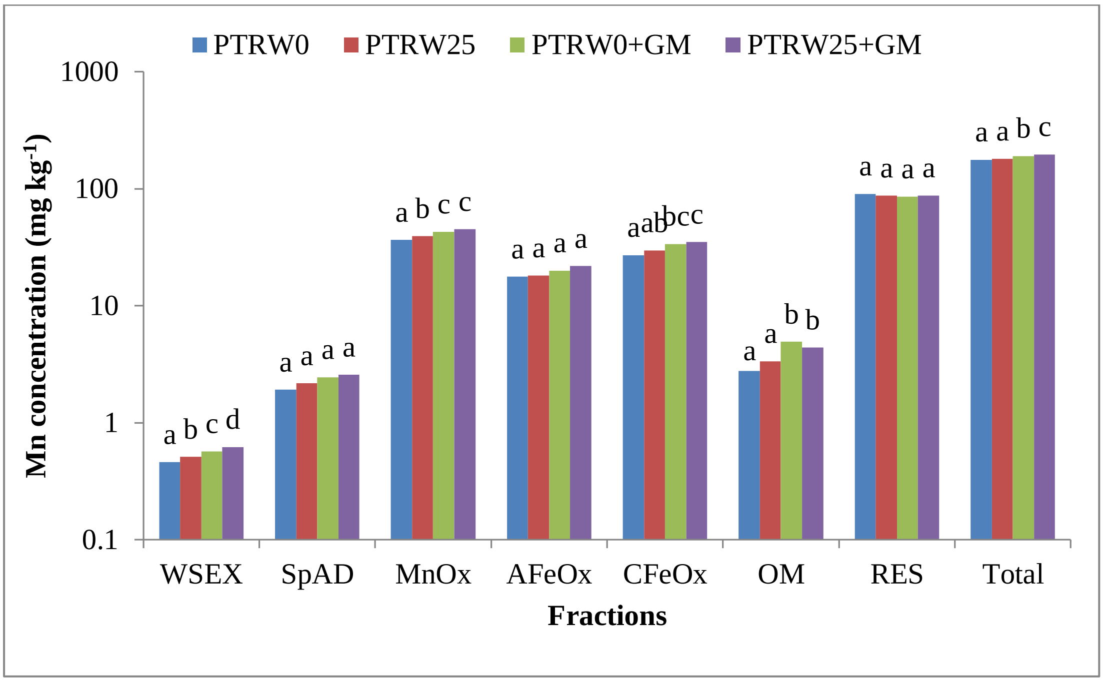


(a)

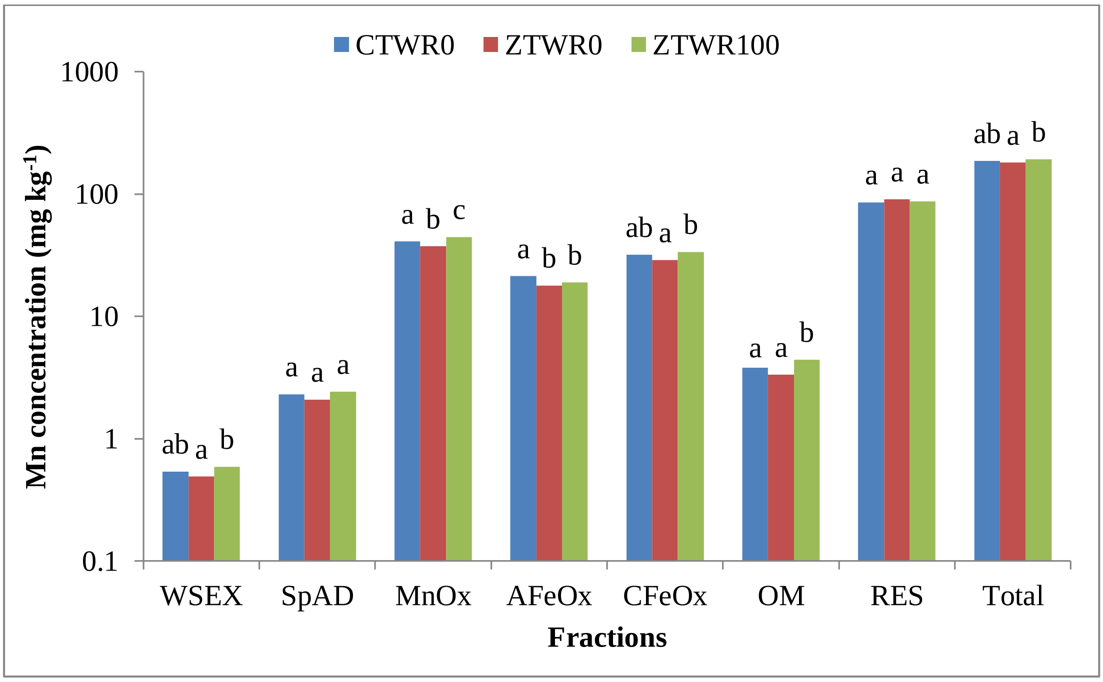


(b)

Fig. 4.14: Effect of tillage, green manuring and wheat straw management practices on different fractions of Fe during 2017 (a) main plots and (b) sub plots

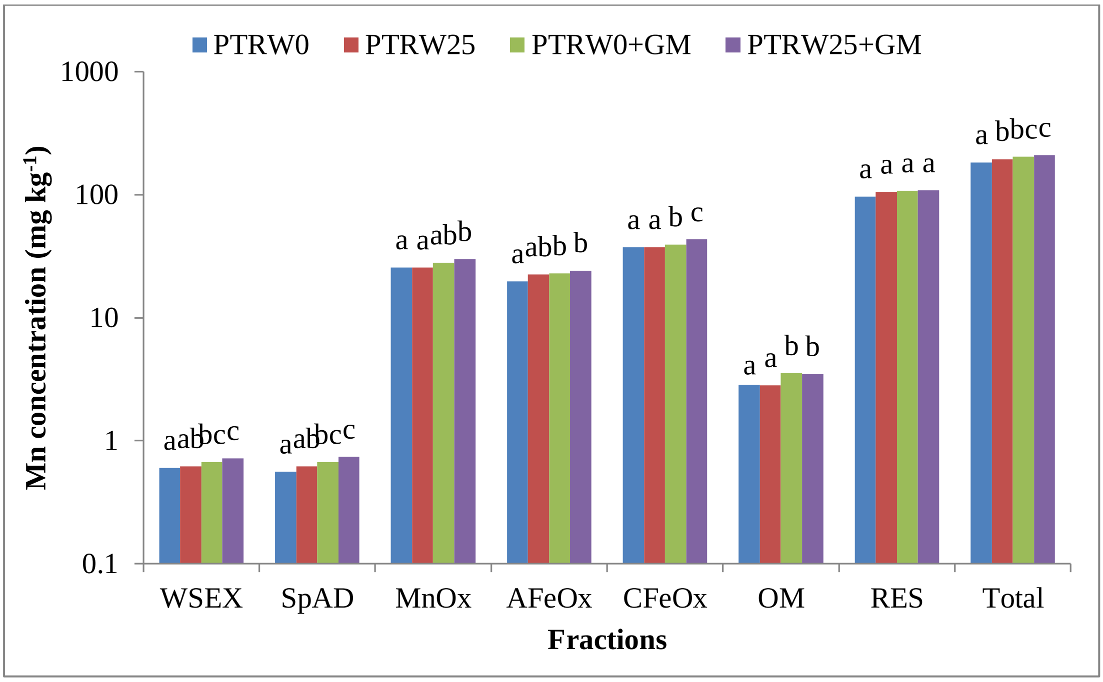


(a)

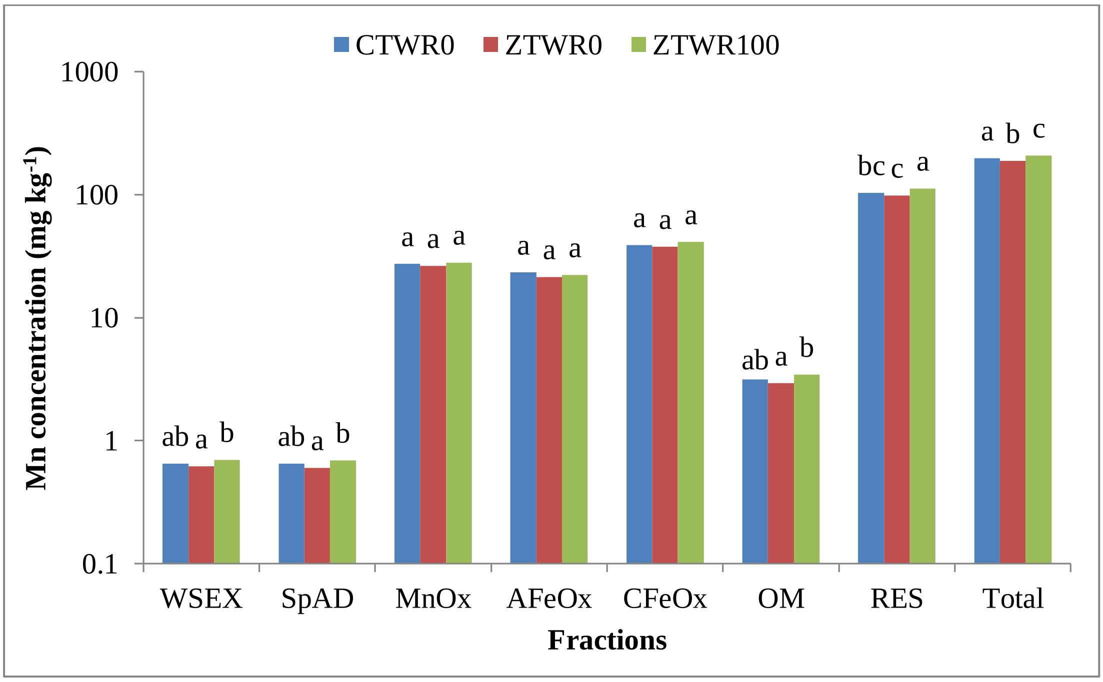


(b)

Fig. 4.15: Effect of tillage, green manuring and wheatstraw management practices on different fractions of Mn during 2015 (a) main plots and (b) sub plots



(a)



(b)

Fig. 4.16: Effect of tillage, green manuring and wheat straw management practices on different fractions of Mn during 2017 (a) main plots and (b) sub plots

CHAPTER V

SUMMARY

India has attained a breakthrough in the age-old yield obstacle, giving new dimensions to agricultural production with a change in the cropping patterns and acceptance of better production technologies and modern farming. Evidence shows that RWS productivity is now declining due to many reasons like lack of water, energy and labour scarcity, increasing cost of production, declining farm profits and unreliable weather events which are the foremost challenges faced by the farmers under intensive tillage based conventional rice–wheat (RW) production system of Indo-Gangetic Plains (IGP) in South Asia. Hence, to address these challenges and to enhance the productivity and keeping pace with the escalating food demand with minimum environmental disturbance, Conservation agriculture (CA) based crop management practices are being developed, adapted as well as promoted in the region. Some of the CA-based RCTs include zero tillage, direct seeded rice (DSR), green manuring and crop residue retention over the soil surface.

High productivity of the wheat can be accomplished by the use of CA (zero tillage (ZT) and drill seedling rather than broadcasting) with the advantage of sustaining soil structure and soil water retention. Happy Seeder allows direct drilling of wheat into rice stubble without burning which ultimately reduces air pollution and loss of nutrients as well as organic carbon, so ultimately it helps in maintaining or increasing yield. To our knowledge, a very few studies have been done to test CA based cropping system with respect to micronutrients uptake and their transformation under rice-wheat cropping system. Hence, there is need to investigate the role of tillage, rice establishment methods and organic materials on micronutrients uptake and their transformation in rice-wheat cropping system with the following objectives:

1. Effect of tillage, green manure, rice establishment methods and crop residue management practices on yield and uptake of micronutrients in grain and straw of wheat and rice
2. Effect of tillage, green manure, rice establishment methods and crop residue management practices on soil pH, EC and SOC
3. Effect of tillage, green manure, rice establishment methods and crop residue management practices on surface and profile distribution of DTPA-extractable micronutrients (Zn, Cu, Fe and Mn) in soil
4. Effect of tillage, green manure, rice establishment methods and crop residue management practices on chemical fractions of micronutrients (Zn, Cu, Fe and Mn) in surface soil

A field study entitled **"Effect of rice establishment methods, tillage and rice straw management practices on micronutrients uptake and transformation in rice-wheat system"** was undertaken on an ongoing field experiments at the research farm of Department of Soil Science, PAU, Ludhiana. The experiment no. 1 (in progress since 2010) consisted of rice establishment methods as well as tillage and rice straw management practices in wheat. These treatment combinations comprised of four main plots of rice establishment methods (direct seeded rice under zero tillage, direct seeded rice under conventional tillage, direct seeded rice under reduced tillage and puddled transplanted rice) and three subplots in wheat (conventional tillage, zero tillage without rice straw and zero till wheat sown with Happy Seeder retaining rice straw as mulch) with three replications in a split plot design. Grain and straw samples of the wheat and rice crop were collected at harvest of each crop.

The grain and straw samples were collected, processed and analyzed for micronutrient cations (Zn, Cu, Fe and Mn). The data regarding the agronomic parameters of both wheat and rice crops were collected and recorded at maturity of each crop. Soil samples were collected from 0-7.5 cm, 7.5-15 cm, 15-30 cm, 30-45 cm and 45-60 cm soil depths before the start of an experiment (after harvest of rice in October, 2015) as well as at the end of an experiment (after harvest of rice in October, 2017). The collected soil samples from different treatments were processed and analyzed for depth-wise distribution of pH, EC, SOC, DTPA-extractable micronutrients cations (Zn, Cu, Fe and Mn) and their different chemical fractions (Water soluble plus exchangeable fraction (WSEX), Specifically adsorbed fraction (SpAd), Mn-oxide bound fraction (MnOX), Amorphous iron oxide bound fraction (AFeOX), Crystalline iron oxide bound fraction (CFeOX), Organically bound fraction (OM) and total fraction of surface soil samples.

ZTW+R produced significantly higher (5 percent and 8 percent in 2017) wheat grain yield as compared to the CTW-R and ZTW-R. The straw yield was found higher in wheat sown with HS i.e ZTW+R and lowest straw yield was recorded in ZTW-R. The rice grain yield was 20 and 19 percent higher under PTR as compared to DSR-ZT and it was 9 and 6 percent higher in PTR with respect to the DSR-CT in 2015 and 2017, respectively, but grain yield in PTR did not showed any significant difference with respect to DST-RT. The straw yield was also found significantly higher in PTR with respect to DST-CT and DSR-ZT during both the years of experimentation. In wheat, number of effective tillers m^{-2}, plant height and panicle length was found higher in ZTW+R as compared to ZTW-R and CTW-R among tillage and rice straw management practices. However, in rice crop, 1000 grain weight was found significantly higher in PTR (24.6 and 25.0 g) with respect to DSR-CT (23.2 and 23.4 g) and DSR-ZT (21.9 and 22.2 g). The rice establishment systems showed that plant height, number of effective tillers m^{-2} and panicle length was higher in PTR as compared to the DSR-

ZT, DSR-RT as well as DSR-CT and lowest in DSR-ZT during both the years i.e. 2016 and 2017.

Zinc concentration at maximum tillering stage of rice was found highest in DSR-RT and lowest in PTR. However, the concentrations of Cu, Fe and Mn were observed higher in PTR as compared to DSR-RT, DSR-CT and DSR-ZT. In wheat crop, ZTW+R was found best treatment as compared to ZTW-R and CTW-R, as the concentration of all micronutrient cations was higher in ZTW+R with respect to ZTW-R and CTW-R.

Among the micronutrients concentration in rice grains, Zn concentration was lower in case of PTR and highest in DSR-RT. In contrast, the Fe concentration in rice grains was significantly higher in PTR (52.02 and 54.25 mg kg^{-1}) with respect to DSR-CT (47.01 and 49.54 mg kg^{-1}) and DSR-ZT (45.90 and 47.45 mg kg^{-1}) during both the years (2015 and 2017). The concentration of Cu and Mn was also found higher in PTR as compared to DSR-RT, DSR-CT and DSR-ZT. Similar trend was found to observe under rice straw. However, among the tillage and rice straw management practices, ZTW+R showed higher Zn, Cu, Fe and Mn content as compared to ZTW-R and CTW-R. In wheat crop, tillage and rice straw management practices showed higher concentration (mg kg^{-1}) of Zn, Cu, Fe and Mn in wheat grain as well as in wheat straw. No significant residual effect of rice establishment methods was found to observe on wheat treatments.

Tillage and rice straw management practices in wheat as well as rice establishment methods showed non-significant effect on the soil pH and EC under all the soil depths (0-7.5, 7.5-15, 15-30, 30-45 and 45-60 cm) during both years of experimentation. SOC content was found significantly higher in ZTW+R than ZTW-R and CTW-R in 0-7.5 cm soil layer. The treatments under rice establishment methods showed non-significant effect on SOC content. SOC was found to decrease gradually from 0-7.5 cm to 7.5-15 cm but the decrease was sharp afterwards in 15-30, 30-45 and 45-60 cm soil layers.

The DTPA-extractable micronutrient cations (Zn, Cu, Fe and Mn) under tillage and rice straw management practices in wheat were significantly higher under ZTW+R as compared to CTW-R and ZTW-R in surface soil layers. Amongst the rice establishment methods, DTPA-extractable Zn was found higher in DSR-RT, DSR-CT and DSR-ZT as compared to PTR. However, DTPA-extractable Cu, Fe and Mn were found higher in PTR as compared to DSR-RT, DSR-CT and DSR-ZT. In deeper soil layers, tillage and rice straw management practices as well as rice establishment methods did not significantly affected the availability of micronutrient cations.

Amongst the sequential fractionation of micronutrient cations, WSEX-Zn, WSEX-Cu, WSEX-Fe and WSEX-Mn as well as SpAd-Zn, SpAd-Cu, SpAd-Fe and SpAd-Mn were found higher under the treatments where crop residue was retained over the soil surface i.e. ZTW+R among the rice establishment methods due to higher OC content on the surface.

Among the tillage and rice straw management practices, WSEX-Fe, WSEX-Mn, SpAd-Fe and SpAD-Mn were found higher in PTR as compared to DSR treatments. The MnOx-Zn, MnOx-Fe and MnOx-Mn were also found higher in ZTW+R as compared to ZTW-R and CTW-R. In contrast to WSEX, SpAd and MnOx bound fractions of Zn, Fe and Mn, the AFeOx and CFeOx bound fractions were found higher for CTW-R treatments than for other tillage systems i.e. ZTW+R and ZTW-R. The decrease of Zn, Fe and Mn in crystalline and amorphous iron oxide bound fractions in ZTW+R was accompanied by a concomitant increase in the WSEX, SpAd and MnOx bound fractions. It denotes that a large part of these micronutrients (Zn, Fe and Mn) released from AFeOx and CFeOx bound fractions and was mobilized in to the MnOx bound fraction, WSEX fraction and SpAd fractions.

The second experiment entitled **"Effect of tillage, green manuring and wheat straw management practices on micronutrient uptake and transformation in rice-wheat system"** comprised of wheat straw and green manure (GM) management in rice, and tillage and rice straw management practices in wheat as subplot treatments. The four main treatments were-wheat straw removed (PTR_{W0}), wheat straw retained (PTR_{W25}), wheat straw removed + green manure (PTR_{W0} + GM) and wheat straw retained + green manure (PTR_{W25} + GM). The subplot treatments comprised of conventional tillage without rice straw (CTW_{R0}), zero tillage without rice straw (ZTW_{R0}) and zero tillage with rice straw as mulch using Turbo Happy Seeder (ZTW_{R100}) with three replications in a split plot design.

Among wheat straw and green manure practices in rice, PTR_{W25}+GM showed 17 and 18.3 percent higher rice grain yield as compared to PTR_{W25} and PTR_{W0} in 2016 and 16.9 and 18 percent higher yield in PTR_{W25}+GM w.r.t. PTR_{W0} and PTR_{W25} in 2017. The residual effect on rice grain yield was found higher in ZTW_{R100} as compared to ZTW_{R0} and CTW_{R0}. The harvest index and 1000 grain weight was also found higher in PTR_{W25}+GM with respect to PTR_{W25} and PTR_{W0}. Among the tillage and rice straw management practices in wheat, grain yield of wheat was found significantly higher (12.6 and 7.58 percent) in ZTW_{R100} as compared to ZTW_{R0} and CTW_{R0}. Even CTW_{R0} wheat produced higher grain yield than ZTW_{R0} in 2016-17. Even the straw yield was 5.40 and 3.88 percent higher under ZTW_{R100} as compared to ZTW_{R0} and CTW_{R0}. The incorporation of green manure and wheat straw retention showed significant residual effect on wheat grain yield. The harvest index as well as 1000 grain weight was found higher in ZTW_{R100} w.r.t. ZTW_{R0} and CTW_{R0} in wheat and in PTR_{W25}+GM w.r.t. PTR_{W0} and PTR_{W25} among different treatment combinations.

The micronutrients viz. Zn, Fe and Mn at maximum tillering stage of rice showed significantly higher concentration in PTR_{W25}+GM as compared to PTR_{W0} and $PTR_{W25.}$ Even the micronutrients concentration was also found higher in PTR_{W0}+GM as compared to PTR_{W0} and $PTR_{W25.}$ The residual effect of tillage and rice straw management practices found higher under ZTW_{R100} followed by CTW_{R0} and ZTW_{R0}. In case of wheat, micronutrients (Zn, Fe and

Mn) concentration was higher under ZTW_{R100} as compared to ZTW_{R0} and CTW_{R0}. The wheat straw and green manure practices in rice also showed significant higher residual effect for Zn, Fe and Mn in PTR_{W25}+GM as compared to PTR_{W0} and $PTR_{W25.}$

The concentration of Zn, Cu, Fe and Mn in wheat grains ranged from 25.9 to 30.0 mg kg^{-1}, 3.82 to 4.45 mg kg^{-1}, 30.6 to 35.2 mg kg^{-1} and 13.1 to 17.9 mg kg^{-1} in 2016-17. The concentration under tillage and rice straw management practices in wheat was found higher under ZTW_{R100} as compared to ZTW_{R0} and CTW_{R0} for all micronutrient cations. Moreover, wheat straw and green manure practices in rice showed their residual effect on micronutrients concentration in wheat grains which was higher under PTR_{W25}+GM and PTR_{W0}+GM as compared to PTR_{W0} and $PTR_{W25.}$ The Zn, Cu, Fe and Mn concentration for wheat straw was also found higher under ZTW_{R100} treatment. In rice crop, micronutrients concentration was observed higher under the treatments where green manure was incorporated in soil before rice i.e. PTR_{W25}+GM and PTR_{W0}+GM as compared to PTR_{W0} and $PTR_{W25.}$ The residual effect of tillage and rice straw management practices showed non-significant effect on micronutrient concentration in rice grains. Likewise, the concentration of Zn, Cu, Fe and Mn in rice straw was also found higher under ZTW_{R100} as compared to CTW_{R0} and ZTW_{R0} and under PTR_{W25}+GM as compared to PTR_{W25} and $PTR_{W0.}$

Wheat straw and green manure practices in rice as well as the tillage and rice straw management practices in wheat showed non-significant effect on depthwise distribution of soil pH and EC during both the years of experimentation. The soil pH was found lower in the treatments where crop residue was retained i.e. ZTW+R or green manure was incorporated (PTR_{W25}+GM and PTR_{W0}+GM) in soil. SOC content was found significantly higher (11.6 and 4 percent) in ZTW_{R100} than ZTW_{R0} in 0-7.5 cm and 7.5-15 cm soil layer in 2017. However, SOC content was also found significantly higher in PTR_{W25}+GM (22.6 and 27.4 percent) as compared to PTR_{W25} and $PTR_{W0.}$ In deeper layers, no significant difference among the treatments was found to observe on soil organic carbon content.

Tillage and rice straw management practices in wheat significantly affected the DTPA-extractable Zn under ZTW_{R100} as compared to ZTW_{R0} in surface soil layers. However, wheat straw and green manure practices in rice also indicated significantly higher content in PTR_{W25}+GM and PTR_{W0}+GM with respect to PTR_{W25} and PTR_{W0}. Similar to DTPA-Zn, the DTPA-Fe and DTPA-Mn content was also found higher in PTR_{W25}+GM and PTR_{W0}+GM with respect to PTR_{W25} and PTR_{W0}. Moreover, DTPA-Fe and DTPTA-Mn content was higher under ZTW_{R100} as compared to ZTW_{R0} and CTW_{R0}. The availability of DTPA-extractable micronutrients (Zn, Cu, Fe and Mn) decreases as the depth increases. However, the trend was not similar for DTPA-Mn because it seems to increase with increase in soil depths.

Results revealed that in case of chemical fractionation of micronutrients (Zn, Cu, Fe and Mn), WSEX-Zn, WSEX-Cu, WSEX-Fe and WSEX-Mn as well as SpAd-Zn, SpAd-Cu, SpAd-Fe and SpAd-Mn were found higher under the treatments where crop residue was retained over the soil surface i.e. ZTW_{R100} as compared to ZTW_{R0} and CTW_{R0} among the tillage and rice straw management practices in wheat due to higher SOC content on the surface layers. Among the wheat straw and green manure practices in rice, the WSEX-Fe, WSEX-Mn, SpAd-Fe and SpAd-Mn were found higher in PTR_{W25}+GM and PTR_{W0}+GM as compared to PTR_{W25} and PTR_{W0} treatments. The MnOx-Zn, MnOx-Fe and MnOx-Mn were also observed higher in ZTW_{R100} as compared to ZTW_{R0} and CTW_{R0}. In contrast to WSEX, SpAd and MnOx bound fractions of Zn, Fe and Mn, the AFeOx and CFeOx bound fractions were found higher for CTW treatments than for other tillage systems i.e. ZTW_{R100} and ZTW_{R0}. The decrease of Zn, Fe and Mn in crystalline and amorphous iron oxide bound fractions in ZTW+R was accompanied by a concomitant increase in the WSEX, SpAd and MnOx bound fractions. It denotes that a large part of these micronutrients (Zn, Fe and Mn) released from AFeOx and CFeOx bound fractions was mobilized in to the organic fraction, MnOx bound fraction, WSEX fraction and SpAd fractions.

Conclusions

The results of first experiment revealed that the ZTW+R showed marked increase in concentration of DTPA-extractable Zn, Fe, Mn and Cu and their transformation from occluded fractions towards bio-available forms. Residual fraction of all the micronutrient cations was found to be the most dominant fraction and water soluble + exchangeable fraction was found to be least dominant in soil. Organically bound fraction of all the micronutrient cations studied was found to be most important fraction contributing towards micronutrient uptake by both rice and wheat crops. The ZTW+R produced significantly higher wheat grain yield than ZTW-R. Moreover, rice grain yield under PTR and DSR-RT was comparable but significantly higher than DSR-CT and DSR-ZT. In second experiment, the results reported that soil pH decreased however, SOC and availability of DTPA-extractable micronutrients increased with crop residue retention and GM incorporation in soil. The DTPA-extractable Zn, Cu, Fe and Mn showed sharp decrease from 0-7.5 cm to 7.5-15 cm soil depth and afterwards the decrease was gradual with further increase in soil depth. The transformation of Zn, Cu, Fe and Mn was found higher under PTR_{W25} + GM treatment from occluded (AFeOx and CFeOx) fractions to mobile (WSEX) ones. Highest productivity and Zn, Cu, Fe and Mn uptake by grain and straw of rice and wheat were also recorded under PTR_{W25} + GM treatment.

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LIST OF ACCEPTED/ SUBMITTED RESEARCH PAPERS

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1	Impact of rice establishment methods, tillage and rice straw management practices on DTPA-extractable micronutrient cations under rice-wheat cropping system	Soil & Tillage Research	NAAS 9.40	Submitted
2	Transformation of micronutrients as influenced by rice establishment methods, tillage and rice straw management practices on rice-wheat cropping system	Nutrient Cycling in Agroecosystems	NAAS 7.84	Submitted

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Impact of rice establishment methods, tillage and rice straw management practices on DTPA-extractable micronutrient cations under rice-wheat cropping system

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Abstract

The present research study (in progress since 2010) has been conducted with prime objective to investigate the impact of rice establishment methods, tillage and rice straw management practices on DTPA-extractable micronutrient cations under rice-wheat cropping system. Laboratory analysis was made on the soil samples collected from an on-going field experiment at Department of Soil Science, PAU, Ludhiana. Treatments applied to RWS were arranged in a split-plot design with twelve treatment combinations replicated thrice. Main plot treatments applied to rice were four combinations of tillage and crop establishment methods (zero till direct seeded rice, DSR-ZT; conventional till direct seeded rice, DSR-CT; reduced till direct seeded rice, DSR –RT and puddled transplanted rice, PTR). The three subplot treatments in wheat were combinations of tillage and residue management options (conventional till wheat without residues, CTW-R; ZT wheat without residues, ZTW-R, and ZT wheat with residues retained as surface mulch using Happy Seeder, ZTW+R). All the DTPA-extractable micronutrient cations (Zn, Cu, Fe and Mn) were analyzed by using Atomic Absorption Spectrophotometer. Among the rice establishment methods, DTPA-extractable Fe and Mn were found higher under PTR as compared to DSR-RT, DSR-ZT and DSR-CT, whereas the DTPA-extractable Zn was found lower under PTR and higher under DSR-RT. The DTPA-Cu did not showed significant effect under main plot treatments during both the years. Under tillage and rice straw management practices in wheat, ZTW+R found as the better treatment as it increased the availability of DTPA-extractable micronutrient cations (Zn, Cu, Fe and Mn) as compared to ZTW-R and CTW-R. DTPA-extractable Zn, Cu, Fe and Mn showed decreasing trend with increased in soil depth.

Key words: Conservation agriculture; DTPA-extractable micronutrients; rice establishment methods; tillage; rice straw management practices; rice-wheat system

1. Introduction

The rice–wheat cropping system (RWS) occupies about 13.5 million hectares (M ha) in the Indo-Gangetic Plains (IGP) of South Asia (Gupta and Seth 2007) and is fundamental to employment, income and livelihood for millions of people in the region. However, sustainability of intensive tillage-based conventional RWS is constrained or limited by water, energy, labour scarcity, increasing cost of production, low fertility status, multiple nutrient deficiencies, imbalanced use of fertilizers, increasing air pollution and deteriorating soil health. Hence, for restoration of soil health and productivity, there is an urgent need to look forward to other options like, crop residues incorporation for supplying plant nutrients. To reverse this situation various Resource Conservation Technologies (RCTs) such as zero tillage, direct seeded rice and crop residue retention are being developed and promoted for RWS (Sidhu et al. 2007; Gathala et al. 2013). Puddling in rice and intensive tillage in wheat are known to cause sub-soil compaction, deterioration of soil structure, and decrease in permeability in the subsurface layer and thereby adversely affecting productivity of RWS as well as availability of macro and micronutrients (Jat et al. 2009). The increasing constraints of labour and time under intensive agriculture have led to the adoption of mechanized farming in RWS leaving large amounts of crop residues in the fields.

As crop residues interfere with tillage and seeding operation for the next crop, farmers in northwestern (NW) India often prefer to burn surplus rice residues on-farm after grain harvest to establish the next wheat crop. Residue burning impacts human and animal health both medically, and by traumatic road accidents due to restricted visibility (Singh et al. 2014). Establishment of wheat crop by ZTW with retention of crop residues on the soil surface potentially offers a labour-saving and cost-effective alternative to the burning of rice residues. A new machine, known as the ‘Happy Seeder’ (HS), has now been developed for this purpose which is capable of direct drilling wheat into heavy rice residue loads, without burning in a single operation (Sidhu et al. 2007; Sidhu et al. 2015). There is currently much interest in dry direct seeded rice (DSR) as an alternative to conventional transplanted rice in North-West India due to labour scarcity for transplanting, and because puddling and transplanting require large quantities of water to establish the rice crop. Zero tillage with rice residue retained on soil surface significantly improve water content in soil, improve overall soil physical and chemical health through replenishing soil organic matter which lead to increase in availability of micronutrients (Zn, Cu, Fe and Mn) and to support sustainable RWS (Jat et al. 2009; Gathala et al. 2013).

2. Materials and Methods

2.1 *Site description*

A two-year (2015-2017) field experiment on irrigated RWS was conducted on a Typic Ustochrept sandy loam soil at the experimental farm of the Punjab Agricultural University, Ludhiana (30°56 ′N and 75°52 ′E) in the IGP in the northwestern India. The top-soil (0-15 cm layer) at the start of experiment was non-saline (electrical conductivity 0.36 dS m^{-1}) with pH 7.88 and contained 4.5 g kg^{-1} Walkley-Black carbon, 8.2 mg kg^{-1} 0.5 M NaHCO3-extractable P and 50.4 mg kg^{-1} 1 N NH4OAc-extractable K. The region has a sub-tropical climate, with hot, wet summers and cool dry winters. Annual mean rainfall is 760 mm, about 80% of which occurs from June to September.

2.2 *Experimental design and treatment applications*

Treatments applied to RWS were arranged in a split-plot design with a total of twelve treatments replicated thrice. Main plot treatments applied to rice were four combinations of tillage and crop establishment methods in rice (zero till direct seeded rice, ZT-DSR; conventional till direct seeded rice, CT-DSR; reduced till direct seeded rice, ZT-DTR and puddled transplanted rice, PTR). The three subplot treatments in wheat were combinations of tillage and residue management options (conventional till wheat without residues, CTW-R; ZT wheat without residues, ZTW-R, and ZT wheat with residues retained as surface mulch using Happy Seeder, ZTW+R). The treatments were assigned to the same experimental plots in the 2 years of the study.

2.3 *Soil and Crop Management*

Wheat straw was removed at harvest in April each year and the plots were fallowed until pre irrigation for rice in early June. DSR-ZT was sown in a single operation using zero-till-fertilizer cum seed drill at 20 cm row spacing. In DSR-CT, plots were prepared by 2 harrowings + 1 cultivator + 1 planking followed by dry seeding of rice. Light irrigation (50 mm) was applied at 1 day after seeding to ensure satisfactory germination, and then at 4-5 day intervals until physiological maturity depending on the rainfall events during the growing season. In PTR, tillage included disking twice in early June followed by two cultivator operations in standing water to puddle the soil and planking. Rice (variety PR 115) was transplanted manually using 30-day-old seedlings spaced at 15 cm x 20 cm in the second week of June. All treatments received a uniform dose of 150 kg N as urea, 26 kg P as di-ammonium phosphate and 25 kg K as muriate of potash. Whole of P and K was applied at rice planting on all the plots. Fertilizer N in PTR was applied in three equal split doses at transplanting and at 3 and 6 weeks after transplanting. While in DSR-RT, DSR-CT and DSR-ZT fertilizer N was applied in three equal spilt doses at 3, 5 and 9 weeks after sowing. Rice was harvested manually in the second week of October in –R to remove the rice straw from the field plots and the combine harvester was used in +R plots to retain the rice straw in the field. All plots received flood irrigation (75-80 mm) prior to planting of wheat. In conventional plots, seed bed was prepared by 2 dry harrowings followed by 2 cultivators and 1 planking. Wheat (variety WH 1105) was sown in the second week of November using a seed rate of 100 kg ha^{-1}. Sowing of wheat was done on the same day in all the treatments at row spacing of 20 cm using Happy Seeder machine. Fertilizer N (120 kg ha^{-1}) as urea was applied in three equal split doses at sowing, and three weeks and 8 weeks after planting. A basal dose of 26 kg P ha^{-1} as single super phosphate and 25 kg K ha^{-1} as muriate of potash were applied on all plots at planting. Wheat was irrigated (each of 75 mm) at crown root initiation (CRI), maximum tillering (MT), panicle initiation and dough stages recommended for wheat crop in the region.

2.4 *Soil Sampling and Analysis*

Soil samples were collected from 0-7.5 cm, 7.5-15 cm, 15-30 cm, 30-45 cm and 45-60 cm soil layers, after the harvest of wheat crop (after 2 cycles of rice-wheat rotation). The soil samples were collected with the help of tube auger (25 mm internal diameter) from randomly selected 4 places within each treatment plot. After removing visible root debris, the soil samples were mixed, sieved (2 mm) and stored for analysis for DTPA-extractable micronutrient cations using Atomic Absorption Spectrophotometer.

2.5 *Statistical Analysis*

All the dataset was analyzed using analysis of variance (ANOVA) and differences among treatments were compared at p=0.05 level of significance. Statistical software used for this study was CPCS1. In all the analyses, significance was accepted at a level of probability (p) of <0.05.

3. Results and discussion

There was no significant interaction effects of rice establishment methods and tillage and rice residue management in wheat) on enzymes activities and chemical properties in all the three soil layers (0-5, 5-10 and 10-15 cm). Rice establishment systems also showed no significant effects on the grain yield of subsequent wheat and any of the soil property measured in the study.

3.1 *Distribution of DTPA-extractable Zn in profile*

The data presented in Fig.1 indicated that the tillage and rice straw management practices as well as the rice establishment systems significantly affected the DTPA-extractable Zn content in soil when the soil samples were collected from the profile (0 – 60 cm) before the start of an experiment in year 2015. DTPA-extractable Zn content fluctuated between 5.84 to 6.64 mg kg^{-1} and from 4.81 to 5.63 mg kg^{-1} during 2015 and 2017 respectively, between tillage and rice straw management practices as well as rice establishment systems. DTPA-extractable Zn was found to be significantly higher in ZT wheat sown with happy seeder (HS) as compared to the ZTW-R in surface soil layer (07.5 cm), but it did not indicated significant difference with respect to CTW. DTPA-extractable Zn content was highest at the surface layer (0-7.5 cm), whereas it was found to decrease with increase in lower layers i.e. 7.5-15, 15-30, 30-45 and 45-60 cm. The accumulation of Zn in surface soil layers might be due to (i) the addition through plant residues left over by the soils which have also been reported by Katyal and Sharma (1991); Setia and Sharma (2004) and Verma et al. (2005). Similar results were revealed by Khan et al. (2002) and Wright et al. (2007). In deeper layers, tillage and rice straw management practices as well as the rice establishment systems failed to cause significant effect on the DTPA-extractable Zn.

Rice establishment methods also influenced the availability of Zn significantly in soil, as it was found to be higher in DSR-RT followed by DSR-ZT followed by DSR-ZT and then PTR (2015). Similarly, rice establishment methods irrespective of the tillage and rice straw management practices in wheat also significantly affected the availability of Zn in soil during second year of the experiment (2017). Similar trend of decrease in DTPA-extractable Zn content was found in 2017 as that in 2015 among rice establishment methods. The interaction between tillage and rice straw management practices in wheat, and rice establishment methods was also found non-significant. Yadvinder Singh et al. (2000) observed that crop residues recycling increases the availability of micronutrients in the soil generally similar to that with green manuring in RWS. Martin-Rueda et al. (2007) considered the effect of different tillage on soil micronutrient content at different depths in continuous barley and found ZT+R had higher DTPA-extractable Zn than CT in the 0-15 cm layer due to the higher soil organic carbon content. Santiago et al. (2008) reported that availability of DTPA-extractable Zn were higher under ZT with crop residues as compared to CT but did not significantly influenced the availability of DTPA-extractable Fe. Prasad et al. (2010) observed that rice and wheat residue incorporation in soil significantly increased DTPA-extractable Zn content in surface (0-15 cm) soil due to build up in organic carbon in soil.

OM addition plays vital role in governing the availability of soil Zn (Chami et al. 2013). The effect of organic matter on the availability of soil-Zn depends on the maturity of organic amendments. The availability of Zn is small where mature organic materials are present such as compost because of the formation of stable organic complexes with organic matter such as humic acid (Smith 2009). In contrast, rapidly degradable organic matter added to soil effectively dissolves originally insoluble Zn, which improves its solubility and availability in soil-plant systems because of water-soluble or labile organic compounds rich in functional groups (e.g. amino, carboxyl, and phenolic) that have strong chelating abilities (Fuente et al. 2011). Aghili et al. (2014) found green manure of red clover and sunflower amendments to calcareous soil raised grain Zn concentration in bread wheat with the increased DTPA-extractable Zn in soils. Habiby et al. (2014) considered that the Zn concentration of wheat grain increased owing to the increase of soil dissolved organic matter after the incorporation of plant residues such as safflower and clover.

3.2 *Distribution of DTPA-extractable Cu in profile*

Tillage and rice straw management practices irrespective of the rice establishment systems significantly affected the DTPA-extractable Cu content (Fig. 2) in soil when the soil samples were collected from the profile (0 – 60 cm) before the start of an experiment in year 2015. DTPA- extractable Cu content wavered between 1.17 to 1.33 mg kg^{-1} and from 1.04 to 1.12 mg kg^{-1} during the year 2015 and 2017 respectively, between tillage and rice straw management practices as well as rice establishment systems (Fig. 2). DTPA-extractable Cu in soil was found to be significantly higher in ZTW+R or ZT wheat sown with happy seeder (HS) as compared to the ZTW-R and CTW in surface soil (0-7.5 cm). DTPA-extractable Cu content was highest at the surface layer (0-7.5 cm), whereas it was started to decrease with increase in lower depths i.e. 7.5-15, 15-30, 30-45 and 45-60 cm. In deeper layers, tillage and rice straw management practices as well as the rice establishment systems failed to cause significant effect on the DTPA-extractable Cu.

Among the different rice establishment methods, availability of Cu did not vary significantly in soil during first year (2015). Similar trend of decrease in DTPA-extractable Cu content was found in 2017 as that in 2015 among rice establishment methods. The interaction between tillage and rice straw management practices in wheat, and rice establishment methods was also found non-significant. Yadvinder Singh et al. (2000) found that recycling of crop residues increases the availability of micronutrients in the soil generally similar to that with green manuring in RWS. Martin-Rueda et al. (2007) studied the effect of different tillage on soil micronutrient content at different depths in continuous barley and found ZT+R had higher DTPA-extractable Cu than CT in the 0-15 cm layer due to the higher soil organic carbon content. Santiago et al. (2008) reported that availability of DTPA-extractable Cu were higher under ZT with crop residues as compared to CT.

Incorporation of crop residues by affected on reduce soil pH that it can increases the solubility of Cu compounds, also with increases organic matter content of soil and increases complexes of them can caused increase the amount of copper and manganese available. Stevenson (1991) reported applications of organic fertilizers helped in improving soil physical and biological properties and increased the concentration and availability of micronutrients (Zn, Cu, Fe and Mn) in the soil. The increase in DTPA-extractable Cu may be attributed to the chelating action of organic compounds released during decomposition of organic manures, which increased the availability of micronutrients by preventing fixation, oxidation, precipitation and leaching. Hao and Chang (2002) reported the effect of 25 annual cattle manure applications on soluble and exchangeable Cu in soil. In an acid soil Lal and Mathur (1989) reported higher levels of DTPA-Cu under combined use of manures and fertilizer treatments.

3.3 ***Distribution of DTPA-extractable Fe in profile***

The data presented in Fig. 3 indicated that the tillage and rice straw management practices as well as the rice establishment systems significantly affected the DTPA-extractable Fe content in surface soil. DTPA- extractable Fe ranged between 26.23 to 37.12 mg kg^{-1} and from 22.98 to 27.63 mg kg^{-1} in the surface layer (0-7.5 cm) during the year 2015 and 2017 respectively, between tillage and rice straw management practices as well as rice establishment systems. DTPA-extractable Fe content was highest at the surface layer (0-7.5 cm), whereas it was found to decrease with increase in soil depths i.e. 7.5-15, 15-30, 30-45 and 45-60 cm. DTPA-extractable Fe was found to be significantly higher in ZTW+R (31.63 mg kg^{-1}) as compared to the ZTW-R (27.94 mg kg^{-1}) in surface soil layer (0-7.5 cm) in 2015, but it did not indicated significant difference with respect to CTW. Similarly, DTPA-extractable Fe exhibited significantly higher content in ZTW+R (27.63 mg kg^{-1}) as compared to the ZTW-R (23.91 mg kg^{-1}) in surface soil layer (07.5 cm) in 2017. Increased accumulation of micronutrients in the surface of no tilled soils has frequently been ascribed to the accumulation of plant residues on the surface and poor soil mixing (Saavedra et al. 2007).

The most significant influence of crop residues in increasing the solubility and availability of Fe in the soil is through solubilization of native soil insoluble Fe and enhanced diffusion and mass flow in the immediate vicinity of plant Dhaliwal et al. (2012). An increase in the availability of Fe in soil with the application of crop residue in rice-wheat cropping system has been reported by Yadvinder Singh et al. (1992, 2000) and Yadav and Kumar (2000). However, crop residue management increased the micronutrients supply to a reasonable extent. Mann et al. (1978) reported an increase in DTPA-Fe by manure application in maize-wheat cropping system. Yadvinder Singh et al. (2000) found that recycling of crop residues increases the availability of micronutrients in the soil generally similar to that with green manuring in RWS. Martin-Rueda et al. (2007) studied the effect of different tillage on soil micronutrient content at different depths in continuous barley and found ZTW+R had higher DTPA-extractable Fe than CTW in the 0-15 cm layer due to the higher soil organic carbon content. Prasad et al. (2010) found that incorporation of residue both rice and wheat significantly increased DTPA-extractable Fe content in surface (0-15 cm) soil due to build up in organic carbon in soil.

Rice establishment methods also influenced the availability of DTPA-extractable Fe significantly in soil, as it was observed that DTPA-extractable Fe was higher in PTR followed by DSR-RT and then DSR-ZT and DSR-CT. Decreasing trend of DTPA-extractable Fe was found with increase in soil depth. The interaction between tillage and rice straw management practices in wheat, and rice establishment methods was found to be non-significant.

3.4 *Distribution of DTPA-extractable Mn in profile*

The effect of tillage and rice straw management practices as well as the rice establishment systems presented in the table showed significant difference among the treatments for DTPA-extractable Mn in soil. DTPA- extractable Mn content (Fig. 4) fluctuated within 4.20 to 5.87 mg kg^{-1} at the time of first soil sampling in 2015 and it varied from 7.91 to 9.55 mg kg^{-1} in 2017 in surface soil layer (0-7.5 cm), between tillage and rice straw management practices as well as rice establishment systems. DTPA-extractable Mn was significantly higher in ZTW+R or ZT wheat sown with happy seeder (HS) as compared to the ZTW-R and CTW during the first year of experimentation. DTPA-extractable Mn content was found to increase with increase in soil depths i.e. 7.5-15, 15-30, 30-45 and 45-60 cm. Rice establishment systems irrespective of the tillage and rice straw management practices in wheat indicated significant effect on the DTPA-extractable Mn. Yadvinder Singh et al. (2000) found that recycling of crop residues increases the availability of micronutrients in the soil generally similar to that with green manuring in RWS. Martin-Rueda et al. (2007) studied the effect of different tillage on soil micronutrient content at different depths in continuous barley and found ZTW+R had higher DTPA-extractable Mn than CTW in the 0-15 cm layer due to the higher soil organic carbon content. Prasad et al. (2010) found that incorporation of residue both rice and wheat significantly increased DTPA-extractable Mn content in surface (0-15 cm) soil due to build up in organic carbon in soil.

4. Conclusions

The study showed that zero tillage with rice residues as surface mulch (ZTW+R) markedly improved the concentration of DTPA-extractable Zn, Cu, Fe and Mn over zero tillage without residue (ZTW-R) after two years of RW cropping sequence. ZTW+R was more effective than ZTW/CTW for increasing the soil organic carbon, Olsen-P, NH4OAc-K and DTPA-extractable micronutrients in soil surface 0-5 cm layer. A significant change in soil enzyme activities occurred after 3 years of ZTW+R. All soil enzymes were positively correlated with each other and with soil chemical properties and grain yield. The increase in enzyme activities in soil may contribute to a long-term sustainability of RWS under semi-arid climate conditions of South Asia. The beneficial effect of resource conservation technologies (RCT) on soil quality was mainly confined to the soil surface layer.

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Fig.1: Effect of rice establishment methods, tillage and rice straw management practices on DTPA-Zn in profile (0-60 cm)

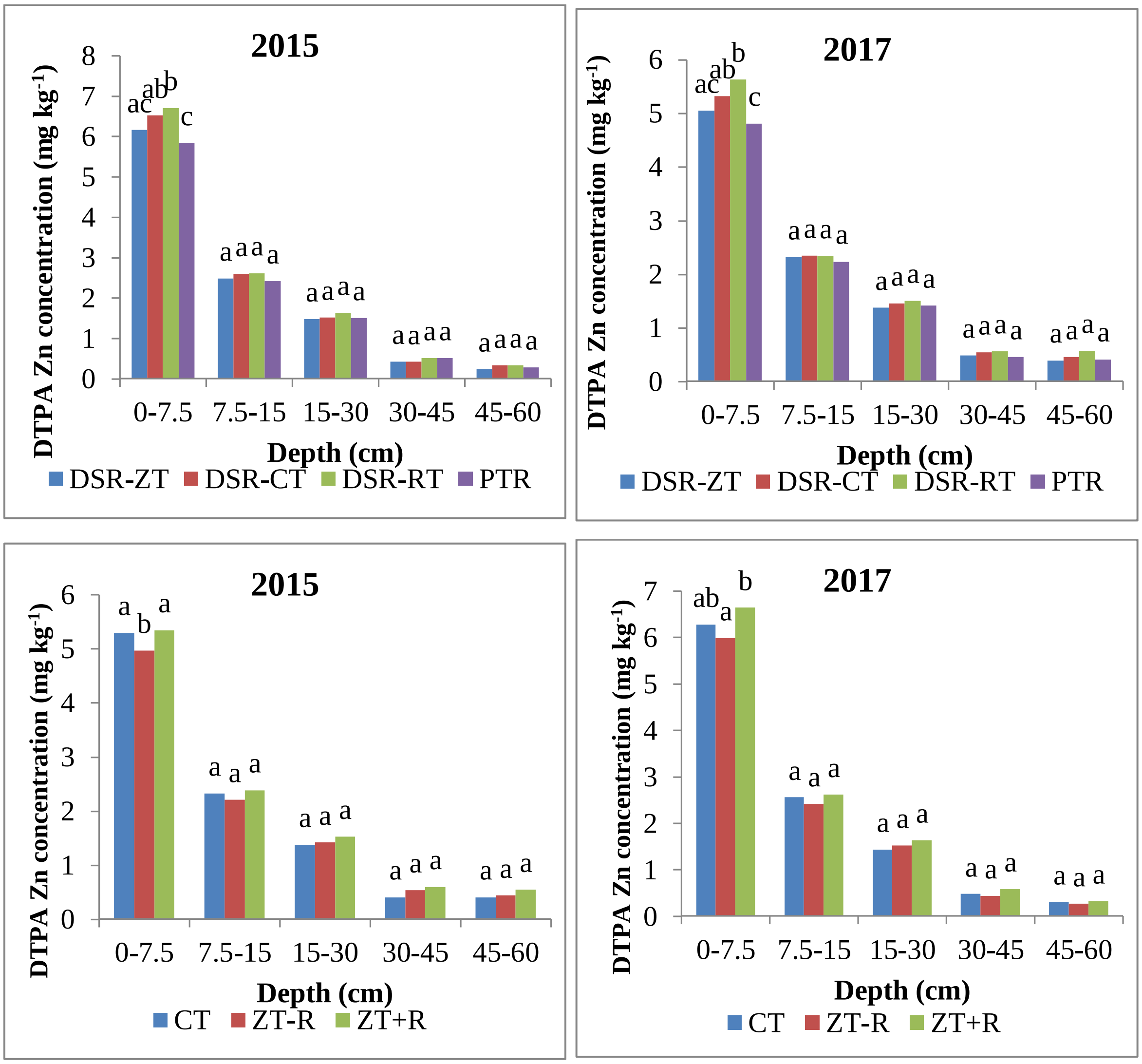


Fig.2: Effect of rice establishment methods, tillage and rice straw management practices on DTPA-Cu in profile (0-60 cm)

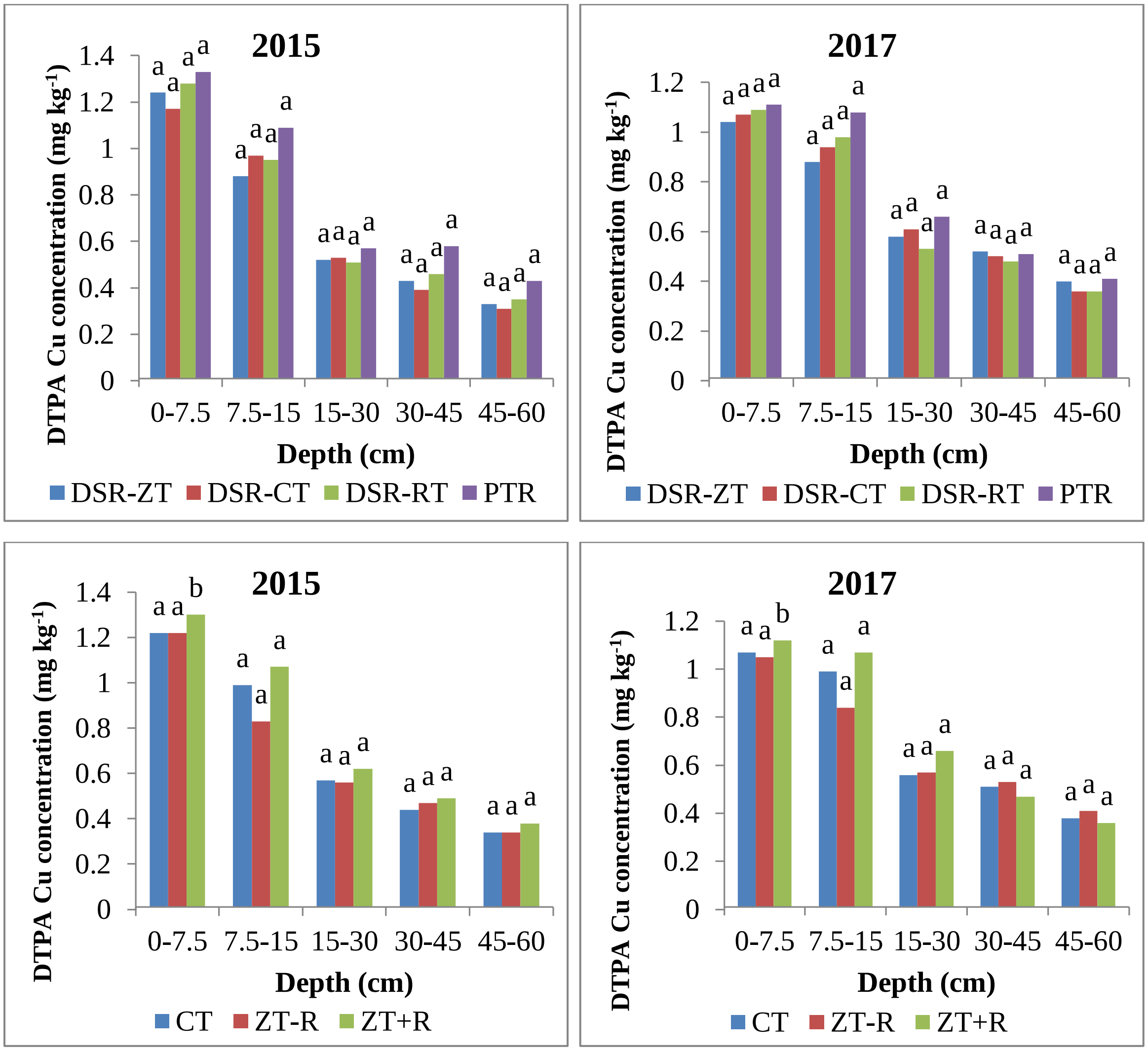


Fig.3: Effect of rice establishment methods, tillage and rice straw management practices on DTPA-Fe in profile (0-60 cm)

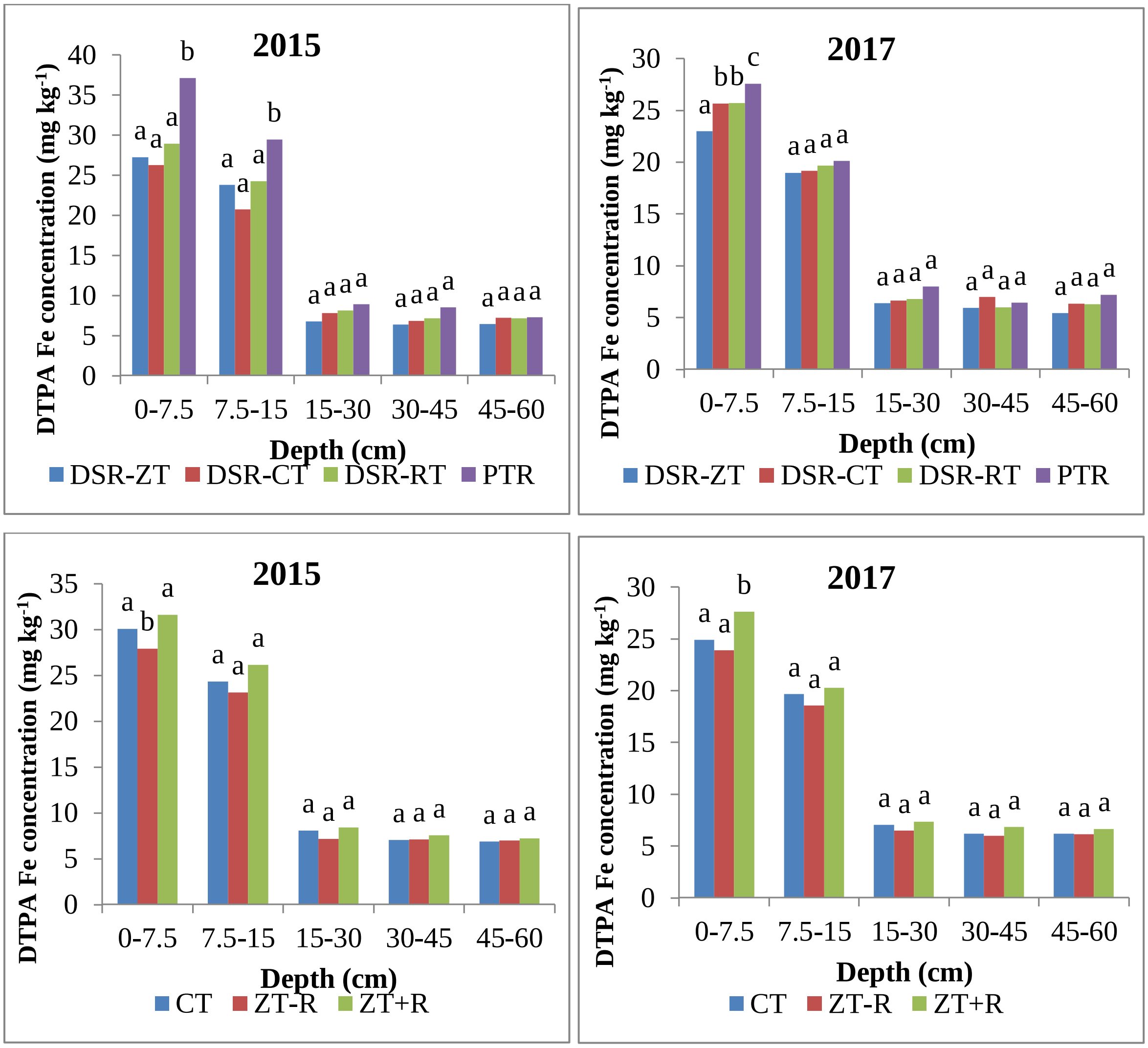
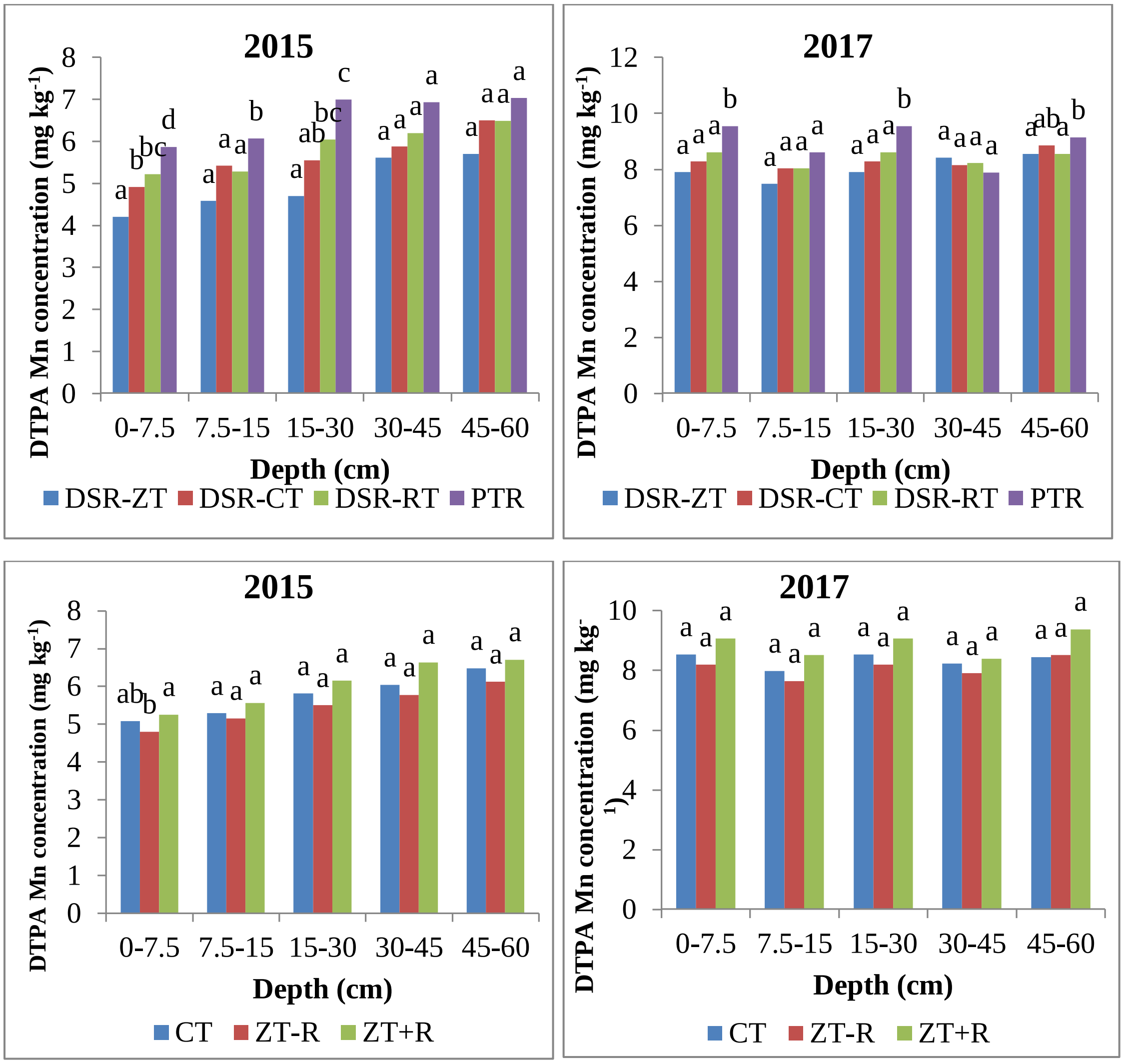


Fig.4: Effect of rice establishment methods, tillage and rice straw management practices on DTPA-Mn in profile (0-60 cm)



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Transformation of micronutrients as influenced by rice establishment methods, tillage and rice straw management practices on rice-wheat cropping system

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Abstract

The field experiment was carried out on an on-going field experiment at Department of Soil Science, PAU, Ludhiana, with an objective to investigate the effect of rice establishment methods, tillage and rice straw management practices on transformation of micronutrient cations (Zn, Cu, Fe and Mn) in the soil under rice-wheat cropping system. The treatment combinations applied to RWS were laid out in split-plot design with twelve treatment combinations replicated thrice. Main plot treatments applied to rice were four combinations of tillage and crop establishment methods in rice (zero till direct seeded rice, ZT-DSR; conventional till direct seeded rice, CT-DSR; reduced till direct seeded rice, ZT-DTR and puddled transplanted rice, PTR). The three subplot treatments in wheat were combinations of tillage and residue management options (conventional till wheat without residues, CTW-R; ZT wheat without residues, ZTW-R, and ZT wheat with residues retained as surface mulch using Happy Seeder, ZTW+R). The inter conversion of micronutrient cations (Zn, Cu, Fe and Mn) from one fraction to the other was accelerated with the addition of the SOM through retention of crop residue over the soil surface. The organic compounds released during decomposition of SOM enhanced the availability of micronutrient cations (Zn, Cu, Fe and Mn) by preventing fixation, oxidation, precipitation and leaching. The decrease in occluded fractions viz. crystalline iron oxide (CFeOx) and amorphous iron oxide (AFeOx) bound fractions indicated the mobilization and concomitant increase in availability of the micronutrient cations (Zn, Cu, Fe and Mn) in to manganese oxide fraction (MnOx), water soluble plus exchangeable (WSEX) fraction and specifically adsorbed (SpAd) fractions.

Keywords Tillage. Rice establishment methods. Rice straw management practices. Chemical fractions of Zn, Cu, Fe and Mn. Rice-wheat system

Introduction

Production of food grains is increasing year after year due to intensive cultivation of land thereby depleting a huge amount of macronutrients along with micronutrients. In several areas with intensive cropping, zinc deficiency appeared initially and subsequently the deficiency of other micronutrients was observed. Micronutrient cations in soils are generally considered to be present in association with soil solutions, inorganic and organic solid phases. These associations are often referred to as speciation

(Ramos et al. 1994) and leads to different chemical pools of these micronutrients such as water soluble, exchangeable, specifically adsorbed and those bound with free calcium carbonate, soil organic matter, oxides and minerals (Iyenger et al. 1981 and Yu et al. 2010). Water-soluble and exchangeable micronutrient forms are considered mobile and available to plants. The carbonate-bound, Fe, Al and Mn oxide-bound and organic matter-bound forms could be considered relatively active or firmly bound, depending upon the physico-chemical properties of the soil (Shuman and Wang 1997; Guan et al. 2011 and Li et al. 2012). Knowledge about the total content of an element in soils is of meager importance as it does not provide information about chemical behavior and availability to plants (Vukasinovic et al. 2015 and Buccolieri et al. 2010). Other forms incorporated into the crystalline lattices of clays are relatively inactive. Different forms of micronutrients have different solubilities.

The distribution of micronutrients in different pools is sensitive to cultivation and management practices (Shuman and Hargrove 1985 and Wang et al. 2016). Application of organic manures resulted in redistribution of micronutrients from non-available form (carbonates and crystalline iron oxides bound) to readily available form (water soluble plus exchangeable) and potentially available (organic fraction, manganese oxides and amorphous iron oxides bound) (Sekhon et al. 2006). Micronutrients supply is influenced by various factors particularly the soil mineral content (Fe, Al, and Mn oxides, hydroxides, and carbonates), pH, organic matter content and tillage practices (Chaignon et al. 2003; Bradl 2004; Fernández-Calviño et al. 2010; Brunetto et al. 2014 and Couto et al. 2016). The knowledge of various fractions of nutrients present in soil and conditions under which these become available to plants is pre-requisite in assessing their availability to plants. An index of soil available nutrients and their uptake by crops can help in understanding the nutrient availability in a better way. It is important to know the relationship between chemical pools of nutrients in the soil and uptake of that nutrient by the crop.

Materials and Methods

Study site

The experimental site is located in the Ludhiana district of Punjab at an elevation of 247m above mean sea level and lie at $30^{0}54'$ latitude and $75^{0}40'$ longitude, which represents the central agro-climatic zone of Punjab under Trans-Gangetic agro-climatic zone of India. Field experiment was conducted on a Typic Ustochrept sandy loam soil in the northwestern India. The surface soil layer (0-15 cm layer) at the start of experiment was non-saline (0.36 dS m^{-1}) with pH 7.88 and contained 4.5 g kg^{-1} Walkley-Black carbon, 8.2 mg kg^{-1} 0.5 M $NaHCO_3$-extractable P and 50.4 mg kg^{-1} 1 N NH4OAc-extractable K. In general, it represents sub-tropical and semi-arid climate with hot and dry summers during April to June, hot and humid conditions during the months July to September, cold winters from November to January and mild climate during February and March. The mean maximum and minimum temperatures show considerable variations during different months of the year.

Experimental setup and treatments

In RWS, different treatments (twelve) were applied which were arranged in a split-plot design with three replications. Main plot treatments applied to rice were four combinations of tillage and crop establishment methods in rice (zero till direct seeded rice, ZT-DSR; conventional till direct seeded rice, CT-DSR; reduced till direct seeded rice, ZT-DTR and puddled transplanted rice, PTR). The three subplot treatments in wheat were combinations of tillage and residue management options (conventional till wheat without residues, CTW-R; ZT wheat without residues, ZTW-R, and ZT wheat with residues retained as surface mulch using Happy Seeder, ZTW+R).

Soil and Crop Management

Wheat straw was removed at harvest in April each year and the plots were fallowed until pre irrigation for rice in early June. DSR-ZT was sown in a single operation using zero-till-fertilizer cum seed drill at 20 cm row spacing. In DSR-CT, plots were prepared by 2 harrowings + 1 cultivator + 1 planking followed by dry seeding of rice. Light irrigation (50 mm) was applied at 1 day after seeding to ensure satisfactory germination, and then at 4-5 day intervals until physiological maturity depending on the rainfall events during the growing season. In PTR, tillage included disking twice in early June followed by two cultivator operations in standing water to puddle the soil and planking. Rice (variety PR 115) was transplanted manually using 30-day-old seedlings spaced at 15 cm x 20 cm in the second week of June. All treatments received a uniform dose of 150 kg N as urea, 26 kg P as di-ammonium phosphate and 25 kg K as muriate of potash. Whole of P and K was applied at rice planting on all the plots. Fertilizer N in PTR was applied in three equal split doses at transplanting and at 3 and 6 weeks after transplanting. While in DSR-RT, DSR-CT and DSR-ZT fertilizer N was applied in three equal spilt doses at 3, 5 and 9 weeks after sowing. Rice was harvested manually in the second week of October in –R to remove the rice straw from the field plots and the combine harvester was used in +R plots to retain the rice straw in the field. All plots received flood irrigation (75-80 mm) prior to planting of wheat. In conventional plots, seed bed was prepared by 2 dry harrowings followed by 2 cultivators and 1 planking. Wheat (variety WH 1105) was sown in the second week of November using a seed rate of 100 kg ha^{-1}. Sowing of wheat was done on the same day in all the treatments at row spacing of 20 cm using Happy Seeder machine. Fertilizer N (120 kg ha^{-1}) as urea was applied in three equal split doses at sowing, and three weeks and 8 weeks after planting. A basal dose of 26 kg P ha^{-1} as single super phosphate and 25 kg K ha^{-1} as muriate of potash were applied on all plots at planting. Wheat was irrigated (each of 75 mm) at crown root initiation (CRI), maximum tillering (MT), panicle initiation and dough stages recommended for wheat crop in the region.

Soil Sampling and Analysis

Soil sampling was done from different soil depths viz. 0-7.5 cm, 7.5-15 cm, 15-30 cm, 30-45 cm and 45-60 cm soil layers, after the harvest of rice crop (after 2 cycles of rice-wheat rotation). The soil samples were collected with the help of tube auger from randomly selected four places within each treatment plot. The soil samples were mixed, sieved (2 mm) and stored for analysis for different fractions of micronutrient cations (Zn, Cu, Fe and Mn) using instrument named Atomic Absorption Spectrophotometer.

Statistical Analysis

All the dataset was analyzed using analysis of variance (ANOVA) and differences among treatments were compared at $p=0.05$ level of significance. Statistical software used for this study was SPSS version 20.0. In all the analyses, significance was accepted at a level of probability (p) of <0.05.

Results

Chemical fractions associated with zinc (Zn)

The Fig. 1, below revealed that WSEX-Zn content fluctuated between 2.28 to 3.42 mg kg^{-1} in the surface soil samples (0-7.5 cm), and it was observed that WSEX-Zn was higher under ZTW+R as compared to the ZTW-R and CTW within tillage and rice straw management practices. Although, the tillage and rice straw management practices failed to cause significant effect on the WSEX-Zn content but still the content was higher under residue retained treatments compared to the conventional tilled treatments during both the years. Rice establishment methods irrespective of the tillage and rice straw management practices also indicated non-significant effect on WSEX-Zn in soil, but the content was higher in DSR-RT followed by DSR-CT followed by DSR-ZT and then PTR. The content for SpAD-Zn varied from 4.43 to 6.69 mg kg^{-1} 2017. Among the rice establishment methods, the content for SpAD-Zn was found significantly higher under DSR-RT with respect to DSR-ZT and PTR. Among the tillage and rice straw management practices, ZTW+R treatments showed significantly higher content for SpAD-Zn (6.24 mg kg^{-1}) with respect to ZTW-R (5.33 mg kg^{-1}), but it had no significant difference with CTW treatment. The MnOx-Zn ranged from 2.89 to 4.01 mg kg^{-1}among different treatment combinations.

Amongst rice establishment methods, the MnOx-Zn content was higher in DSR-RT (4.01 mg kg^{-1}) followed by DSR-CT (3.66 mg kg^{-1}) and DSR-ZT (3.58 mg kg^{-1}) as compared to PTR (3.22 mg kg^{-1}). A close examination of data indicated that AFeOx-Zn varied from 7.16 to 8.84 mg kg^{-1} under different treatment combinations. Among the rice establishment methods, the content for AFeOx-Zn was found significantly higher in direct seeded rice treatments viz. DSR-RT (8.84 mg kg^{-1}), DSR-ZT (8.61 mg kg^{-1}) and DSR-CT (8.51 mg kg^{-1}) as compared to PTR (7.16 mg kg^{-1}). However among the tillage and rice straw management practices, the AFeOx-Zn showed reverse trend as compared to the previous fractions by indicating higher content under CTW instead of ZTW+R and ZTW-R, but the results were found non-significant amongst the tillage and rice straw management practices.

The CFeOx-Zn content fluctuated between 10.29 to 11.16 mg kg^{-1} amongst the tillage and rice straw management practices as well as rice establishment methods in the surface soil samples. It was observed that among the tillage and rice straw management practices, CFeOx-Zn was found higher in CTW (11.16 mg kg^{-1}) as compared to ZTW+R (10.29 mg kg^{-1}) as well as ZTW-R (10.81 mg kg^{-1}). On the other hand, rice establishment systems irrespective of the tillage and rice straw management practices failed to cause significant effect on the CFeOx-Zn content but still the content was higher under direct seeded rice treatments i.e. DSR-CT, DSR-RT and DSR-ZT as compared to the puddled transplanted rice (PTR). The content for OM-Zn varied from 4.96 to 6.34 mg kg^{-1} within all the treatment combinations. Among the rice establishment methods, the content for OM-Zn was higher for DSR-RT (6.08 mg kg^{-1}) followed by DSR-ZT (6.34 mg kg^{-1}) followed by DSR-CT (5.32 mg kg^{-1}) as compared to PTR (4.96 mg kg^{-1}) However, among the tillage and rice straw management practices, the OM-Zn was highest for ZTW+R followed by ZTW-R and then in CTW.

The RES-Zn content fluctuated between 66.6 to 77.8 mg kg^{-1} in the surface soil and it was observed that amongst the tillage and rice straw management practices in wheat, RES-Zn was significantly higher under ZTW+R (77.8 mg kg^{-1}) as compared to the ZTW-R (73.2 mg kg^{-1}) and CTW (66.6 mg kg^{-1}). Rice establishment methods indicated non-significant effect on RES-Zn in soil, but the content was higher in DSR-RT followed by DSR-ZT followed by PTR and then DSR-CT. The total-Zn varied from 104.3 to 115.3 mg kg^{-1} within all the treatments. Total-Zn was significantly higher for DSR-RT (114.6 mg kg^{-1}) as compared to DSR-CT (107.6 mg kg^{-1}) as compared to PTR (104.3 mg kg^{-1}) However, among the tillage and rice straw management practices, total-Zn was significantly higher in ZTW+R (115.3 mg kg^{-1}) followed by CTW (108.5 mg kg^{-1}) and then in ZTW-R (104.5 mg kg^{-1}).

Chemical fractions associated with copper (Cu)

A persual of data revealed that WSEX-Cu content fluctuated from 0.27 to 0.29 mg kg^{-1} and SpAd-Cu fluctuated from 0.06 to 0.07 mg kg^{-1} in the surface soil samples. It was almost similar but slightly higher under ZTW+R as compared to the ZTW-R and CTW within tillage and rice straw management practices for WSEX-Cu as well as SpAd-Cu. Rice establishment methods irrespective of the tillage and rice straw management practices also indicated non-significant effect on WSEX-Cu and SpAd-Cu content in soil and it was nearly similar under DSR-RT, DSR-CT, DSR-ZT and in PTR. The MnOx-Cu content varied between 0.14 to 0.17 mg kg^{-1} in the surface soil samples. Among the tillage and rice straw management practices as well as rice establishment methods, no significant differences among the treatments were observed. A perusal of the data in Fig. 2 revealed that amorphous iron oxide bound copper fluctuated between 2.48 to 2.79 mg kg^{-1}. The AFeOx-Cu and CFeOx-Cu did not differ significantly among the treatments under rice establishment methods. CFeOx-Cu content fluctuated between 2.88 to 3.63 mg kg^{-1} in the surface soil samples (0-7.5 cm). It was revealed that CFeOx-Cu content was ranged as 3.56 mg kg^{-1}, 3.63 mg kg^{-1}, 3.59 mg kg^{-1} and 3.54 mg kg^{-1} in DSR-ZT, DSR-CT, DSR-RT and PTR, respectively. Tillage and rice straw management practices irrespective of the rice establishment methods indicated non-significant effect on CFeOx-Cu content in soil. The OM-Cu content ranged from 0.18 to 0.20 mg kg^{-1} in the surface soil samples (0-7.5 cm). OM-Cu content was ranged as 0.19 mg kg^{-1}, 0.20 mg kg^{-1}, 0.18 mg kg^{-1} and 0.21 mg kg^{-1} in DSR-ZT, DSR-CT, DSR-RT and PTR, respectively. RES-Cu content ranged from 14.1 to 15.2 mg kg^{-1} and was found that RES-Cu was higher under ZTW+R as compared to the ZTW-R and CTW within tillage and rice straw management practices. Rice establishment methods irrespective of the tillage and rice straw management practices also indicated non-significant difference within the treatments on RES-Cu content in soil. Total-Cu content was found to have non-significant effect between the treatments during both the years. It was revealed that total-Cu content was ranged as 20.1 mg kg^{-1}, 21.3 mg kg^{-1}, 21.0 mg kg^{-1} and 21.2 mg kg^{-1} in DSR-ZT, DSR-CT, DSR-RT and PTR, respectively.

Chemical fractions associated with iron (Fe)

The WSEX-Fe content in surface soil (0-7.5 cm) fluctuated from 1.26 to 1.67 mg kg^{-1} and SpAd-Fe varied from 1.43 to 1.59 mg kg^{-1}, WSEX-Fe as well as SpAd-Fe content was found significantly higher in PTR with respect to other treatments viz. DSR-RT, DSR-CT and DSR-ZT. Rice establishment systems irrespective of the tillage and rice straw management practices showed non-significant differences among the different treatments. In case of tillage and rice straw management practices, SpAD-Fe was found higher in ZTW+R as compared to the ZTW-R and CTW. The MnOx-Fe content indicated significant differences among the different treatments between tillage and rice straw management practices in 2017 in surface soil (0-7.5 cm).

The MnOx-Fe content was significantly higher in PTR (25.42 mg kg^{-1}) as compared to the DSR-RT (23.57 mg kg^{-1}), DSR-CT (23.36 mg kg^{-1}) and DSR-ZT (22.33) mg kg^{-1}). MnOx-Fe was found higher in ZTW+R treatment as compared to the ZTW-R as well as CTW during both the years. The AFeOx-Fe was likewise found higher in ZTW+R (129.8 mg kg^{-1}) treatment as compared to the ZTW-R (127.2 mg

kg^{-1}) as well as CTW (128.9 mg kg^{-1}). The data pertaining to CFeOx-Fe fraction indicated that CFeOx-Fe content varied from 234.8 to 237.8 mg kg^{-1} and it was higher under CTW instead of ZTW+R and ZTW-R within tillage and rice straw management practices. The OM-Fe content OM-Fe was likewise found significantly higher in ZTW+R (156.2 mg kg^{-1}) treatment as compared to the ZTW-R (148.2 mg kg^{-1}) but not significantly higher with respect to CTW (152.8 mg kg^{-1}). No significant differences were found among under tillage and rice straw management practices in wheat. Total-Fe content varied from 1.55 to 1.72 percent it was observed that total-Fe was higher under ZTW+R or ZT wheat sown with happy seeder treatment (1.71 percent) as compared to the ZTW-R (1.55 percent) and CTW (1.63 percent) within tillage and rice straw management practices. Rice establishment methods irrespective of the tillage and rice straw management practices indicated that the total-Fe in soil was found higher under PTR (1.72 percent) followed by DSR-RT (1.67 percent), DSR-CT (1.51 percent) and DSR-ZT (1.61 percent), respectively.

Chemical fractions associated with manganese (Mn)

An examination of the data in Fig. 4 revealed that WSEX-Mn content varied from 0.53 to 0.63 mg kg^{-1} and SpAd-Mn ranged from 0.53 to 0.73 mg kg^{-1} in the surface soil samples (0-7.5 cm) and it was observed that WSEX-Mn and SpAd-Mn was higher under ZTW+R as compared to the ZTW-R and CTW within tillage and rice straw management practices. Rice establishment methods irrespective of the tillage and rice straw management practices indicated significant effect on WSEX-Mn in soil. The MnOx-Mn content varied from 22.29 to 27.32 mg kg^{-1} and it was observed that MnOx-Mn was higher under ZTW+R or ZT wheat sown with happy seeder treatment as compared to the ZTW-R and CTW within tillage and rice straw management practices. Rice establishment methods irrespective of the tillage and rice straw management practices indicated significant effect on MnOx-Mn in soil.

The CFeOx-Mn content fluctuated from 37.99 to 46.18 mg kg^{-1} amongst the tillage and rice straw management practices as well as rice establishment methods and CFeOx-Mn was found significantly higher in ZTW+R (46.18 mg kg^{-1}) as compared to ZTW-R (40.46 mg kg^{-1}) as well as CTW (40.46 mg kg^{-1}). On the other hand, rice establishment systems irrespective of the tillage and rice straw management practices cause significant effect within the treatments. The OM-Mn content fluctuated between 2.71 to 3.59 mg kg^{-1} and it was found significantly higher in ZTW+R (3.42 mg kg^{-1}) as compared to ZTW-R (2.93 mg kg^{-1}) as well as CTW (2.99 mg kg^{-1}). Rice establishment systems irrespective of the tillage and rice straw management practices failed to cause significant effect on the OM-Mn content in 2017 but it cause significant effect within the treatments in 2015. Highest content for OM-Mn was observed in PTR treatment as compared to the DSR-RT, DSR-CT and DSR-ZT amongst all the treatments.RES-Mn was ranged from 64.9 to 76.8 mg kg^{-1} amongst the tillage and rice straw management practices as well as rice establishment methods in the surface soil samples. Data revealed that amongst the tillage and rice straw management practices, RES-Mn was found significantly higher in ZTW+R (71.3 mg kg^{-1}) as compared to

ZTW-R (70.8 mg kg^{-1}) as well as CTW (70.7 mg kg^{-1}). Rice establishment systems irrespective of the tillage and rice straw management practices failed to cause significant effect on the RES-Mn content in 2017. A close examination of data indicated that rice establishment methods significantly affected the total-Mn content and it varied from 157.3 to 178.3 mg kg^{-1}. Among the rice establishment methods, the content for total-Mn was found higher in PTR (157.3 mg kg^{-1}) as compared to direct seeded rice treatments viz. DSR-RT (172.2 mg kg^{-1}), DSR-CT (170.7 mg kg^{-1}) and DSR-ZT (168.9 mg kg^{-1}). However, among the tillage and rice straw management practices irrespective of the rice establishment methods, the total-Mn indicated higher content under ZTW+R (178.3 mg kg^{-1}) as compared to ZTW-R (161.7 mg kg^{-1}) and CTW (161.8 mg kg^{-1}).

Discussion

Chemical fractions associated with zinc (Zn)

In our study, WSEX-Zn content was higher under ZTW+R treatments which might be due to the decrease in pH and higher organic matter content in case of the plots where the residue was retained as compared to the CTW treatments. Our results are in agreement with Shuman and Hargrove (1985), who stated that using various tillage systems, there was significant increase in EXCH Zn for NT and minimum tillage practices compared to MB tillage. The higher content of WSEX-Fe under ZTW+R treatment than CTW can be attributed to higher soil organic carbon content in this treatment which might have provided the suitable sites (broken edges) for the adsorption of iron from the soil solution. WSEX-Mn form is considered to be held by weak electrostatic forces. Similar results were provided by Mandal and Mitra (1982), who reported that the application of organic matter brought an increase in the water soluble and exchangeable Mn in soils. Zinc forms strong complexes with soil organic matter (Sharad and Verma 2001 and Umesh et al. 2013).

The water soluble, exchangeable and organically complexed Zn forms are plant available (Viets 1962). Increase in the exchangeable fraction because of pH was also observed in other works (Sims and Patrick 1978 and Iyenger et al. 1981) and has been attributed to the conversion of Zn into bioavailable forms (Harter 1991). Sekhon *et al* (2006) observed increase in soluble and exchangeable zinc forms with integrated use of manure or crop residue along with fertilizers. Tiecher et al. (2013), also observed greater soluble and exchangeable Zn concentrations in the surface layer. Shuman et al. (2001) also found an increase in Zn in manganese fractions due to organic amendments. On contrary to WSEX-Zn, the Zn fraction combined with AFeOx was significantly more for disking and moldboard treatments as compared to other tillage systems i.e. no tillage. This observation was partially ascribed to high pH values of these two tillage treatments (Falatah 2009). Reduction of Zn bound to crystalline and amorphous iron oxide in residue retained plots might be due to solubilization of non-labile form into labile form. Soil organic matter has been reported to form strong complexes with iron (Iyenger et al. 1981, Sharma et al. 2004 and Dhiman 2007). Since the addition of crop residues increased the soil organic matter content, so most of Fe might have formed strong complexes with the soil organic matter and thus render little amount of oxides for zinc adsorption. So a decrease in Zn bound to crystalline and amorphous iron oxides was observed. Besides this, the zinc released during organic complexes formation with Fe might have converted to other Zn fractions. This explains the decrease in the content of amorphous and crystalline iron oxide bound zinc with application of residues (Sharma et al. 2004 and Dhiman 2007). Another reason for decline in Zn bound on iron oxide might be decline in soil pH. Stahl and James (1991) observed that with decrease in pH, Zn sorbed on the surface of Fe-oxides transformed from non-exchangeable form to more exchangeable form.

Chemical fractions associated with copper (Cu)

WSEX-Cu and SpAD-Cu are the fractions which directly contribute to plant availability (Iyenger et al. 1981). The lower Cu value in exchangeable and specifically adsorbed forms indicates the low affinity of soil exchange sites for Cu ions, as observed by Atanassova and Okazaki (1997). WSEX-Cu and SpAD-Cu increase with decrease in pH, which might be due to the precipitation of Cu as hydroxides and hydroxyl carbonates at higher soil pH. It may also be due to decreased specific adsorption of Cu by soil components (Saha and Mandal 2000). Fathi et al. (2014) also observed negative correlation of exchangeable and specifically adsorbed Cu with pH. Higher content of WSEX-Cu and SpAD-Cu fractions in residue retained plots as compared to the other treatments might be due to the fact that the content of these two fractions also depends upon organic carbon content and cation exchange capacity (CEC) of the soil, which increases with the application of organic manures (Sharma et al. 2014). Low amount of Cu bound to manganese oxide bound fraction denotes that more of the copper is bound in crystalline form. Sims (1986) also observed that only small portion of total copper is bound to manganese oxide bound fraction. Increase in MnOx-Cu might be due to transformation of Cu from iron oxide pools to manganese oxide bound pool. Agbenin and Felix-Henningsen (2004) also observed increase in MnOx-Cu with the application of crop residue and chemical fertilizers.

The content for AFeOx-Cu followed the reverse trend as compared to the other fractions, as it was found higher under ZTW-R and CTW instead of ZTW+R. Cu in the AFeOx fraction was significantly higher under DS (disking) and MB (moldboard) treatments as compared to NT (no tillage), HR (harrowing), and CH (chiseling) systems. LeRiche and Weir (1963) also observed higher amounts of Cu in the Fe oxide fraction. Some studies on Cu in soil revealed that for pH > 6.9, more Cu was in combined with AFeOx (McLaren and Grawford 1973). The DS and MB tillage treatments may have shifted Cu in the AFeOx fraction to the soil surface. Amorphous and crystalline iron oxide bound fractions as considered relative unavailable forms. Metals with the higher electro-negativity form strong covalent bond with oxygen atoms from soil colloids and have higher hysteresis for the adsorption (McBridge 1994). Sekhon et al. (2006) observed decrease in Cu content in the crystalline iron oxide fractions and increase water soluble plus exchangeable and comparatively more soluble (organic, manganese oxides and amorphous iron oxides) fractions in soils under long-term experiment at Kaul. Additions of organic matter caused the transformation of Cu from fixed form into the non-mobile fraction to mobile (Saha and Mandal 2000) due to an increase in the complexing capacity of organic matter.

Chemical fractions associated with iron (Fe)

The higher content of WSEX-Fe under ZTW+R treatment than CTW can be attributed to higher soil organic carbon content and cation exchange capacity of the soil in this treatment which might have provided the suitable sites (broken edges) for the adsorption of iron from the soil solution. WSEX and organic Fe were higher for the conservation tillages (NT, HR, and CH) than for the conventional tillage (DS and MB) treatments (Falatah 2009). Crystalline iron oxide bound Fe fraction is the second most dominant fraction of iron after residual Fe. The hydroxides or oxides might have provided the sites for adsorption of the cations on the broken edges therefore increasing the amount of AFeOx-Fe and CFeOx-Fe bound fraction of Fe. The differences in the contents of amorphous and crystalline iron oxide bound Fe under different treatments might be due to the effect of soil pH and soil organic matter. "Iron associated with either CFeOx fractions was significantly higher for the DS and MB tillage treatments. Soil organic matter plays a major role in influencing organically bound fraction micronutrients. Similar results have also been reported by Sharma et al. (2008) in different parts of country.

Chemical fractions associated with manganese (Mn)

The higher content of WSEX-Mn under ZTW+R treatment as compared to the other treatments were attributed to comparatively lower pH and higher organic matter content in the soil under these treatments which might have solubilized the bound forms of Mn in the solution. WSEX-Mn form is considered to be held by weak electrostatic forces. Similar results were provided by Mandal and Mitra (1982), who reported that the application of organic matter brought an increase in the water soluble and exchangeable Mn in soils. Organically bound fraction, AFeOx bound, and residual Mn were significantly influenced by the different tillage systems (Falatah 2009). High total-Cu content in residue treated plots might be due to build-up of organic matter under continuous manuring possibly results in higher total micronutrients content in soil Chaudhary and Narwal (2005). The increase in organic fraction in residue retained plots can probably be ascribed to the formation of organic complexes of Mn with organic acids produced during decomposition of the organic materials (Sekhon et al. 2007).

Conclusions

The inter conversion of micronutrient cations (Zn, Cu, Fe and Mn) from one fraction to the other was accelerated with the addition of the SOM through retention of crop residue over the soil surface. The organic compounds released during decomposition of SOM enhanced the availability of micronutrient cations (Zn, Cu, Fe and Mn) by preventing fixation, oxidation, precipitation and leaching. Water soluble and exchangeable (WSEX) as well as specifically adsorbed (SpAd) fraction contributes little as compared to the other fractions viz. Crystalline Fe-oxide (CFeOX) and Amorphous Fe-oxide (AFeOX) fractions. The decrease in occluded fractions viz. crystalline iron oxide (CFeOx) and amorphous iron oxide (AFeOx) bound fractions indicated the mobilization and concomitant increase of these micronutrient cations (Zn, Cu, Fe and Mn) in to manganese oxide fraction (MnOx), water soluble plus exchangeable (WSEX) fraction and specifically adsorbed (SpAd) fractions The residual (RES) fraction is the dominating fraction among all the fractions excluding total.

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Fig 1: Effect of rice establishment methods, tillage and rice straw management practices on different fractions (WSEX, SpAd, MnOx, AFeOx, CFeOx, OM, RES, Total) of Zn

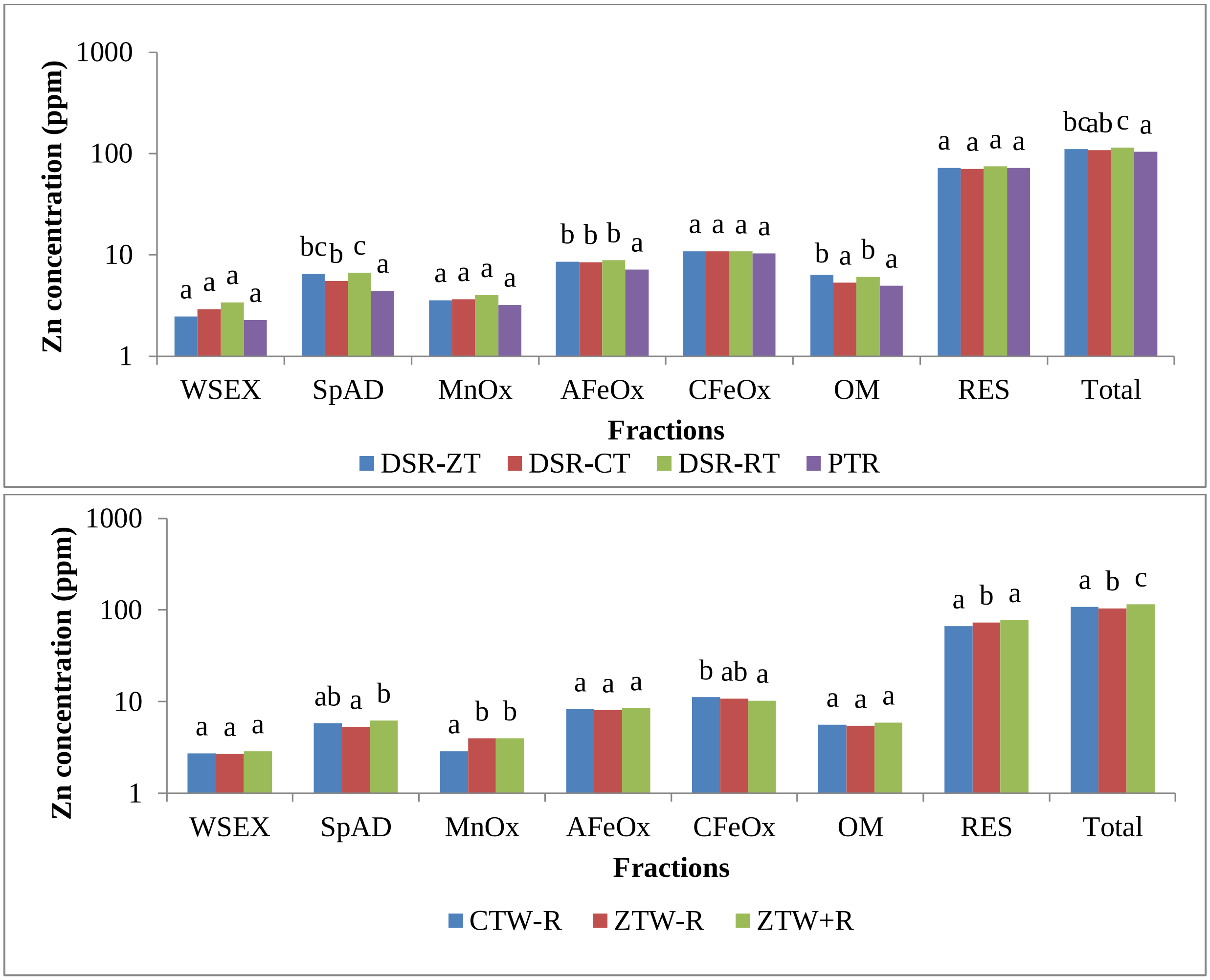


Fig.2: Effect of rice establishment methods, tillage and rice straw management practices on different fractions (WSEX, SpAd, MnOx, AFeOx, CFeOx, OM, RES, Total) of Cu

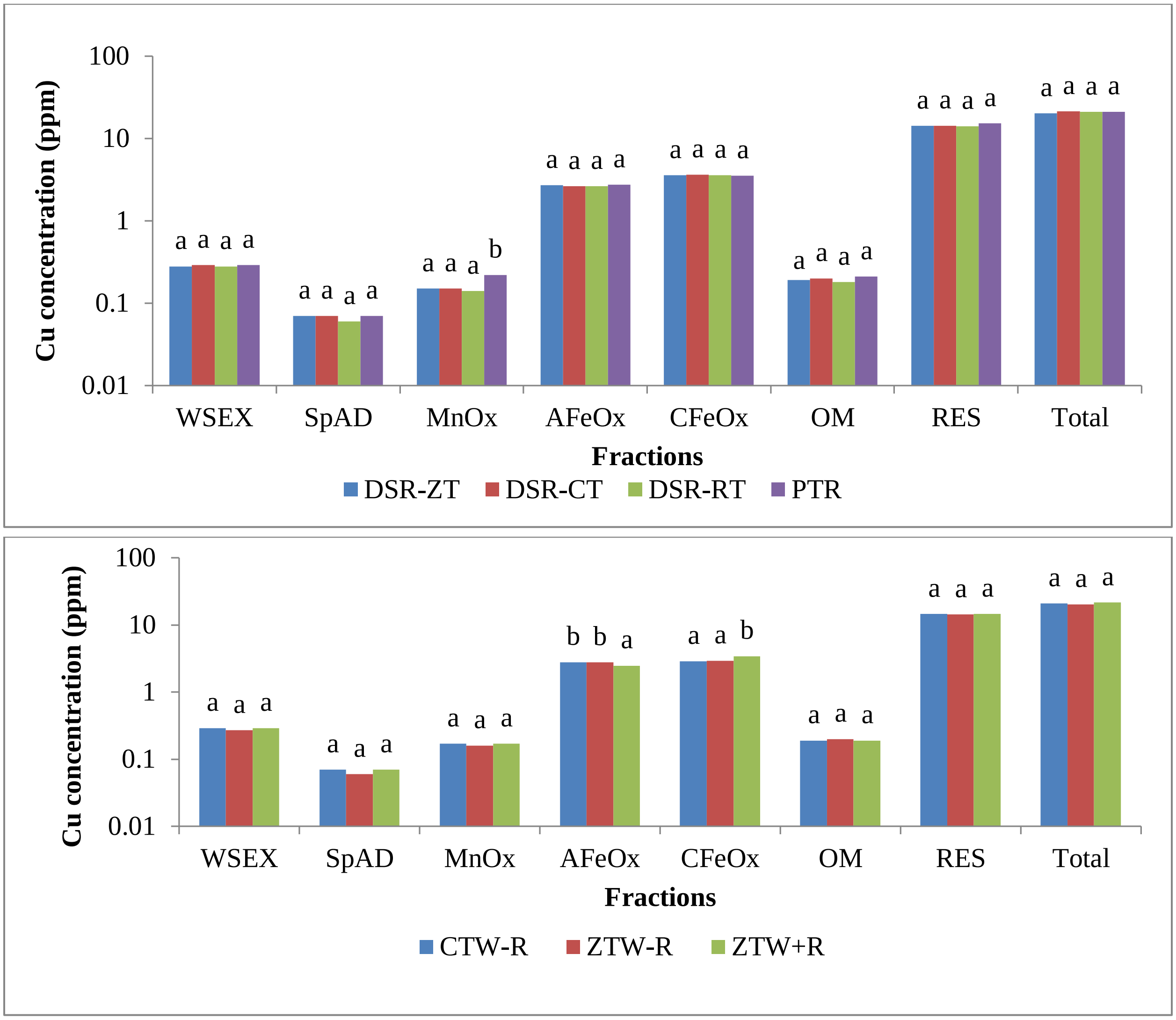
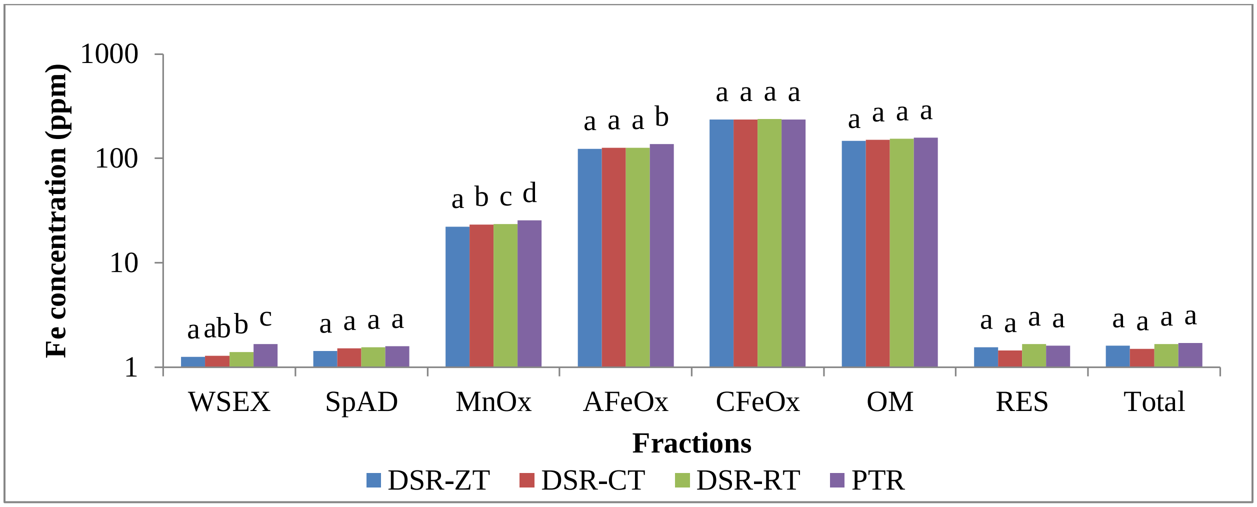


Fig. 3: Effect of rice establishment methods, tillage and rice straw management practices on different fractions (WSEX, SpAd, MnOx, AFeOx, CFeOx, OM, RES, Total) of Fe



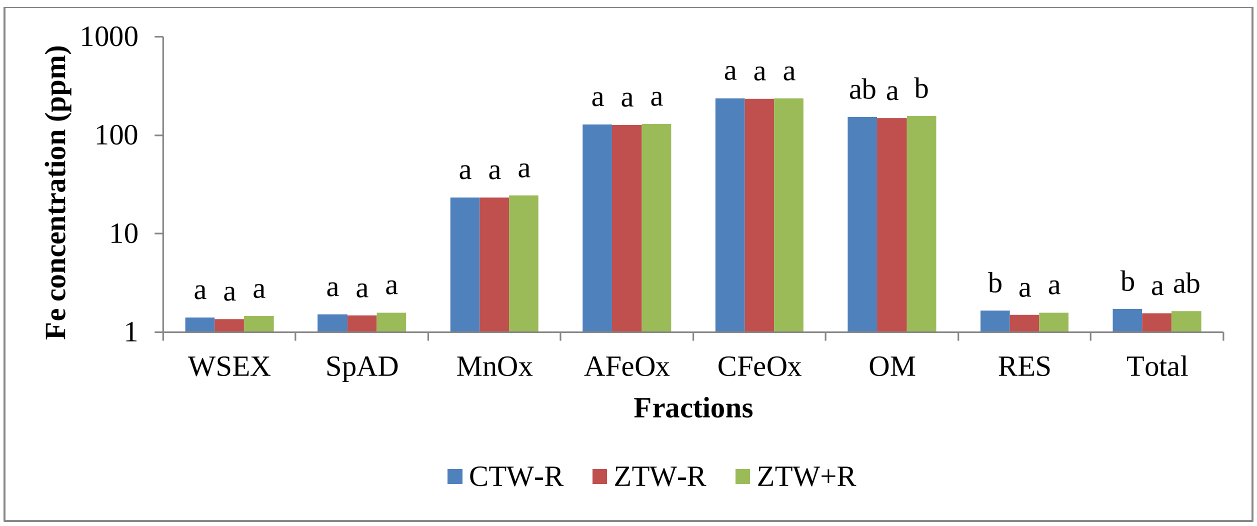
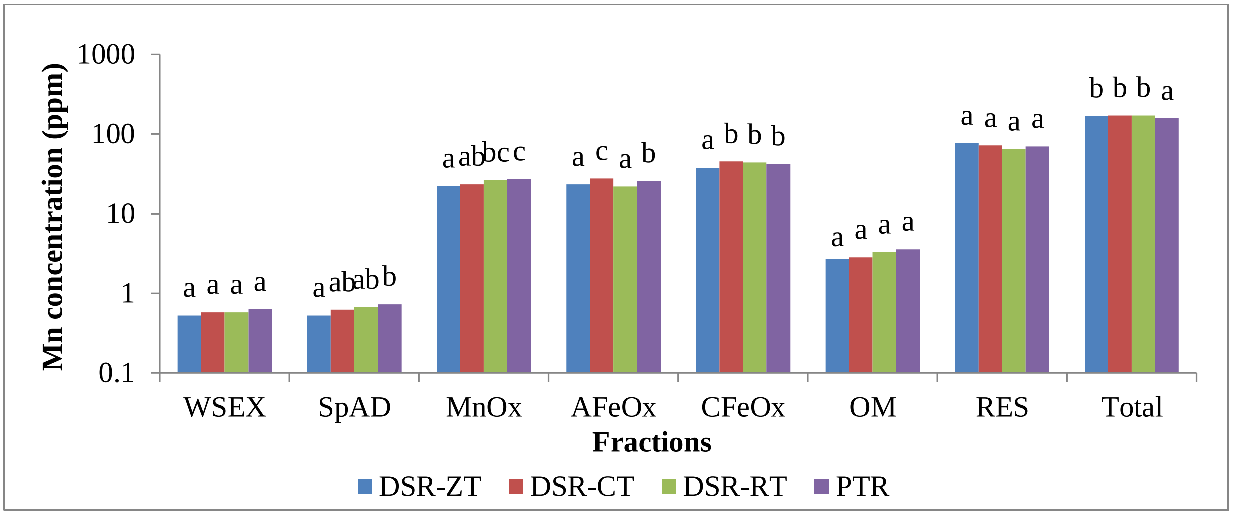
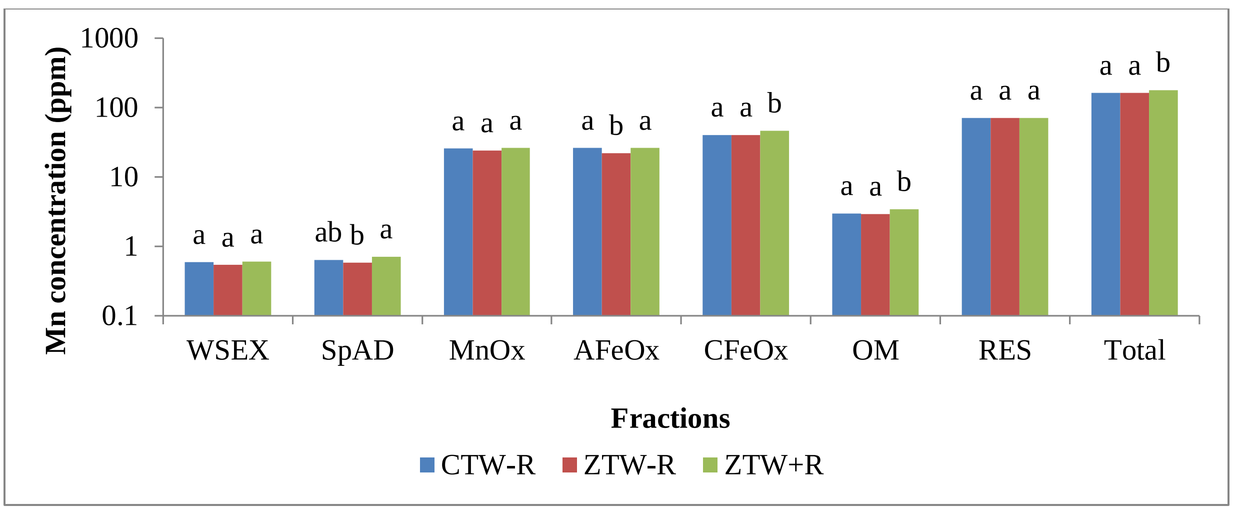


Fig. 4: Effect of rice establishment methods, tillage and rice straw management practices on different fractions (WSEX, SpAd, MnOx, AFeOx, CFeOx, OM, RES, Total) of Mn





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