SOIL BIOCHEMICAL CHANGES UNDER TILLAGE, GREEN MANURE AND STRAW MANAGEMENT PRACTICES AND THEIR EFFECT ON WHEAT

Thesis

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

MASTER OF SCIENCE
in
SOIL SCIENCE
(Minor Subject: Microbiology)

By

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(L-2015-A-146-M)

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CERTIFICATE – I

This is to certify that the thesis entitled, "**Soil biochemical changes under tillage, green manure and straw management practices and their effect on wheat**" submitted for the degree of **M.Sc.** in the subject of **Soil Science** (Minor subject: **Microbiology**) to the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Mr. Rituparna Saikia (L-2015-A-146-M)** under my supervision and that no part of this thesis has been submitted for any other degree.

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

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CERTIFICATE II

This is to certify that the thesis entitled **"Soil biochemical changes under tillage, green manure and straw management practices and their effect on wheat"** submitted by **Mr. Rituparna Saikia (L-2015-A-146-M)** to the Punjab Agricultural University, Ludhiana, in partial fulfillment of the requirements for the degree of **M.Sc.**, in the subject of **Soil Science** (Minor subject: **Microbiology**) has been approved by the Student's Advisory Committee along with External Examiner after an oral examination on the same.

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ABSTRACT

Intensive tillage, removal or burning of crop residues, limited organic manure use, declining irrigation water resources are the major causes of soil degradation and unsustainability of rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) system (RWS) in South Asia. Twelve treatment combinations of green manuring, tillage, and crop residue management included four main plot treatments of wheat straw and *Sesbania* green manure (GM) management in rice (1) $PTR_{W0,}$ puddled transplanted rice with no wheat straw retained (2) PTR_{W25}, puddled transplanted rice with 25% anchored wheat straw retained (3) PTR_{W0} + GM, and (4) PTR_{W25}+GM, and three sub-plots treatments (1) CTW_{R0}, conventional tillage wheat with rice residue removed (2) ZTW_{R0}, zero tillage wheat with rice residue removed and (3) ZTW_{R100}, ZTW with 100% rice residue retained as mulch in subsequent wheat. The current study evaluated the effects of wheat straw and green manure practices in rice and tillage and rice straw management on subsequent wheat on changes in soil enzyme (dehydrogenase, fluorescein diacetate, alkaline phosphatase, acid phosphatase, phytase, urease, L-asparaginase, β-glucosidase, xylanase, cellulase, polyphenol oxidase, peroxidase, total polysaccharide carbon, total carbohydrate carbon, total and easily extractable glomalin, microbial biomass carbon and soil respiration) activities and soil chemical properties (pH, electrical conductivity (EC), organic carbon (OC), available N, available P and available K) at different growth stages of wheat after five cycles of continuous RWS. The result showed that PTR_{W25}+GM and ZTW_{R100} increased wheat yield, chemical properties and soil enzyme activities except polyphenol oxidase and peroxidase. ZTW_{R100} increased wheat yield by 19.9 and 8.7 % as compared with ZTW_{R0} and CTW_{R0}, respectively. The majority of the enzyme activities were higher at vigorous vegetative growth stage as compared with the reproductive growth stage. Soil enzyme activities were significantly and positively correlated with each other, OC, available P, available N and grain yield of wheat and negatively correlated with polyphenol oxidase and peroxidase activity. Principal component analysis (PCA) identified dehydrogenase, acid phosphatase, β-glucosidase, microbial biomass carbon and soil respiration as the most sensitive indicators for assessing soil quality for conservation agriculture based RWS. The present study provided reliable biochemical indicators to monitor soil biological quality changes in response to conservation agriculture practices in RWS.

Keywords: Rice-wheat system, soil enzymes, wheat straw and green manure practices, tillage and rice straw management practices

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

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ਸਾਰ-ਅੰਸ਼

ਦੱਖਣੀ ਏਸ਼ੀਆ ਵਿੱਚ ਭੂਮੀ ਅਪਰਕਸ (ਅਧੋਗਤੀ) ਕਣਕ ਅਤੇ ਝੋਨੇ ਦੀ ਗ਼ੈਰ ਹੰਡਣਸਾਰਤਾ ਦੇ ਮੁੱਖ ਕਾਰਣ ਗਹਨ ਵਹਾਈ, ਪਰਾਲੀ ਦਾ ਜਲਣਾ, ਜੈਵਿਕ ਖਾਦਾਂ ਦਾ ਘੱਟ ਉਪਯੋਗ, ਸਿੰਚਾਈਯੋਗ ਪਾਣੀ ਦੇ ਸ੍ਰੋਤ ਦੀ ਕਮੀ, ਅਤੇ ਲੇਬਰ ਦੀ ਘਾਟ ਹਨ। ਹਰੀ ਖਾਦ, ਵਹਾਈ ਅਤੇ ਫ਼ਸਲੀ ਰਹਿੰਦ-ਖੂੰਦ ਪ੍ਰਬੰਧਨ ਦੇ ਸੁਮੇਲ ਨਾਲ 12 ਉਪਚਾਰਾਂ ਦੀ ਵਰਤੋਂ ਕੀਤੀ ਗਈ ਜਿੰਨਾ ਵਿੱਚ ਕਣਕ ਦੇ ਨਾੜ ਅਤੇ ਹਰੀ ਖਾਦ ਪ੍ਰਬੰਧਨ (1), PTR_{W0}, ਕੱਦੂ ਕੀਤਾ ਝੋਨਾ ਬਿਨਾ ਕਣਕ ਦੇ ਨਾੜ ਤੋਂ (2) PRT_{W25}, ਕੱਦੂ ਕੀਤਾ ਝੋਨਾ 25% ਕਣਕ ਦੇ ਨਾੜ ਨਾਲ (3) PTR_{WO} + GM ਅਤੇ PTR_{W25} + GM(4) ਨੂੰ ਮੁੱਖ ਪਲਾਟਾਂ ਵਿੱਚ ਜਦਕਿ ਸਭ ਪਲਾਟਾਂ ਵਿੱਚ (i) CTW_{R0}, ਰਵਾਇਟੀ ਵਹਾਈ ਕਣਕ ਅਤੇ ਝੋਨੇ ਦੀ ਹਟਾਈ ਹੋਈ ਪਰਾਲੀ (2) ZTW_{R0}, ਜੀਰੋ ਟਿਲੇਜ਼ ਕਣਕ ਝੋਨੇ ਦੀ ਹਟਾਈ ਹੋਈ ਪਰਾਲੀ ਅਤੇ (3) ZTW_{R100}, ZTW ਦੇ ਨਾਲ ਕਣਕ ਵਿੱਚ ਸਾਰੇ ਝੋਨੇ ਦੇ ਨਾੜ ਨੂੰ ਢੱਕਣੇ ਦੇ ਤੌਰ ਤੇ ਸਨ। ਮੌਜੂਦਾ ਅਧਿਐਨ ਵਿੱਚ ਕਣਕ ਦੇ ਨਾੜ ਅਤੇ ਝੋਨੇ ਵਿੱਚ ਹਰੀ ਖਾਦ ਅਤੇ ਝੋਨੇ ਦੀ ਪਰਾਲੀ ਪ੍ਰਬੰਧਨ ਅਤੇ ਵਹਾਈ ਦਾ ਆਉਂਦੀ ਕਣਕ ਦੀ ਫ਼ਸਲ ਉੱਪਰ ਪ੍ਰਭਾਵ, ਮਿੱਟੀ ਵਿੱਚ ਇੰਜਾਇਮ ਬਦਲਾਅ (ਡੀਹਾਇਡਰੋਜੀਨੇਜ, ਫਲੂਰੋਸੀਨ ਡਾਇਏਸੀਟੇਟ, ਅਲਕੇਲਾਇਨ ਫਾਸਫਾਟੇਜ, ਏਸਿਡ ਫੋਸਫਾਟੇਜ ਯੂਰੀਏਜ, ਐੱਲ-ਐਸਪਰਜੀਨੇਜ, ਬੀਟਾ-ਗਲੂਕੋਸੀਡੇਜ, ਸੈਲੂਲੇਜ, ਪੋਲੀਫਿਨੋਲ ਆਕਸੀਡੇਜ, ਪਰਆਕਸੀਡੇਜ ਕੁੱਲ ਪਾਲੀਸੇਕਰਾਇਡ ਕਾਰਬਨ, ਕੁਲ ਕਾਰਬੋਹਾਇਡਰੇਟ ਕਾਰਬਨ, ਕੁਲ ਅਤੇ ਜਲਦੀ ਨਿਕਲਣ ਵਾਲਾ ਗਲੋਮਾਲਿਨ ਅਤੇ ਮਿੱਟੀ ਸ਼ਵਸਨ) ਕਿਰਿਆ ਅਤੇ ਮਿੱਟੀ ਦੀਆਂ ਰਸਾਇਣਿਕ ਵਿਸ਼ੇਸ਼ਤਾਵਾਂ (pH, EC, OC, ਉਪਲੱਬਧ N, P, K) (ਕਣਕ ਦੇ ਵੱਖ-ਵੱਖ ਅਵਸਥਾ ਉੱਪਰ) ਕਣਕ-ਝੋਨੇ ਦੇ ਲਗਾਤਾਰ ਪੰਜ ਸਾਲ ਦੇ ਚੱਕਰ ਬਾਅਦ। ਨਤੀਜੇ ਦਰਸਾਉਂਦੇ ਹਨ ਕਿ ਬਿਨਾ ਕਣਕ ਦੇ ਨਾੜ ਰੱਖੇ PTR ਅਤੇ ਹਰੀ ਖਾਦ ਅਤੇ CTW_{R0} ਜਾਂ ਬਿਨਾ ਝੋਨੇ ਦੀ ਪਰਾਲੀ ਰੱਖੇ ZTW_{R0} ਦੇ ਮੁਕਾਬਲੇ ਪੋਲੀਫਿਨੋਲ ਆਰਸੀਡੇਜ ਅਤੇ ਪਰਆਕਸੀਡੇਜ ਨੂੰ ਛੱਡ ਕੇ ਸਾਰੇ ਭੂਮੀ ਇੰਜਾਇਮ ਦੀ ਕਿਰਿਆ PTR_{W25}+GM ਅਤੇ ZTW_{R100} ਨਾਲ ਵਧੀ। ਝੋਨੇ ਦੀ ਪਰਾਲੀ ਨੂੰ ਢੱਕਣੇ ਦੇ ਤੌਰ ਤੇ ਰੱਖਕੇ ZT (ZTW_{R100}) ਨਾਲ ZTW_{R0} ਅਤੇ CTW_{R0} (ਬਿਨਾ ਰਹਿੰਦ ਖੂੰਦ) ਦੇ ਮੁਕਾਬਲੇ, ਕਣਕ ਦਾ ਝਾੜ ਕ੍ਰਮਵਾਰ 19.9% ਅਤੇ 8.7% ਵਧਿਆ। ਜਿਆਦਾਤਰ ਇੰਜਾਇਮ ਦੀ ਕਿਰਿਆ ਵਨਸਪਤੀਕ ਅਵਸਥਾ ਉੱਪਰ ਨਿਸਰਨ ਦੇ ਮੁਕਾਬਲੇ ਜਿਆਦਾ ਸੀ। ਭੂਮੀ ਇੰਜਾਇਮ ਕਿਰਿਆ ਆਪਸ ਵਿੱਚ ਅਰਥਪੂਰਨ ਤੌਰ ਤੇ ਅਤੇ ਸਾਕਾਰਾਤਮਕ ਤੌਰ ਤੇ ਸਹਿਸਬੰਧ ਸੀ। OC ਉਪਲੱਬਧ P, N ਅਤੇ ਕਣਕ ਦਾ ਝਾੜ ਪੋਲੀਫਿਨੋਲ ਆਕਸੀਡੇਜ ਅਤੇ ਪਰਆਕਸੀਡੇਜ ਕਿਰਿਆ ਨਾਲ ਨਾਕਾਰਾਤਮਕ ਤੌਰ ਤੇ ਸਹਿ ਸਬੰਧਿਤ ਸੀ। ਪ੍ਰਿੰਸੀਪਲ ਕੰਪੋਨੇਂਟ ਵਿਸ਼ਲੇਸ਼ਣ (PCA) ਨੇ ਕਣਕ-ਝੋਨਾ ਫ਼ਸਲੀ ਚੱਕਰ ਆਧਾਰਿਤ ਹਿਫਾਜਤੀ ਖੇਤੀ ਲਈ ਮਿੱਟੀ ਦੀ ਗੁਣਵੱਤਾ ਦੇ ਸੂਚਕ ਦੇ ਤੌਰ ਸਭ ਤੋਂ ਸੰਵੇਦਨਸ਼ੀਲ ਸੂਚਕ ਦੇ ਤੌਰ ਤੇ ਡੀਹਾਇਡਰੋਜੀਨੇਸ, ਏਸਿਡ ਫਾਸਫਾਟੇਜ, ਬੀਟਾ-ਗਲੂਕੋਸੀਡੇਜ, ਜੈਵਿਕ ਮਾਦਾ ਕਾਰਬਨ ਅਤੇ ਮਿੱਟੀ ਸ਼ਵਸਨ ਨੂੰ ਪਹਿਚਾਣਿਆ। ਮੌਜੂਦਾ ਅਧਿਐਨ ਕਣਕ-ਝੋਨੇ ਫਸਲੀ ਚੱਕਰ (RWS) ਵਿੱਚ ਹਿਫਾਜਤੀ ਖੇਤੀ ਪ੍ਰਥਾ ਦੇ ਪ੍ਰਤੀ ਉੱਤਰ ਨੂੰ ਭੂਮੀ ਜੈਵਿਕ ਗੁਣਵੱਤਾ ਬਦਲਾਅ ਨੂੰ ਦੇਖਣ ਲਈ ਭਰੋਸੇਯੋਗ ਸੂਚਕ ਪ੍ਰਦਾਨ ਕਰਦੀ ਹੈ।

ਮੁੱਖ ਸ਼ਬਦ: ਝੋਨਾ-ਕਣਕ ਪ੍ਰਣਾਲੀ, ਭੂਮੀ ਇੰਜਾਇਮ, ਕਣਕ ਨਾੜ ਅਤੇ ਹਰੀ ਖਾਦ ਦੀ ਵਰਤੋਂ, ਵਹਾਈ ਅਤੇ ਝੋਨੇ ਦੀ ਪਰਾਲੀ ਦਾ ਪ੍ਰਬੰਧਨ।

ਮੁੱਖ ਸਲਾਹਕਾਰ ਦੇ ਹਸਤਾਖਰ **ਵਿਦਿਆਰਥੀ ਦੇ ਹਸਤਾਖਰ**

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CHAPTER I

INTRODUCTION

Rice-wheat system (RWS) is an important cropping sequence for food security, employment, income and livelihood for millions of people in Asia (Chauhan *et al* 2012, Singh *et al* 2014). This system occupies about 13.5 million hectares (M ha) in the Indo-Gangetic plains (IGP) of South Asia (Gupta and Seth 2007). Intensive tillage, imbalanced use of fertilizers, depletion of water resources and environment pollution have led to stagnation or declining trends in yields of the RWS in many parts of South Asia (Srinivasan *et al* 2012). This calls for immediate solution by adopting better management practices for improving soil and environment quality, and maintain social ecosystem. Sustainability of conventional RW production system in many parts of South Asia including north-west India has become a major concern owing to its ecological consequences, scarcity of farm labour, alarming fall of water table, straw burning, stagnating system productivity and diminishing economic returns (Ladha *et al* 2009, Humphreys *et al* 2010).

Both wheat and rice straws constitute greater than 80% of the entire amount of crop residues produced in northwest India. Wheat straw is collected by farmer with specially designed machine known as straw combine, for using it as animal fodder, leaving behind about 20-25% of straw in the ground after harvesting of wheat crop. Farmers generally burn the wheat straw left on the field before preparing seed bed for rice transplanting. In-situ burning of whole of the rice residue is the normal and easiest method of residue management because it interferes with tillage and seeding operations for the next wheat crop and has no alternate use (Yadvinder-Singh and Sidhu 2014). The burning of crop residue in open field has detrimental effect on air quality (particulates, smoke, greenhouse gases), which may leads to human respiratory ailments in intensive rice-wheat production regions in north-west India. Burning lead to complete waste of organic matter and nitrogen, 25 % loss of phosphorus, 20 % potassium loss and 50-60 % sulphur losses (Dobermann and Fairhurst 2002, Yadvinder-Singh *et al* 2014). Conservation agriculture (CA) practices (zero tillage, residue retention) are gaining momentum as an alternative to conventional practices for addressing the issues of energy, labour, water scarcity, environment quality and climate change (Gathala *et al* 2013, Jat *et al* 2016), and improved productivity of RWS in South Asia (Zhang *et al* 2014, Dikgwatlhe *et al* 2014). The ecological concern over deteriorating soil and environment quality and sub-optimal water management in RWS could be addressed by promoting the practice of leaving crop residues on the soil surface as mulch. This required development and promotion of a zero tillage (ZT) machine that could seed crops into heavy load of crop residues thus avoiding harmful effects of burning. The development of ‘Turbo Happy Seeder that enables ZT seeding of wheat in rice residue without burning became a significant step towards filling this gap (Sidhu *et al* 2007). Retention of crop residues on soil surface facilitates conservation of soil moisture, suppression of weeds, enrich soil organic matter and improve soil structure (Kumar *et al* 2013, Yadvinder-Singh *et al* 2014, Kaur *et al* 2014) resulting in higher wheat yield in numerous on-farm trials.

Leguminous green manure is a standard management tool in cropping systems, because it highly affects soil productivity and N dynamics in the soil–plant system and provides nitrogen to subsequent crops (Chauhan *et al* 2012, Singh *et al* 2014). The inclusion of legume crops as green manure or grain legumes in the RWS is considered to be highly advantageous than a simple rice-wheat sequence (Gathala *et al* 2013, Cupina 2014). Along with biological nitrogen fixation, legumes in rotation also increase availability of nutrient in soil, improve soil structure, prevent leaching losses, prevent incidence of disease and encourage colonization mycorrhiza in soil (Cupina 2014). The addition of green manure with low C/N ratio to lowland rice brings about many changes in chemical properties of soil and various nutrient transformations which can improve the sustainability of soil N fertility in lowland rice. Incorporating wheat straw with green manure may be a means for reducing fertilizer N needs and improving crop yields. Increases in rice yields were observed when whole wheat straw incorporation was combined with in-situ grown *Sesbania* green manure (Aulakh *et al* 2001, Yadvinder-Singh *et al* 2004) in RW system. The soil compaction due to puddling in rice adversely impacts soil structure and root growth of succeeding wheat crop resulting in inefficient use of both water and nutrients (Kirchhof and So 1996, Gathala *et al* 2011).

The effects of green manuring, tillage and crop residue recycling are site-specific so that adoption of these practices cannot be generalized in agro-ecological regions with large variability in soil and climatic conditions (Haque *et al* 2016). The most sustainable CA-based practices (e.g. ZT and residues retention) may lead to significant changes in biochemical properties of soils and alter the activities of soil microbial community and improves soil quality (Magnan and Lynch 1986, Finkenbein *et al* 2012).

Soil chemical, physical and biological properties as well as their interactions mainly depict the soil quality. Organic matter in soil (SOM) imparts an important part in all dimensions of soil quality (structure, water relations, chemical fertility and biodiversity) and hence regarded as a key indicator for soil quality (Carter 2002). However, change in SOM is a gradual process therefore specific fractions or biologically active components of SOM, such as microbial biomass and enzyme activities are considered as better option to assess short term changes in soil quality (Jin *et al* 2009). Therefore, microbiological properties, such as soil enzyme activities have been regarded as a valuable indicator to evaluate the result of various soil and crop management practices on soil quality under different cropping systems (Bandick and Dick 1999, Trasar-Cepeda *et al* 2000). The use of single enzyme activity as indicator of soil quality may not depict the overall activity of microbial community in soil, since they usually take part in only one specific process and therefore they cannot reflect the rate of all of the soil metabolic processes (Piotrowska-Długosz and Wilczewski 2014).

Studies have shown that tillage and straw management practices caused significant increases in the SOC content, microbial activity and C-cycling processes in different environments, mainly under non-rice based cropping systems (Eivazi *et al* 2003, Luo *et al* 2013, Wei *et al* 2015). Until now no systematic study has been conducted on the impact of CA practices in RWS of north-western region of IGP towards soil biochemical indicators at different growth stages of wheat. Hence, the present study aims to provide a holistic appraisal of different soil biochemical indices is critical for estimating the sustainability and ecological viability of the CA-based practices in RWS. Our scientific hypothesis was that a group of crucial and sensitive soil quality indicators would be able to assess appropriately the best critical growth stage of soil sampling during wheat growing season. Furthermore, the use of simple biochemical indicators which have importance to farmers and other land managers will likely be the most productive means of linking science with CA based practice in evaluating the sustainability of management practices (Romig *et al* 1996). Consequently, a long-term field experiment was established for understanding of the effects of tillage, green manure and rice straw management practices changes on biochemical indicators of soil after 5 years of rice-wheat system with the following objectives.

I. To study the periodic changes of biochemical activities in soil during growing season of wheat and their relationship with yield and nutrient uptake of wheat

II. To correlate soil biochemical activities with yield and nutrient uptake of wheat as influenced by tillage, green manure and straw management

CHAPTER II

REVIEW OF LITERATURE

Literature on soil biochemical changes, wheat yield and nutrient uptake as influenced by wheat straw and green manure practices in rice and tillage and rice straw management practices in subsequent wheat in a rice-wheat system have been reviewed under following headings:

2.1 Soil enzyme activities

2.2 Soil chemical properties

2.3 Yield and yield attributes of rice and subsequent wheat

2.4 Nutrient uptake by wheat

2.5 Correlation between soil enzyme activities, chemical properties, nutrient uptakes and yield

2.1 Soil enzyme activities

Soil management practices influences population of microorganisms and soil microbial processes through changes in the quantity and quality of plant residues in the soil profile (Kandeler *et al* 1999). The hydrolytic enzymes are involved in the dynamics of soil nutrient transformations and their activity in soil is considered to be a major contributor of overall soil microbial activity (Frankenberger and Dick 1983) and soil quality (Visser and Parkinson 1992). Modification of microbial dynamics on account of management practices may also be reflected in differences in enzyme activities in soils. Soil physical, chemical, biological and biochemical properties can be significantly altered by tillage and residue management practices, which in turn lead to alteration of the composition, distribution and activities of soil microbial community and enzymes (Doran 1980, Dick 1984, Magnan and Lynch 1986). Accumulation of organic matter and nutrients at the surface soil layer under reduced tillage produces beneficial effects on soil physical, chemical and biological properties (Beare *et al* 1997). These improvements are generally associated with enhanced rhizosphere biological activities (Kladivko 2001). No-tillage (NT) has been shown to increase microbial biomass (Helgason *et al* 2010), improve soil carbon (Lal *et al* 2003), increase mineralizable N (Spargo *et al* 2011), soil moisture (Ma *et al* 2008) and enzyme activities (Alvear *et al* 2005). Soil enzyme activities are accepted as early and are more reliable bio indicators than soil physico-chemical properties under different tillage systems. Dick *et al* (1988) and Nannipieri (1994) recommend the measurement of enzymatic activity as both an early and sensitive indicator of management-induced changes in soil quality.

Dehydrogenase activity (DHA) is reported to be a sensitive indicator of overall soil biological and microbial activity (Quilchano and Maranon 2002) because it is associated with oxidation-reduction processes in living cell (Alef and Nanniperi 1995). Quantity of DHA in soil provides an estimate of living organisms present in soil as well as total microbial activity of the soil (Makoi and Ndakidemi 2008). DHA represents the total range of oxidative activity of soil microflora and therefore acts as a good indicator of microbiological activity (Nannipieri *et al* 1990). DHA has been reported to be an efficient indicator of soil quality in rice–wheat–jute and other cropping systems (Chaudhury *et al* 2005). Majchrzak *et al* (2016) observed significant impact of tillage systems on DHA in a wheat crop. They investigated DHA under conventional and NT systems at different wheat growth stages (before sowing, tillering, earing and harvesting stage) and observed significantly higher activity under NT at all the growth stages of wheat. Among different growth stages, maximum DHA was recorded at earing stage of wheat. Parihar *et al* (2016) carried out a long term field experiment comprising different tillage permutations (permanent raised bed, zero tillage and conventional tillage) and different intensive maize-based cropping systems (Maize-wheat-Mungbean, Maize-Chickpea-*Sesbanea*, Maize-Musturd-Mungbean, Maize-Maize-*Sesbanea*). They observed that DHA was significantly higher under zero tillage and permanent bed than conventional tillage (CT). They further observed higher DHA under Maize-Chickpea-*Sesbanea* cropping system as compared with other systems. Mangalassery *et al* (2015) reported 60% higher DHA under NT than CT in temperate region in the East Midlands of UK. They also reported that β-glucosidase activity was higher in NT than CT. Gajda *et al* (2008) observed higher DHA under reduced tillage than conventional tillage in a wheat crop. Tajeda *et al* (2008) observed that the incorporated residues of *Trifolium pretense* L. significantly increased the activities of dehydrogenase, β-glucosidase, phosphatase, urease and arylsulfatase as compared with the control soil, followed by *Trifolium pretense* L. + *Brassica napus* L. and *Brassica napus* L. amended soils in a maize crop after 4 year. Nivelle *et al* (2016) conducted a 5 year study in northern France comprising different tillage permutations and presence of cover crop. They observed significant increase of dehydrogenase and urease activity under NT practices as compared with conventional tillage (CT) practices, irrespective of the presence of cover crops. Bhaduri *et al* (2017) observed that DHA after harvesting of wheat crop was 11% higher under previously non puddled soil as compared with puddled soil in a long term rice-wheat system in Indo-Gangatic plain in India. They further observed that application of green manure and rice residue along with chemical fertilizer showed 58% higher activity compared with application of mineral fertiliser alone.

Fluorescein diacetate activity (FDA) is reported to be an indirect appraisal of metabolic activity of microbial population in soils. The FDA represents the hydrolytic activity of soil microorganisms and quantify overall microbial activity (Adam and Duncan 2001, Dutta *et al* 2010). The hydrolysis of fluorescein diacetate has the latent ability to broadly depict soil enzyme activities (Schnurer and Rosswall 1982) and accumulated biological effects since FDA is hydrolyzed by a number of diverse groups of enzymes such as protease, lipase and esterases (Rotman and Paperaster 1966) which are associated with the microbial decomposition of organic matter in soil. Kumawat *et al* (2017) reported significant increase of FDA in 0-5 cm soil layer in a maize-wheat system with 50% and 75% residue retention of each crop. Kumar *et al* (2017) reported significant increase of FDA under reduced tillage practices (30.8 µg ha^{-1}), followed by no tillage (27.9 µg ha^{-1}) as compared with conventional tillage practices (22.9 µg ha^{-1}) in 0-15 cm soil layer. Neogi *et al* 2014 reported 15.4% increase in FDA under minimum tillage as compared with conventional tillage in a rice-maize-cowpea cropping system.

Acid and alkaline phosphatase are associated with release of inorganic phosphate from organic matter, and are known to perform important role in phosphorus cycle in soil ecosystems (Speir and Ross 1975). These extracellular enzymes act as an important link between biologically unavailable and mineral phosphorus as they catalyze the hydrolysis of organic phosphate esters to orthophosphate. Alteration of soil environment by tillage, water logging, compaction and fertilization significantly affect phosphatase activity in soil. Acid and alkaline phosphatases have different substrate specificity and pH optimum (Balota *et al* 2003, Canarutto *et al* 1995). These enzymes originate either from plant roots (and associated mycorrhiza or other fungi) or from bacteria (Tarafder and Marschner 1994). Alkaline phosphatases are mainly produced by bacteria, fungi and earthworm (Hebrien and Neal 1990). These enzymes are frequently referred as ecto–enzymes i.e. enzymes acting outside but still linked to cells of their origin. Acosta-martinez *et al* (2003) observed significant increase in alkaline phosphatase activity under conservation tillage as compared with conventional tillage practices in semi arid agricultural soil under cotton based cropping systems. Parihar *et al* (2016) reported 16.6% higher alkaline phosphatase activity under ZT than CT after 7 year under intensive maize based cropping systems. They further observed that alkaline phosphatase activity under maize-chickpea-*sesbanea* cropping system was significantly higher as compared with other maize based cropping systems. Gajda *et al* (2012) reported 18-30% higher alkaline phosphatase activity in a wheat crop under reduced tillage (RT) as compared with conventionally tilled wheat. Singh and Ghosal (2013) concluded that application of FYM and wheat straw along with inorganic fertilizer significantly increased the activity of alkaline phosphatase in 0-10 cm soil layer as compared with the application of inorganic fertilizer alone in a double no-till rice-wheat system. Mathew *et al* (2012) reported that acid and alkaline phosphatase activity was higher under NT than CT soil at 0-5 cm soil depth in a long-term tillage experiment in continuous corn system in a silt loam soil. They further observed significantly higher enzyme activity in 0-5 cm soil layer as compared with 5-

15 cm soil layer. The most comprehensive study on the effects of tillage and residue management reported by Deng and Tabatabai (1997) showed that the activities of phosphatises (alkaline and acid phosphatase and phosphodiesterase), amidohydrolases (urease, amidase, L-asparaginase and L-glutaminase), glycosidases (α and β-glucosidases and α and β-galactosidases and arylsulfatase were generally greater under ZT and double mulch plots than those in the other treatments studied (no-till/bare, no-till/normal, chisel/normal, chisel/mulch, moldboard/normal and moldboard/single mulch).

Phytase (myo-inositol hexakisphosphate phosphohydrolases) catalyses the hydrolysis of inositol phosphates and are potentially important in the soil for their role in phosphorus mineralization due to conversion of organic-P from phytate to plant available form (Ariza *et al* 2013). The stability and activity of phytases in soil is affected by sorption on soil particle surfaces which may reduce the potential for interaction with substrates. However this may also provide long-term advantages for their persistence and function in soil (Nannipieri *et al* 1996). Yadav and Tarafdar (2004) observed that NT practices substantially increases phytase activity in soil. They concluded that roots of the weeds decomposed and contributed to increase in organic matter and microbial build up thereby increased phytase activity in soil.

Urease is a microbial enzyme, which hydrolyses the C-N peptide bonds of linear amides of urea and urea type N substrates, producing carbon dioxide and ammonia (Tabatabai 1982). Urease is released from living and disintegrated microbial cells and acts as extracellular enzymes adsorbed on clay particles or encapsulated in humic complexes (Nannipieri *et al* 1994). Raisi and Kabiri (2016) reported higher urease activity in a barley crop under reduced tillage practices comprising of chisel and disk plough as compared with CT practices comprising of rotary and mouldboard plough in a 6 year study in semi-arid calcareous soil in central Iran. Evazi *et al* (2003) carried out a study to evaluate the effect of long term tillage on soil enzymatic activities (acid and alkaline phosphatases, alpha-glucosidase, arylsulfatase and urease) and revealed that enzyme activities were higher in continuous corn under no tillage than conventionally tilled soil. Zhang *et al* (2016) carried out a 3 year study to investigate the effect of incorporation of different proportion of wheat and maize straw on sucrase and urease activity in soil. They observed that activity of the enzymes increased with the amount of straw applied. They further observed that incorporation of maize straw was more effective to increase enzyme activities as compared with wheat straw incorporation because of narrow C:N ratio of maize straw than wheat straw which facilitates faster decomposition of maize straw.

Amidohydrolases are enzymes associated with the hydrolysis of organic N compounds in soils. These enzymes are extensively distributed in nature and have been found in plants, animals and microorganisms (Tabatabai 1994). One of the most important enzyme belong to this group is L-asparaginase, which catalyzes hydrolysis of L-asparagine to L-aspartic acid and ammonia. Hamido and Kpomplekou (2009) studied the effect of two tillage systems (no till and conventional till) and cover crops comprising black oat (*Avena strigosa* L.), crimson clover (*Trifolium incarnatum* L.), or mixture of crimson clover and black oat on urease, arylamidase, L-asparaginase and L-glutaminase activities. They observed that no tilled plot preceded by leguminous crimson clover (*Trifolium incarnatum* L.) exhibited higher activity of all the enzymes as compared with the plots preceded by black oat (*Avena strigosa* L.) or mixture of crimson clover and black oat. Ekenler and Tabatabai (2004) investigated the dynamics of arylamidase, L-asparaginase, L-glutaminase, amidase, urease and L-aspartase activity under three different tillage systems (no till, ridge till and chisel plough). They observed higher activity of all the enzymes under no till systems.

β-glucosidase catalyzes the hydrolysis of β-glucosides in soil (Hayano and Tubaki 1985) and such hydrolysis is of fundamental importance for microorganisms to obtain energy from soil (Evazi and Zakaria 1993). The enzyme β-glucosidase acts in the final stage of decomposition of cellulose by hydrolysing the cellubiose residue to simple sugars (Passos *et al* 2008), which are an important energy source for microbes (Waldrop *et al* 2000). β-glucosidase enzyme is sensitive to any change in the management practices in soil and directly related to the amount of organic matter and considered as a promising soil quality indicator for assessing the changes induced by tillage practices (Ekenler and Tabatabai 2003). De la Horra *et al* (2003) investigated the effect of NT, CT and native pasture as control plot on β-glucosidase and protease activity in soil and observed higher activity of both the enzyme under native pasture plot. Among the tillage permutations NT exhibited significantly higher activity of both the enzymes at the surface (0-5 cm) soil layer as compared with CT. Roldan *et al* (2003) concluded that NT with moderate amount of crop residue (33%) and legume cover has significantly improved soil enzyme activities (DHA, urease, protease, β-glucosidase and acid phosphatase).

Xylanase (endo-1,4-β-xylanase) enzymes are mainly responsible for decomposition of the polysaccharides of xylose. Xylanases are directly associated with decomposition of the hemicelluloses (Sinsabaugh *et al* 1994) into short chain glycosides (Wong *et al* 1988). Kandeler and Bohm (1996) observed higher xylanase activity at 0-10 cm soil layer under minimum tilled soil as compared with conventionally tilled soil in a fine sandy Haplic chernozem soil. Conversely, an opposite trend was observed at 20-30 cm soil layer; in this soil layer xylanase activity was significantly higher under conventional tillage as compared with minimum tilled soil.

Cellulases are a group of enzymes that catalyze the breakdown of cellulose, a polysaccharide formed of β-1, 4 linked glucose units. Hence, cellulases perform a crucial role at the initial phase of decomposition of organic matter in soil. Li *et al* (2016) investigated the effect of different combinations of mineral fertiliser and rice straw nitrogen on cellulase activity at different wheat growth stages. They observed that cellulase activity increases with application of rice straw as compared with application of mineral fertilizer and control (no fertilizer or straw). Cellulase activity was maximum under treatment with 30% rice straw N plus 70% fertilizer N. They further observed that cellulase activity in 0-20 cm soil layer gradually increased from pre-sowing to the seedling stage of wheat, reduced at tillering stage, and then increased to the maximum at jointing or maturity stage. Bini *et al* (2014) reported that cellulase activity under no tillage was lower as compared with conventional tillage. Meena (2008) reported that cellulase activity under conventional tillage system was 31.3-74.6% higher than ZT practices in lentil-finger millet cropping system in a sandy clay loam soil in Himalayan sub-temperate region. Deng and Tabatabai (1996) reported that cellulase activity was higher under no till/double mulch as compared with chisel and mouldboard plough without mulching. Balota *et al* (2003) recorded 68%, 90%, 219%, 46% and 61% increase of amylase, cellulase, arylsulfatase, acid phosphatase and alkaline phosphatase activity under NT as compared with CT in wheat based cropping systems in a subtropical ecosystem in Brazil.

Phenol oxidase enzyme removes phenolic hydrogen to form radicals or quinines, hence catalyzes polyphenol oxidation in the presence of oxygen (O_2). These products go through nucleophilic addition reactions in the presence or absence of free-NH_2 groups with the eventual production of humic acid-like polymers (Martin and Haider 1980, Stevenson 1994). The occurrence of phenol oxidase in soil environments is essential for the formation of humic substances. Peroxidases are enzymes associated with depolymerising lignin and use H_2O_2 as electron acceptor. Matocha *et al* (2004) observed that after 33 year of imposed tillage and N fertilization treatments, activity of phenol oxidase under NT soil was 1.7 times higher than soil tilled with mouldboard plough in a corn/rye system. They further observed that under NT, N fertilization significantly decreased phenol oxidase activity in spite of increase in soil organic carbon. Benitez *et al* (2006) reported lower phenol oxidase activity under NT as compared with conventional tillage in an olive orchard in Spain. Chu *et al* (2016) analysed the effect of long term tillage and crop rotation practices on soil enzyme activities and observed significantly higher activity of phenol oxidase, dehydrogenase and β-glucosaminidase in the no tilled plot as compared with conventionally tilled plot. But the activity of peroxidase enzyme was significantly higher under CT plot than NT plot. Zhao *et al* (2016) evaluated the effect of long term (30 years) maize straw incorporation at the rate of 0, 2.25 and 4.50 t ha^{-1} on phenol oxidase activity in a wheat-maize cropping system. They observed that incorporation of maize straw at the rate of 2.25 and 4.5 t ha^{-1} decreased the activity phenol oxidase as compared with control. Mangalassery *et al* (2015) observed that the activities of dehydrogenase, cellulase, xylanase, β-glucosidase, phenol oxidase and peroxidase were higher in ZT as compared with CT after 7 years in wheat and oilseed rape crop.

Polysaccharides are of plant and microbial origin, represents a significant part of the labile pool of soil organic C and are thought to act as a vital binding agent involved in stabilizing soil aggregates (Puget *et al* 1999, Jolivet *et al* 2006). Because of their labile nature, polysaccharides are more sensitive to land use change and management than the more stable and recalcitrant organic binding agents (Guggenberger *et al* 1995, Piccolo *et al* 1996) thus it is important to characterize the association of polysaccharides in soil aggregation. It is possible to calculate the amount of C in the total polysaccharide by considering the mass ratio of 0.4 for C: CH_2O. On an average total polysaccharide constitutes 13% of total organic carbon in soil. Dilute acid-extractable polysaccharides constitutes 86 to 94% of total polysaccharides, signifying that the easily hydrolysable polysaccharides represents a major part of polysaccharides in the soil. Chan *et al* (1994) reported significantly higher aggregate stability and polysaccharide content under direct drilling and stubble retention practices as compared with conventional tillage with burning of stubbles in wheat (*Triticum aestivum* L.) and lupin (*Lupinus angustifolius* L.) crop. Sandeep *et al* (2016) analysed the effect of soil management practices comprising of two tillage system (bed planting and conventional tillage) and six nutrient management practices comprising of incorporation of organic amendments, crop residue, green manure and mineral fertilizer in different proportions under maize-wheat system. They revealed that labile polysaccharide content in soil was significantly increased (17%) under bed planting system as compared with conventional tillage. They further observed that total polysaccharide content in soil was not significantly influenced by tillage practices but the effect of nutrient management was significant. Treatments which are amended organically with incorporation of crop residue showed higher content of total polysaccharide in soil.

Soil carbohydrates are labile fraction of SOM, accounting for approximately 5-25% of total SOM (Stevenson 1994, Schmitt and Glaser 2011). It plays crucial function in formation of soil aggregate and contributes to nutrition of soil microorganisms (Martín *et al* 2011). Soil carbohydrates constitute a considerable part of the labile SOC pool signifying a huge contribution of non-cellulosic and cellulosic polysaccharides in the soil. Several studies (i.e. Ball *et al* 1996, Beare *et al* 1997) demonstrated augmentation of microbial derived carbohydrates under NT as compared with CT. A greater quantity of microbial-derived as compared with plant-derived carbohydrates under NT compared with CT may be attributed to the relatively higher fungal biomass under NT (Frey *et al* 1999). Bottinelli *et al* (2017) analyzed the effect of no tillage, surface tillage and conventional tillage practices and observed 31% higher hot water extractable carbohydrate (HWEC) under NT than surface tillage and CT practices.

Glomalin is secreted by hyphae of AM fungi but not by other groups of soil fungi (Wright *et al* 1996). The improvement in aggregate stability by AM is attributed to the physical effect of a hyphal network around soil particles, together with the production of significant quantity of an insoluble glycoprotein referred as glomalin (Wright and Upadhyaya 1996), which cements soil particles (Wright and Upadhyaya 1998, Wright *et al* 1999, Rillig *et al* 2002). According to Rilling *et al* (2002), amounts of C in glomalin relative to total organic carbon may be higher than C in microbial biomass (4-5% against 0.08-0.2%). Glomalin may be usefull as a sensitive indicator of soil C changes due to land-use practices (Rillig *et al* 2003) and could even be involved in C-sequestration (Rillig *et al* 1999). Borie *et al* (2006) highlighted that glomalin content in soil was significantly affected by tillage practices in a 6 year study in a Chilean ultisol cropped with wheat. They reported that glomalin content in soil was significantly increased under no till and reduced till practices as compared with conventional tillage practices. Sandeep *et al* (2016) concluded that glomalin content in soil was significantly affected by tillage and nutrient management practices in maize-wheat system. Curaquo *et al* (2011) evaluated the effect of NT and CT on AM fungal propagules (spore density, total and active fungal hyphae), glomalin content in spring wheat (*Triticum turgidum* L.)–maize (*Zea mays* L.) cropping system in a mollisol from central Chile. They observed that the number of mycorrhizal propagules, glomalin content in soil and water stable aggregates were higher under NT as compared with CT. Jun *et al* (2007) observed significant increase in both easily extractable glomalin (EEG) and total glomalin (TG) content in soil under combined application of chemical fertilizer and straw as compared with sole application of chemical fertilizer or no fertilizer application. The EEG and TG content in soil under NPKS + rice straw incorporation treatment were 4.6% and 5.6% greater than the CK (unfertilized control) treatment and 9.8% and 6.2% greater than those of the NPK treatment, respectively. They further observed that chemical fertilizer application did not produce a statistically significant effect on glomalin content in soil as compared with no fertilizer application. Avio *et al* (2013) reported that both easily extractable and total glomalin concentration in soil was higher under no tilled soil than tilled soil cropped with *Medicago sativa* L. in a Mediterranean agro ecosystem. The higher concentrations of glomalin in no-tilled than tilled soil suggests either the occurrence of higher density of AMF in no tilled soil or a difference in AMF community composition leading to the production of larger amounts of glomalin (Lovelock *et al* 2004, Bedini *et al* 2009).

The microbial biomass is a sensitive indicator of soil biological quality and considered most reliable and frequently used among the specific biochemical parameter (Gillsotres *et al* 2005). Alvear *et al* (2005) suggested the use of microbial biomass and enzyme activity as indicators of soil quality due to their relationship with soil biology, ease of measurement, rapid response to changes in soil management and high sensitivity to temporary alterations in soil caused by management and environmental factors. Sun *et al* (2016) studied the influence of different tillage permutations (no till, ridge till and mouldboard plough) and sampling dates (April, June and September) on microbial biomass at 3 soil depths (0-5, 5-10 and 10-20 cm) under maize monoculture or maize-soybean cropping system. MBC averaged across all sampling dates was significantly higher under no tillage as compared with ridge till or mouldboard plough. Microbial biomass carbon (MBC) was higher in 0-5 cm soil layer than 5-10 cm and 10-20 cm soil layer. Heideri *et al* (2016) observed significant increase of MBC, DHA, acid phophatase and alkaline phosphatase activity under no tillage cropped with soybean as compared to conventional tillage. Pal and Marschner (2016) observed that incorporation of faba bean (*Vicia faba* L.) residue into soil significantly increased carbon use efficiency (cumulative respiration per unit of MBC) as compared with incorporation of wheat straw into soil. Similar trend was observed for MBC. MBC concentration in soil was higher under incorporation of residue mixtures of 50% wheat and faba bean as compared with incorporation of wheat straw residue alone. Guo *et al* (2016) carried out a 3 year study comprising of tillage practices including intensive tillage, no tillage and straw management practices including returning of crop residue and residue removal in a rice-wheat cropping system in central china. They observed 11.2% increase in MBC under NT as compared with CT. They further observed that MBC was significantly increased (29.8%) with incorporation of residue of the previous crop compared to its removal. Similar study pertaining to increase of microbial biomass C and N under NT than CT under rice-wheat and rice-oilseed cropping systems were reported by Gao *et al* (2004), Jiang *et al* (2011) and Li *et al* (2012).

Soil respiration provides an overall potential of microbial activity and is considered as a sensitive bio-indicator of soil quality (Puglisi *et al* 2006, Dutta *et al* 2010). Soil respiration may increase in response to increase in microbial biomass or as a result of the increased activity of a stable biomass after addition of organic matter (Harris and Steer 2003). Generally greater amount of CO_2-C is generated in the upper layer of NT compared with CT because of greater population and activity of soil microorganisms (Gajda and Prezewoka 2012, Stark *et al* 2007).

Pandey *et al* (2014) reported that MBC and microbial biomass nitrogen (MBN) and activities of β-D-glucosidase, cellobiohydrolase, urease and alkaline phosphatase increased with no tillage as compared with conventional tillage practices in a rice-wheat system. Ye *et al* (2014) showed that soil microbial biomass carbon, nitrogen, and the activity of soil urease, acid phosphatase, sucrase and catalase increased with the application of green manure.

Compared with the control, after application of green manure the content of soil microbial biomass carbon and nitrogen increased by 1.9–93% and 2.3–145%, respectively, and the activity of soil urease, acid phosphatase, sucrase, and catalase increased by 1.45–56.5%, 2.34–33.2%, 0.96–172.7%, and 3.3%–85.7%, respectively. Use of *Raphanus sativus* L. and *Pisum sativum* L. as green manures significantly increased soil enzyme activities during the growing period of following main crop wheat (Piotrowska and Wilczewski 2012). Yogesh and Hiremath (2014) reported that dehydrogenase and phosphatase activity in soil was significantly higher in cowpea and sunnhemp plots as compared to fallow.

Ming *et al* (2014) analysed the effect of residue management practices on enzymatic activities in soil in double-cropping rice crop in south China at different growth stages of rice. Residue of winter cover crops including ryegrass (*Lolium multiforum* L.), Chinese milk vetch (*Astragalus sinicus* L.) and rape (*Brassica napus* L.) was incorporated into soil. Soil enzyme activities were increased with residue incorporation and the activities of β-glucosidase reached peak value at tillering stage after incorporation of residue. Alkaline phosphatase activity gradually increased upto booting stage. Mankolo *et al* (2012) reported that no tillage, mulch tillage and winter cover cropping increased the activity of phosphatase, β-glucosidase and arylsulphatase activity in 0-10 cm soil layer. But reverse trend was observed in 10-20 cm soil layer. Kumar *et al* (2017) observed significantly higher SOC, DHA and FDA in 0-15 cm soil layer under no tillage and reduced tillage practices as compared with conventional tillage practices in a Vertisol in central India. Singh *et al* (2015) inferred increase in MBC, phosphatase, β-glucosidase, DHA, FDA and soil respiration under application of crop residue along with FYM and biofertilizer as compared with control in rice-wheat and rice-wheat-mungbean cropping system in the Indo-Gangetic plains. Carvalho *et al* (2015) investigated the effect of 4 different green manure plant (*Crotalaria*, *Cajanus, Mucuna and Canavalia*) on soil chemical and biological properties. They reported that P and K content in soil were greater in plot with *Crotalaria*. MBC concentration in soil was higher in plot with *Munaca* as compared with other green manure plant. Similarly, FDA was greater in plot with *Munaca* and *Canavalia* plant. Sanchez-Llerena *et al* (2016) observed higher total N content and activity of soil enzymes (DHA, β-glucosidase, phosphatase and arylsulfatase) under NT as compared with CT in a 3 year study on aerobic rice crop in semi arid Mediterranean conditions of south-west Spain.

In double rice cropping systems, Li *et al* (2005) observed that soil microbial activity was lower at tillering and maturity stages but higher at booting stage under ZT than under CT. On the other hand, Ou *et al* (2010) reported that soil respiration and cellulose decomposition rates during rice growth were lower at tillering, booting and grain-filling stages but higher at maturity stage under ZT as compared with CT. In rice-wheat/oilseed rape cropping systems, Gao *et al* (2004) observed that soil urease, catalase, invertase and dehydrogenase activities were higher under ZT than CT at rice tillering stage. Bera (2015) reported that zero tillage wheat with rice residues retention (ZTW+R) significantly increased soil enzymes activities, chemical properties and wheat yield as compared with zero tillage wheat without rice residues retention (ZTW-R) and conventional tillage wheat without rice residues retention (CTW-R). The majority of the enzymes activities were highest at maximum tillering growth stage of wheat. Tamilselvi *et al* (2015) reported that microbial biomass, counts of microbial communities and hydrolytic enzymes were highest in organically managed and integrated nutrient management imposed soils at active vegetative stage of maize crop under long term experimentation of maize-sunflower cropping system. Baoyi *et al* (2015) reported that soil enzyme activities like urease, phosphatase and saccharase generally followed the order; deep tillage (DT) +straw > CT+straw > DT no straw. This study suggested that straw recycling increased most of the soil enzyme activities. Jin *et al* (2009) also reported that sub soiling with mulch consistently had higher enzyme activities as compared with NT with mulch. Govaerts *et al* (2006) evaluated the effect of ZT with residue retention, ZT-partial elimination of residue and ZT-complete elimination of residue in wheat and concluded that wheat performed the best in ZT with residue retention. Variation in SMB-C, SMB-N, SMB-P, dehydrogenase and alkaline phosphomonoesterase activities confirmed the positive effect of ZT, especially at the soil surface (0–10 cm depth) as reported previously (Gonzalez-Chavez *et al* 2010). The significant correlations among the activities of the enzymes reported that tillage and residue management practices have similar effects on the activities of the enzymes involved in C, N, P, and S cycling in soils.

2.2 Soil chemical properties

Anyanzwa *et al* (2010) investigated the effect of conservation tillage practices and crop residue management on soil organic matter and total nitrogen content in a maize-legume system. They observed higher SOC and total nitrogen under conservation tillage practices with residue retention as compared with conventional tillage practices with residue removal. Nagar *et al* (2016) observed lower bulk density, pH and EC and higher SOC, available N, P, K and MBC under pegionpea+blackgram intercropping system as compared with sole pigeon pea system. Khushwah *et al* (2016) evaluated the long-term effect of 3 wheat residue management practices comprising of residue burning, incorporation and surface retention on soil organic carbon and available phosphorus in a soybean-wheat system in a vertisol in Bhopal. They observed that SOC content and available P in soil was significantly increased under incorporation or surface retention of wheat residue as compared with the regular practice of residue burning. Islam *et al* (2015) investigated the effect of different tillage and residue retention practices on soil chemical properties in a rice-maize system for 3 years.

They observed that after third year, soil organic carbon at 0-7.5 cm soil layer was significantly higher under strip tillage as compared with zero tillage and conventional tillage. Irrespective of tillage practices, residue incorporation significantly increased soil organic carbon in soil. They further observed that available N, P and K in soil were not significantly affected by tillage or residue management practices as well as their interaction at 0-7.5 and 7.5-15 cm soil layer. Balesdent *et al* (2000) reported higher mineralizable N at 0-10 cm soil layer under no tillage than conventional tillage. The higher mineralizable nitrogen content under no tillage as compared with conventional tillage is might be due to greater pool of labile nitrogen with a slow decomposition rate (Germon *et al* 1991). Neugschwandtner *et al* (2014) observed that pH and $CaCO_3$ were not influenced by tillage practices. But SOC, total N, available N, P and K increased with the reduction in tillage intensity. Lopez-Fando and Pardo (2009) observed that soil pH was lower under no tillage as compared with mouldboard plough after 5 years. This may be due to acidifying processes such as mineralization of organic matter, nitrification of applied N and root exudation. Tarkalson *et al* (2006) reported that Bray-P and CEC was increased under no tillage as compared with conventional tillage at 0-5 cm soil layer after 27 years under dryland spring wheat-sorghum (*Sorghum vulgare* L.) cropping sequence. But Ca, base saturation and pH reduced under no tillage. Sainju *et al* (2011) observed that soil pH, Ca and Na contents at 0-30 cm soil layer was higher under no tillage as compared with conventional tillage after 9 year in western Montana.

Martinez *et al* (2013) studied the effect of different tillage systems comprising of zero tillage with maize residue as mulch and conventional tillage with incorporation of maize residue into soil on pH and EC in a maize-wheat system. They observed that EC was increased in 0-15 cm soil layer under ZT as compared with CT. An opposite trend was observed in case of pH. Soil pH decreased under ZT practices which can be attributed to the release of H^+ ion during the decomposition of maize residue. Liu *et al* (2011) reported 29% increase in SOC content in soil under ZT as compared with CT in 0-5 cm soil layer. While in 10-20 cm and 20-30 cm soil layer no significant difference in SOC was observed between ZT and CT practices. Total N content in soil followed the similar pattern to that of SOC. They further reported that total phosphorus under ZT was 7.6% higher than CT, but the differences between ZT and CT treatment were not significant in 10-20 cm and 20-30 cm soil layer.

Zhang *et al* (2016) carried out a long-term study to evaluate the effect of no tillage with straw cover and traditional tillage with straw removal on SOC and total N content in soil in a rain-fed maize crop in northern China. They observed significant increase in SOC and total N in 0-5 cm soil layer under no tillage with straw retention as compared with traditional tillage with straw removal. Gangwar *et al* (2006) studied the effect of different tillage systems on SOC content after 3 year in a rice-wheat system and observed significantly higher SOC content under ZT practices than CT practices. They further observed that available P in soil was not significantly affected by tillage practices during the first 2 years of the study. But it was significantly increased under ZT in the third year. Margenot *et al* (2016) reported higher total phosphorus content in 0-15 cm soil layer after 9 years of reduced tillage as compared to conventional tillage practices in a Kenyan oxisol. Bhattarai *et al* (2015) analysed the effect of ZT and CT with two levels of residue treatment comprising of retention of rice residue at 25 cm height and residue removal except root biomass on soil chemical properties and nutrient uptake by wheat in a rice-wheat system. They observed that SOC, total N and available P content in soil was higher under ZT than CT. But soil pH and available K content was higher under CT as compared with ZT. They further observed that rice residue retention produced higher SOC, pH, total N, available P and K than removal of rice residue. Xie *et al* (2016) substituted fertilizer N with green manure (*Astragalus sinicus* L.) at different proportions (80%, 60%, 40% and 20% fertilizer N plus 20%, 40%, 60% and 80% N through green manure) in a rice-rice system. They observed that SOC and total N in 0-15 cm soil layer and rice yield was significantly increased by substitution of fertilizer nitrogen by green manure.

2.3 Yield and yield attributes of rice and subsequent wheat

In rice-wheat system, residues incorporation by disc plough or by mould-board plough is a better option for effective disposal of residues and may produce higher yield and net farm returns compared to their removal or in-situ burning. Yadvinder-Singh *et al* (2010) reported that rice straw incorporation has higher wheat grain yields and builds up soil fertility as compared with no-rice straw application. Qamar *et al* (2012) reported that ZT recorded higher grain yield of wheat under deep tillage as compared with 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 less number of effective tillers and low 1000-grain weight as compared with ZT. Gathala *et al* (2011) observed that direct-drilling of wheat in the presence of rice residue using the Happy Seeder produced significantly higher grain yield as compared to ZT without rice residue and CT. Higher wheat yield was also obtained under ZT over CT (Yadav *et al* 2005). Naresh (2013) conducted a field experiment over 3 year to study the potential of rice residues and its management options on soil properties and crop productivity. The result showed that before wheat planting, incorporation of residues of both crops in rice-wheat system (RWS) increased the available N, P and K contents in soil over removal and burning. Surface retention of residues increased N, P and K uptake by 14.6, 28.5 and 17.7%, respectively. Total system productivity increased by 10.9-15.8% in residue retention with permanent wide beds planting, Happy Seeder sown and NT planting system over CT. Rahman *et al* (2005) reported that rice straw mulching had a significant effect on conserving initial soil moisture and reducing weed growth. They further observed that rice straw mulching with 120 kg N ha^{-1} had significantly higher 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) reported that in a hot arid climate under irrigated conditions 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 mouldboard plough and deep tillage with chisel plough. They observed that maize crop under chisel plough exhibited higher leaf area index and crop growth rate, which finally resulted 23% and 8% higher grain and dry matter yield, respectively as compared with mouldboard tilled plots.

Incorporation of green manure in combination with wheat residue can be advantageous in mitigating the adverse effects of wheat residue on rice due to N immobilization and can increase yield (Yadvinder-singh *et al* 2004). Sharma *et al* (1995) reported that *Sesbania* green manuring and mungbean residue incorporation in rice increased grain yield of succeeding wheat by 0.3-0.7 t ha^{-1}. Sharma and Prasad (1999) reported that both *Sesbania aculeata* and *Sesbania rostrata* increased the succeeding wheat yield by 0.2-0.3 t ha^{-1}. Saha *et al* (2000) observed that dry matter production of wheat was significantly influenced by preceding green manure crops. Kumar and Sharma (2000) found that *Dhaincha* and blackgram had significant positive effects on the growth and yield attributes of wheat which ultimately resulted in significantly higher grain yield of wheat as compared to control (no green manure application). According to Voisin *et al* (2014), growing of leguminous crop (*Astragalus 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 minimum 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) concluded that inclusion of legumes in the wheat rice cropping sequence resulted in higher wheat equivalent yield than the W–F–R (wheat—fallow—rice) cropping sequence. Total system productivity increased by 64%, 50% and 4% in 2009–2010, and by 49%, 39% and 8% in 2010–2011 in wheat—mungbean—rice, wheat—black gram—rice and wheat–soyabean–rice, wheat—dhaincha—rice, respectively, than in wheat-fallow-rice, indicating that the recycling of legume residues could partially replace N for rice and had a considerably positive effect on the ensuing wheat crop. Lampurlanes *et al* (2016) reported higher yield of wheat, barley, canola and pea crop in a long term tillage experiment under no tillage followed by sub soiling up to 50 cm soil depth and lowest yield was observed under mouldboard plough. Singh *et al* (2016) observed that grain yield of transplanted puddle rice

(TPR) 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 under 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 days after harvesting rice as compared with zero tillage and conventional tillage practices. Mu *et al* (2016) investigated the effect of different tillage practices on crop yield in a wheat-maize system in north China. They observed that deep mouldboard ploughing to a 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 mouldboard ploughing to a depth of 15 cm.

2.4 Nutrient uptake by wheat

Ebrahimian *et al* (2016) investigated the influence of tillage and wheat residue management on N uptake, N uptake efficiency, N use efficiency and N harvest index in wheat in a 2 year study. They observed highest grain nitrogen percentage, nitrogen uptake efficiency and nitrogen use efficiency under chisel plough as compared with disk plough. They further reported that nitrogen uptake efficiency and nitrogen use efficiency was significantly increased in proportion to the amount of wheat residue application. Bhattarai *et al* (2015) observed that wheat crop under ZT showed higher uptake of N (53.9 kg ha^{-1}), P (23.4 kg ha^{-1}) and K (22.6 kg ha^{-1}) than CT. They further observed that rice residue retention at 25 cm height showed higher uptake of N (51.2 kg ha^{-1}) and K (22.1 kg ha^{-1}) but lower uptake of P (22.6 kg ha^{-1}) than removal of rice residue. Malhi and Lemke (2007) observed that N uptake by wheat grain were significantly higher under ZT than CT. They further reported N uptake by wheat straw and grain was significantly higher under rice straw retained as compared with straw removal.

A two year study carried out by Stanislawska-Glubiak and Korzeniowska (2012) to compare the contents of N, P and K at different growth stages (tillering, early flowering stage and harvesting stage) of wheat grown under different tillage systems (ZT and CT). They observed that N, P and K concentration in wheat plant was not significantly affected by tillage practices, except for P concentration at early flowering stages. At this stage concentration of P in wheat was significantly higher under ZT as compared with CT. Devkota *et al* (2013) studied the effect of crop establishment and rice straw management on mineral N dynamics in irrigated rice-wheat system. They observed that higher amount of wheat residue retention under ZT-DSR could have immobilized N or higher amount of N could have lost through N_2O denitrification and NH_3 volatilization. Pandiaraj *et al* (2015) analysed the influence of incorporation of pulses in crop sequences, crop residue management and addition of fertilizer

N on soil nitrogen content, SOC, nutrient uptake and wheat yields. They observed that incorporation of crop residue significantly increased grain and straw yield of wheat. They further reported that inclusion of legume (green gram) in the cropping system increased N uptake in grain by 1.32 times and in straw by 1.67 times as compared with the treatments with residue removal. Kachroo *et al* (2006) observed significantly higher total N, P and K under rice and wheat straw incorporation and left over stubble than under residue removal. Verma and Bhagat (1992) found that N uptake was significantly higher under rice straw mulching as compared with removal or burning of rice straw. They further observed that fertiliser N was more effective in ZT when rice straw was retained rather than its removal. Chakraborty *et al* (2010) observed that N uptake and N use efficiency were significantly higher under rice straw mulching. Acharya and Sharma (1994) reported that ZT with mulch significantly increased total uptake of N, P and K than conventional tillage without mulch in wheat.

2.5 Correlation between soil enzyme activity, chemical properties, nutrient uptake and yield

Espinoza *et al* (2014) observed significant correlation between available N vs. grain yield (R^2=0.84) and N uptake vs. grain yield (R^2=0.55) of wheat in an experiment conducted to compare legume-wheat rotation with oat-wheat systems in Mediterranean climate region of central Chile. Zhang *et al* (2016) observed high positive correlation of soil organic matter with total N and soil water content in a long term tillage experiment comprising of no tillage with straw cover and conventional tillage without straw cover in northern China. Nugis *et al* (2016) reported that DHA was positively correlated with gravimetric water content in soil and organic carbon. They further observed that DHA was negatively correlated with dry bulk density and soil density index. Curaqueo *et al* (2011) observed significant correlation between glomalin and total mycelium of AM fungi (r=0.58, $p<0.05$), glomalin and water soluble aggregate (r=0.66, $p<0.05$) and between glomalin and total carbon content in soil (r=0.60, $p<0.05$) in a wheat-maize cropping system under two contrasting tillage systems comprising of ZT and CT. Hazarika *et al* (2011) reported that hot water extractable carbohydrate (HWEC) showed significant positive correlation with MBC (R^2=0.65, $p<0.001$), acid phosphatase activity (R^2=0.76, $p<0.001$), β-glucosidase activity (R^2=0.93, $p<0.001$) in a wheat crop under contrasting tillage and residue management practices. They further observed that HWEC was negatively correlated with soil bulk density (R^2=0.44, $p<0.001$) and soil pH (R^2=0.44, $p<0.001$). Chu *et al* (2016) reported that DHA and β-glucosaminidase was positively correlated with SOC. But phenol oxidase and peroxidase showed no correlation with SOC. Similar significant correlation between DHA and SOC were reported by Chu *et al* (2007) and Gracia-Gil *et al* (2000). Ekenler and Tabatabai (2002), Miller *et al* (1998) reported that β-glucosaminidase activities were highly correlated with SOC and fungal biomass in soil.

Zhang *et al* (2016) observed significant negative correlation between alkaline phosphatase and soil pH in a tobacco field under maize and wheat straw application. They further reported significant positive correlation of surcease and urease with alkali-hydrolysable N. Catalase activity was negatively correlated with available K in soil, while mean weight diameter and geometric mean diameter was positively correlated with SOC, total N, total P and total K. Wang *et al* (2011) reported that total phosphorus in soil was positively correlated with acid phosphphatase, alkaline phosphatase and inorganic pyrophosphatase activity in a wheat-maize rotation system under tillage and residue management practices. But no significant correlation was observed between available P and phosphatase activity in soil.

Melero *et al* (2011) analysed correlation between different chemical and biological properties. Bivariate correlations indicated that total soil organic carbon showed high positive correlation with water soluble carbon, active carbon, microbial biomass carbon, microbial biomass nitrogen and enzymatic activities. Liu *et al* (2011) reported that MBC was positively correlated with urease, protease, acid phosphatase activity and available P in soil and urease activity was significantly and positively correlated with MBC, protease and acid phosphatase. They further observed positive correlation between available N and MBN.

Meena *et al* (2013) reported significant positive correlation between urease activity vis. organic carbon content and DHA vis. SOC at flowering and harvest stages of wheat. Nath *et al* (2011) revealed that DHA, FDA, and alkaline phosphatase actitivities were significantly correlated to each other. Qin *et al* (2010) found that urease and alkaline phosphatase were significantly correlated with available P content in soil. Green *et al* (2007) reported that enzymes involved in C, N, P and S cycling in soil was significantly inter correlated with tillage and crop rotation systems. They obtained high correlation between analysed enzymes and total soil organic carbon indicating that organic carbon provides a better environment for stabilizing and protecting extracellular enzymes through association with organic and inorganic colloids thus supporting a greater microbial biomass and activity (Balota *et al* 2011).

CHAPTER III

MATERIALS AND METHODS

The present investigation was carried out at the experimental area of Department of Soil Science, Punjab Agricultural University, Ludhiana, Punjab.

3.1 Description of the experimental site and climate

A field experiment on irrigated rice-wheat cropping system was established in 2011 starting with rice on a Typic Ustochrept sandy loam soil (135 g clay, 160 g silt and 705 g sand kg^{-1}) at the experimental farm of the Punjab Agricultural University, Ludhiana, Punjab (30°56′N and 75°52′E) in the Indo-Gangatic plains in the north-western India. Before imposing treatments in rice in 2011, the experiment was laid out before sowing of previous wheat crop (2010-11) which was raised by applying recommended dose of fertilizers to the whole field. The experimental field was under conventional rice-wheat cropping system for the last more than 10 years. The surface soil (0–15 cm) layer at the initiation of experiment was non-saline (electrical conductivity 0.34 dS m^{-1}) with pH 7.81 (1:2 soil: water) and contained 3.51 g kg^{-1} Walkley-Black carbon, 11.3 mg 0.5 *M* $NaHCO_3$-extractable P kg^{-1} (Olsen *et al* 1954) and 46.3 mg 1 N NH_4OAc-extractable K kg^{-1}. 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 received in June to September. Mean minimum and maximum temperatures (averaged across 30 years) in wheat (November to April) are 6.7 and 22.6^{0}C and in rice (June to October) are 18 and 35^{0}C, respectively. The weather conditions at the experimental location during rice growing seasons and wheat growing seasons were quite variable in all the 5 years of experimentation. During the wheat growing period the lowest mean monthly air temperature of 4.7 ^{o}C was attained in January and highest of 39.9 ^{o}C in May. This showed uncertainty of weather and hence the need to adopt climate resilient management practices for sustainable crop production. Mean weekly meteorological data recorded at the meteorological observatory of the Department of Agro meteorology during crop season have been presented in Fig. 3.1.

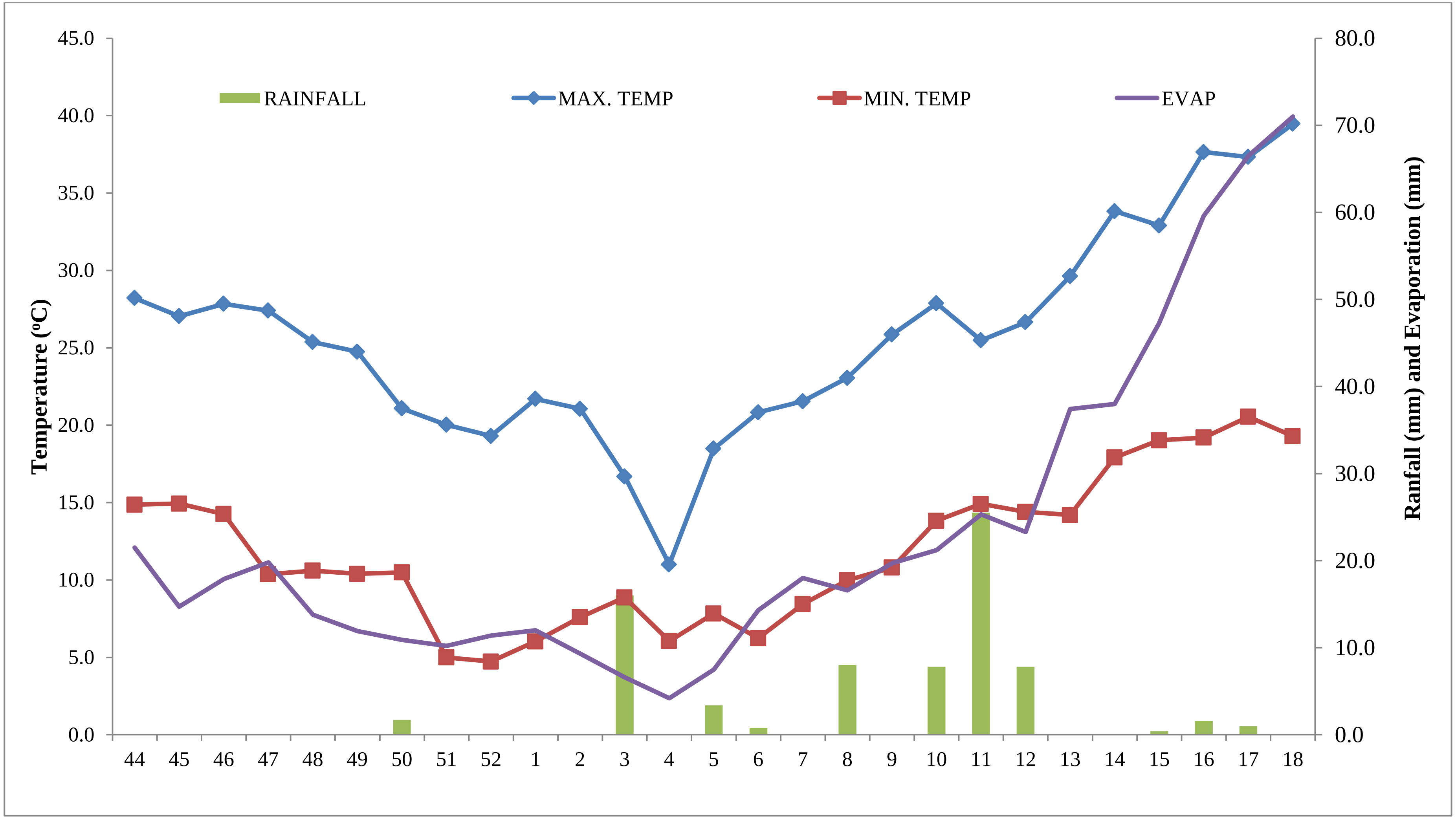


Fig. 3.1: The weekly maximum temperature (mean), rainfall (total) and evaporation (total) from crop season (November 2015 to April 2016).

3.2 Experimental layout and treatments

The experiment was laid out in a split plot design. There were three replications. Treatments comprised of four combinations of wheat straw and *Sesbania* green manure (GM) management ($PTR_{W0,}$ puddled transplanted rice with no wheat straw retained; PTR_{W25}, puddled transplanted rice with 25% anchored wheat straw (12-15 cm high stubbles) retained; PTR_{W0} + GM, and PTR_{W25}+GM) in main plots and three combinations of tillage and rice residue management in sub plots in subsequent wheat (CTW_{R0}, CT wheat with rice residue removed; ZTW_{R0}, ZT wheat with rice residue removed and ZTW_{R100}, ZTW with 100% rice residue retained as mulch). The treatments were assigned to the same experimental plots in all years of the 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 (PTR_{w0})
- Wheat straw retained (PTR_{w25})
- Wheat straw removed + green manure (PTR_{w0}+GM)
- Wheat straw retained + green manure (PTR_{w25}+GM)

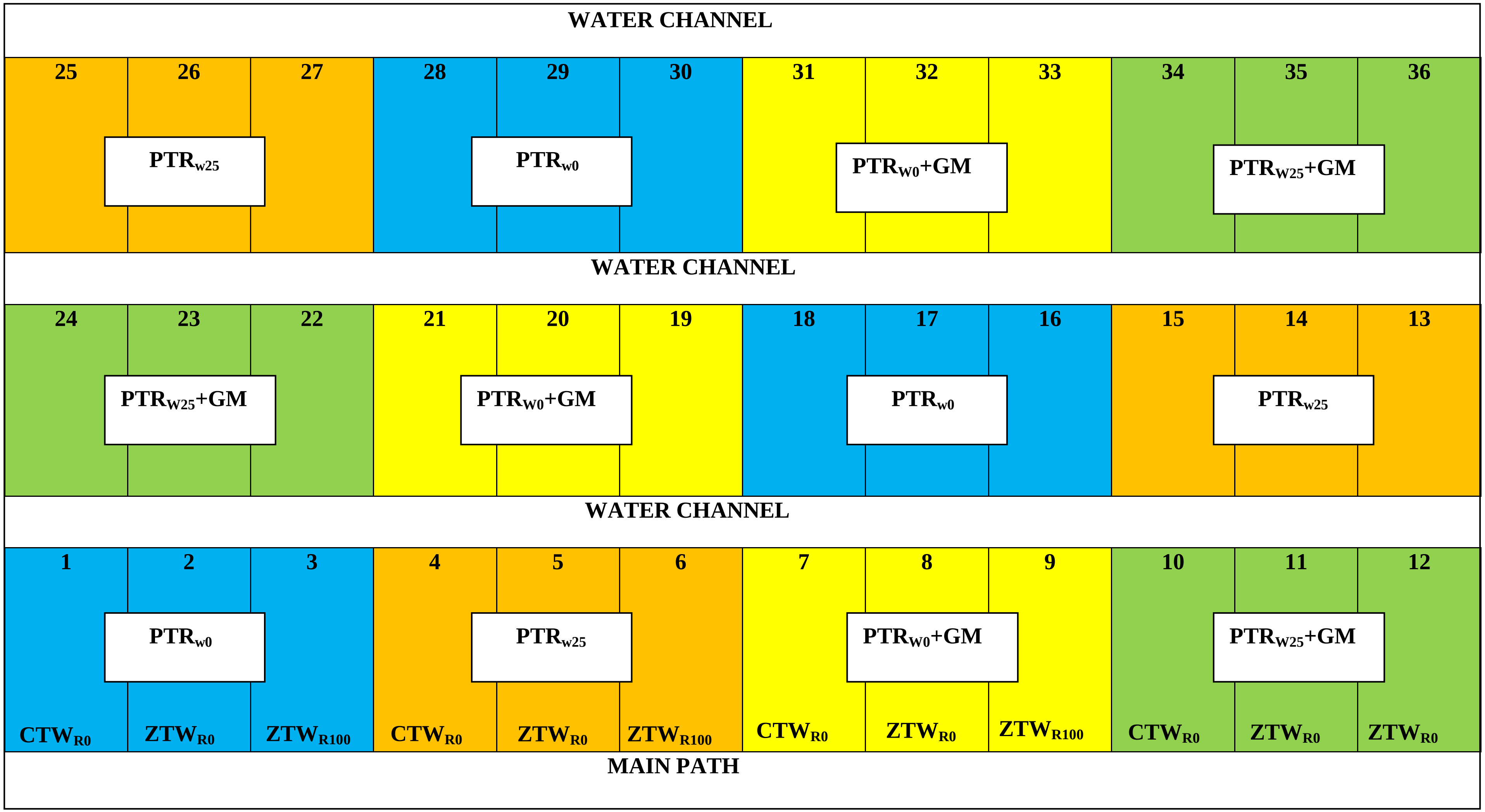
b) Sub plots- Tillage and rice straw management practices in wheat (3)

- 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	:	HD-2967
Date of sowing	:	20/11/2015
Date of harvesting	:	23/04/2016
Row spacing	:	20 cm
Harvested area	:	1.4 x 9 m= 12.6 m^2

The layout of the field experiment is shown in Fig-3.2

Fig. 3.2 Layout of the field Experiment



3.3 Soil and crop management

3.3.1 Green manure, tillage and crop establishment in rice

All the plots after wheat harvest were irrigated and GM (*Sesbania aculeata*) was sown with zero till using seed rate of 50 kg ha^{-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 during different seasons depending upon the climatic conditions. At the age of 6-7 weeks GM was incorporated into soil 1-2 days before rice transplanting by two diskings followed by two harrowing and planking. All the treatment plots were puddled (wet tillage) following different tillage operations. Wheat was harvested close to the ground manually with sickles and all harvested biomass removed from the W_0 plots. In W_{25} treatments, wheat was harvested at 12-15 cm above the ground level to simulate combine harvesting. Rice seedlings of 30 days old (variety PR 115) were manually transplanted at 15 cm x 20 cm spacing in the June 2^{nd} week each year.

3.3.2 Tillage and rice residue management in wheat

Rice 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 HD 2967 was sown on 20/11/ 2015 in rows 20 cm apart using a seed rate of 100 kg per ha 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.

3.3.3 Fertilizer management

Rice received a uniform dose of 13 kg P per ha as diammonimum phosphate, 25 kg K per ha as MOP (muriate of potash) and 10 kg Zn per ha as zinc sulphate (21% Zn). Rice received only 75 kg N per ha in GM treatments (PTR_{W0}+GM and PTR_{W25}+GM) and 150 kg N per ha in no-GM treatments. Urea was the source of N after compensating N applied through diammonium phosphate at time of sowing. At planting whole amounts of P, K and Zn were applied on all the plots. Fertilizer N was divided in three equal split doses an applied at transplanting and at 3 and 6 weeks after transplanting.

Wheat received a uniform dose of 150 kg N, 26 kg P as diammonium phosphate and 25 kg K as muriate of potash ha^{-1}. $1/3^{rd}$ of total N and entire amount of P and K fertilizers were drilled at wheat sowing. The remaining 2/3 of N was applied in two equal split doses immediately before first irrigation applied at 3 weeks (crown root initiation) and immediately before second irrigation applied at 8 weeks (maximum tillering) after sowing.

2.3.4 Irrigation water management

Rice plots were kept flooded (50 mm of standing water) for first 2 weeks, followed by irrigation (50 mm depth) 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 (crown root initiation, maximum tillering, panicle initiation and dough) 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. The crop was harvested on 23 April, 2016.

3.4 Yield contributing parameters and crop yields

(i) Effective tillers

The number of spike bearing tillers was counted from middle rows from two spots of one meter row length in each plot at harvest and was expressed as effective tiller per square meter.

(ii) Non-effective tillers

The number of non-spike bearing tiller was counted from middle rows from two spots of one meter row length in each plot at harvest and was expressed as non-effective tiller per square meter.

(iii) Plant height

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

(iv) Spike length

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

(v) Grains per spike

Ten spikes were taken from each plot. Seeds of each spikes were counted and their means taken as grains per spike.

(vi) 1000-grain weight

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

(vii) Grain yield

Bundle weights of harvest from a net plot area of 12.6 m^2 were taken after sun drying. Grain yield was recorded after hand threshing

(viii) Straw yield

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

3.5 Collection and preparation of soil and plant samples

Soil samples were collected from surface (0-7.5) and sub-surface (7.5-15) cm soil depths at different wheat growth stages viz. before sowing, crown root initiation (CRI), maximum tillering, flowering and harvesting after 5 years of rice-wheat system. The soil samples were collected by auger randomly from four places in each treatment plots. Soil 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. For determination of enzymatic activities, soil samples were collected from each plots and immediately sieved through 2 mm sieve and stored at 4^{o}C. The grain and straw samples were collected at harvesting of wheat crop and dried to a constant weight at 65°C for 48 h and ground to pass through a 0.5 mm sieve and stored in paper bags.

3.5 Methods used for soil and plant analysis

3.5.1 Determination of enzymatic activities of soil samples

(i) Determination of dehydrogenase activity

Dehydrogenase was assayed by the standard protocol given by Tabatabai (1982). 1 g of fresh processed (<2 mm) soil sample was taken in a test tube (15 ml capacity). 0.2 ml of 3% 2, 3, 5-Triphenyl tetrazolium chloride and 0.5 ml of 1% glucose were added to it. After mixing the tubes were incubated for 24 hours at 30^{o}C. After incubation, 10 ml of methanol was added to it and mixed properly. The tubes were placed in refrigerator for 3 hours. The production of Triphenyl fromazon (TPF) was determined by measuring absorbance at 485 nm. The amount of TPF released was calculated using calibration curve prepared using standard solutions of TPF. The activity of dehydrogenase was expressed as µg TPF released per gram dry soil per hour.

(ii) Determination of Fluorescein di-acetate activity

Fluorescein di-acetate activity was assayed by the method given by Adam and Duncan (2001). Two gram of fresh processed (<2 mm) soil sample was placed in 50 ml conical flask and 15 ml of 60 mM potassium phosphate buffer (pH 7.6) was added. 0.02 ml 1000 µg FDA ml^{-1} solution was added to soil as substrate. In blanks FDA substrate was not added. The flasks were incubated at 30^{o}C for 20 minute. Immediately after incubation 15 ml of solution containing chloroform: methanol at 2:1 ratio (v/v) was added to terminate the reaction. The content was vigorously shaken by hand and transferred to 50 ml centrifuge tube and centrifuged at 2000 rpm for approximately 3 min. The supernatant from each sample was filtered and absorbance was measured at 490 nm on a spectrophotometer. The fluoescein concentration released during the assay was determined using calibration curve derived from 0-5 µg fluorescein ml^{-1} standard solutions.

(iii) Determination of alkaline and acid phosphatase activity

Alkaline and acid phosphatase activities (EC 3.1.3.1 and 3.1.3.2) were estimated by the methods given by Tabatabai and Bremner (1969). 1 g of processed soil was taken in an Erlenmeyer flask, to which 0.2 ml of toluene, 4 ml of modified universal buffer (pH 11 for determination of alkaline phosphatase and pH 6.5 for acid phosphatase activity) and 1 ml of p-nitrophenyl phosphate solution were added. The flask was swirled for few second and incubated at 37^oC for 1 hour. After 1 hour, 1 ml of 0.5 M $CaCl_2$ and 4 ml of 0.5 M NaOH were added to the flask and mixed properly. The soil suspension was filtered through a whatman no. 1 filter paper. The yellow colour intensity of the filtrate was measured with colorimeter at 420 nm.

(iv) Determination of phytase activity

Phytase activity (EC 3.1.3.8) was assayed by the protocol given by Ames (1966). 1 g of soil was placed in a 15 ml screw cap tubes. Then 4 ml of sodium-acetate buffer solution (pH 4.5) and 1 ml of 1 µM sodium phytate solution were added. The tubes were shaken to mix the content properly and incubated at 37^oC for 1 hour. After 1 hour 0.5 ml of 10% trichloroacetic acid was added and the soil buffer suspension was filtered. Then phosphorous content in the filtrate was measured by ascorbic acid method given by Morphy and Riley (1977).

(v) Determination of urease activity

Urease activity (EC 3.5.1.5) was assayed by the method of Douglas and Bremner (1970). 2.5 g soil was placed in 150 ml volumetric flask to which 2.5 ml of 2000 ppm urea solution was added and incubated at 37^oC for 5 hours. After 5 hours 25 ml of 2 M KCl-PMA solution was added to the flask and shaken for 1 hour in an electrical shaker. The soil suspension is then filtered. 1 ml of this filtrate was taken in a 25 ml volumetric flask. Then 5 ml of extracting reagent and 15 ml of colouring reagent were added to the volumetric flask and placed it in a boiling water bath for 30 minutes. After cooling down to room temperature final volume is made to 25 ml and intensity of red colour developed was determined at 527 nm on spectrophotometer.

(vi) Determination of L-asparaginase activity

L-asparaginase activity (EC 3.5.1.1) was determined by the protocol given by Frankenberger and Tabatabai (1991). 5 g of processed soil was taken in a 50 ml flask, to which 0.2 ml toluene, 9 ml of THAM buffer and 1 ml of 0.5 M L-asparagine solution was added. The content in the flaks were mixed properly and incubated at 37^oC for 2 hour. After incubation, 50 ml of KCl-Ag_2SO_4 solution was added and mixed it properly. 20 ml of aliquot from the soil suspension was taken into a 100 ml distillation flask and 0.2 g of MgO was added to it. Then NH_4^+-N was determined by steam distillation method in a kjeldhal assembly.

(vii) Determination of β-glucosidase activity

β-glucosidase activity (EC 3.2.1.21) was estimated by the standard protocol given by Evazi and Tabatabai (1988). 1 g of soil sample was taken in a test tube to which 0.25 ml of toluene, 4 ml of modified universal buffer (pH 6) and 1 ml of p-nitrophenyl glucopyranoside solution were added. The soil solution in the tube was mixed properly and incubated at 37^oC for 1 hour. After 1 hour, 1 ml of 0.5 M $CaCl_2$ and 4 ml of THAM buffer (pH 12) were added. Then the tube was swirled for few minute and soil suspension was filtered and colour intensity of the filtrate was measured at 400 nm on spectrophotometer.

(viii) Determination of xylanase activity

Xylanase (E.C. 3.2.1.8) activity was assayed using 1 per cent xylan from brichwood as a substrate suspended in acetate buffer at 50 ^0C for 24 hours as described by Schinner and von Mersi (1990). The reducing sugars released were determined by dinitrosalicylic acid (DNS) method (Miller 1959).

(ix) Determination of cellulase activity

Cellulase (E.C. 3.2.1.4) activity was assayed as per method given by Pancholy and Rice (1973). The method involved the determination of reducing sugars produced when soil samples were incubated with carboxymethyl cellulose (CMC) as substrate at 30 ^0C for 24 hours for assaying cellulose activity.

(x) Determination of polyphenol oxidase and peroxidase activity

Polyphenol oxidase activity (EC 1.14.18.1 and 1.11.1.x) was assayed by incubating soil with L-dihydroxy-phenylalanine (DOPA) and oxidized reaction product was measured subsequently (Shi *et al* 2006). Briefly, 4 ml of 50 mM acetate buffer and 1 ml of substrate solution of 10 mM DOPA was added to 0.5 g soil and incubated at room temperature 0.5 h. Soil-substrate mixture were then filtered and the filtrates were assayed calorimetrically at 460 nm. Exactly similar procedure was followed to determine peroxidase activity, except the tubes received 10 ml 0.3% H_2O_2 along with 1ml of 1mM L-DOPA and 4 ml of 50 mM acetate buffer.

(xi) Determination of total polysaccharide carbon

Total polysaccharide carbon in soil was estimated by the method of Lowe (1993). 0.5 g soil was digested with 4 ml of 12 M H_2SO_4 and then autoclaved for 1 hour. After cooling, soil suspension in the flask was filtered and 1 ml of the filtrate was taken in a test tube and 1 ml of 5% phenol solution followed by 5 ml of concentrated H_2SO_4 solution was added to it. After 10 min it was placed in a water bath at 25-30^oC for 25 min. After cooling colour intensity of the solution was measured at 490 nm and calibrated against a standard curve prepared using glucose as standard.

(xii) Determination of total carbohydrate carbon

Total carbohydrate in the soil was assayed by phenol-method without acid hydrolysis (Safarik and Santruckova 1992). In brief, the filtrate was mixed with 5% phenol solution (1:1 ratio) and the absorbance determined at 485 nm and glucose was used as standard.

(xii) Determination of total and easily extractable glomalin

Total and easily extractable glomalin content was extracted from soil samples by following the standard protocol (Wright and Upadhyaya 1998). The protein content in the supernatant was determined by following standard protocol (Lowry 1951).

(xiii) Determination of microbial biomass carbon

Microbial biomass carbon was assayed by chloroform fumigation extraction method (Vance *et al* 1987). 10 g of soil sample was fumigated with ethanol free chloroform for 24 hour. Both fumigated and non-fumigated soils were extracted with 40 ml of 0.5 M K_2SO_4 by shaking it for 30 min on an end to end shaker. The MBC was calculated as

MBC= (C_{org} in fumigated soil - C_{org} in unfumigated soil)/K_{ec}

Where, K_{ec}=0.41 is the recovery factor used to convert the extracted organic C to MBC.

(xiv) Determination of basal soil respiration

Basal soil respiration was assayed by the method of Anderson (1982), which involves adsorption of CO_2 evolved during a given period of time in known volume and strength of alkali (NaOH). The excess of NaOH was treated against standard HCl. Then the exact amount of NaOH used for CO_2 was recorded and amount of CO_2 released was calculated.

3.5.2 Soil analysis

(i) pH and EC

20 g of air dried soil was stirred with 40 ml distilled water for half an hour and pH (1:2 soil: water suspension) was determined with pH meter. Soil suspension was kept for overnight and EC of the supernatant was measured with conductivity meter.

(ii) Organic carbon

Organic carbon was determined by following Walkley and Black (1934) chromic acid wet oxidation method.

(iii) Available nitrogen

Available N in soil was determined by the method of Subbiah and Asija (1956).

(iv) Available phosphorus

Available P in soil was measured by using extracting agent 0.5 M $NaHCO_3$ (Olsen *et al* 1954).

(v) Available potassium

Available K in soil was determined by neutral normal ammonium acetate method (Merwin and Peech 1950).

3.5.3 Plant analysis

(i) Determination of total nitrogen in wheat grain and straw

Total nitrogen in wheat grain and straw was measured by kjeldhal method.

(ii) Determination of total phosphorus and potassium in wheat grain and straw

The grain and straw samples were digested using di-acid (3 part HNO_3:1 part $HClO_4$) according to the procedure described by Piper (1966). The phosphorus in the digest was estimated calorimetrically by Vanado-Molybdo phosphoric acid method and potassium content was assayed by flame photometer. Total phosphorus and potassium uptake was calculated by multiplying the P and K content with grain and straw yield than summarized.

3.7 Statistical analysis

The data were analysed using analysis of variance for split plot design. All the dataset were analysed using analysis of variance (ANOVA) and differences among treatment means were separated by least significant difference at $p<0.05$ level of significance using IRRISTAT data analysis package (IRRI 2000). Pearson correlation coefficients and probabilities were calculated to assess correlation among variables using IBM SPSS statistics 23. Principal component analysis (PCA) (Wold *et al* 1987) was performed on the data set to reveal the similarities and differences between samples and to assess the relationships between the observed variables. The variables that explained less than 50% of the total variability of the data set were excluded to reduce the number of variables in the data set.

CHAPTER IV

RESULTS AND DISCUSSION

Results of the field experiment conducted to study the "Soil biochemical changes under different tillage, green manure and straw management practices and their effect on wheat yield under rice-wheat system" are described in this chapter under following headings:

4.1 Effect of wheat straw and green manure practices in rice and tillage and rice straw management practices in subsequent wheat on soil biochemical properties during 5th crop of wheat

4.1.1 Dehydrogenase activity

4.1.2 Fluorescein diacetate activity

4.1.3 Alkaline phosphatase activity

4.1.4 Acid phosphatase activity

4.1.5 Phytase activity

4.1.6 Urease activity

4.1.7 L-asparaginase activity

4.1.8 β-glucosidase activity

4.1.9 Xylanase activity

4.1.10 Cellulase activity

4.1.11 Polyphenol oxidase activity

4.1.12 Peroxidase activity

4.1.13 Total polysaccharide carbon

4.1.14 Total carbohydrate carbon

4.1.15 Total and easily extractable glomalin related soil protein

4.1.16 Microbial biomass carbon

4.1.17 Soil respiration

4.2 Effect of wheat straw and green manure practices in rice and tillage and rice straw management practices in subsequent wheat on soil chemical properties during 5th crop of wheat

4.2.1 Soil pH and EC

4.2.2 Oxidizable soil organic carbon

4.2.3 Available nitrogen content

4.2.4 Available phosphorus content

4.2.5 Available potassium content

4.3 Effect of wheat straw and green manure practices in rice and tillage and rice straw management practices in subsequent wheat on wheat yield and nutrient uptake during 5th crop of wheat

4.3.1 Yield and yield attributes of wheat

4.3.2 Total N, P and K concentration and uptake in grain and straw of wheat

4.4 Correlation among soil enzyme activities, chemical properties, nutrient uptake and wheat yield

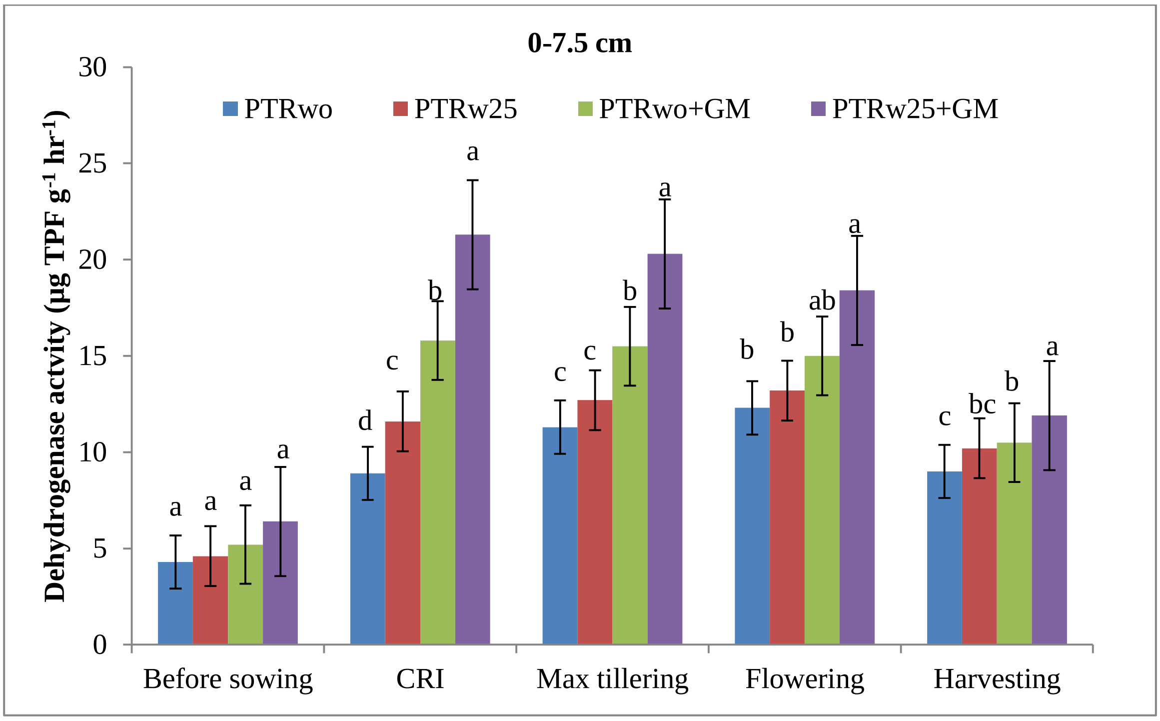
4.1.1 Dehydrogenase activity

Dehydrogenase activity (DHA) in surface (0-7.5 cm) soil layer as well as in subsurface (7.5-15 cm) soil layer determined after 5 year of rice-wheat cropping system was significantly affected by wheat straw and green manure practices in rice at all the growth stages of wheat except before sowing in the surface soil layer (Fig 4.1 and 4.2). Tillage and rice straw management practices in wheat significantly affected DHA at all the growth stages in both the soil layers, producing the highest DHA under ZTW_{R100} followed by ZTW_{R0} and $CTW_{R0.}$ The interaction between wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was significant at crown root initiation (CRI), maximum tillering (MT) and harvesting stage in the surface soil layer and only at harvesting stage in the sub-surface soil layer. In the surface soil layer, maximum DHA was observed at CRI stage in PTR_{w25}+GM/ZTW_{R100} followed by PTR_{w25}+GM/ZTW_{R0}, which was significantly reduced under PTR_{w25}+GM/CTW_{R0}. However, tillage and rice straw management practices under PTR_{w0}+GM failed to differ significantly among themselves. Under PTR_{w0} and $PTR_{w25,}$ DHA was significantly higher in ZTW_{R100} as compared with ZTW_{R0} and CTW_{R0}. Similarly, at maximum tillering stage, PTR_{w25}+GM/ZTW_{R100} exhibits significantly higher DHA than the other treatments. In the subsurface soil layer at harvesting stage, maximum DHA was observed under PTR_{w25}+GM/ZTW_{R100} whereas, CTW_{R0} exhibited significantly lower DHA under all wheat straw and green manure practices in rice. In the surface soil layer, at CRI stage, maximum DHA was observed in PTR_{w25}+GM/ZTW_{R100}, which was 3.2 fold higher than PTR_{w0}/$CTW_{R0.}$ Similarly, DHA under PTR_{w25}+GM/ZTW_{R100} was 3.25 and 1.9 times higher than PTR_{w0}/CTW_{R0} at maximum tillering and harvesting stage, respectively. At harvesting stage, DHA under PTR_{w25}+GM/ZTW_{R100} was 2.3 fold higher than PTR_{w0}/CTW_{R0} in sub-surface soil layer. The results of this study support the previous finding of Roldan *et al* (2003) suggesting that no tillage with moderate amount of residue retention (33%) along with planting leguminous crops significantly increased DHA in soil cropped with maize. Jat *et al* (2015) observed that incorporation of green manure Dhaincha (*Sesbania rostrata* L.) for 3 consecutive year increased DHA from 81 µg TPF/g soil to 120 µg TPF/g soil in a maize-wheat cropping system. Bhaduri *et al* (2017) observed 58% increase of DHA activity with application of green manure in a rice-wheat cropping system. In the line of our results, Chandra (2011) reported significant increase of DHA with the incorporation of rice straw as substrate and source of energy for microorganisms. Similarly, Heidari *et al* (2016) observed increase in DHA under no tillage with addition of organic manure in a soybean crop as compared with conventional tillage along with mineral fertiliser application. In the present investigation, maximum value of DHA was observed at maximum tillering stage followed by flowering stage and least was observed before sowing of wheat in both the soil layers. DHA was highest at maximum tillering stage, which is in agreement with earlier finding by Mandal *et al* (2007) and Meena *et al* (2013) for wheat crop, which may be due to higher root biomass at this stage. Jin *et al* (2009) reported higher enzyme activity at the stages with vigorous vegetative growth (such as jointing stage and before winter) than in stages with productive growth (such as filling and maturity stages), which indicates that the development of plant growth and climatic conditions (soil temperature and moisture) during the particular growth stage may have large impact on soil enzymatic activity. In our study, soil moisture remained at optimum level during whole season of irrigated wheat and soil temperature remained nearly favourable, except towards maturity. Zero tillage and crop residue as surface mulch have demonstrated to improve SOC status of soils, which correspond with higher enzymes activities (Melero *et al* 2009). The increased availability of substrate and favourable habitat for microbial biomass and activity seem to be responsible for higher enzyme activity under ZTW_{R100} (Balota *et al* 2004). The increase in DHA in ZTW_{R100} as compared with CTW_{R0} may be ascribed to the higher microbial activity as a result of an increase in supply of substrate and oxygen availability (Mangalassery *et al* 2015).

4.1.2 Fluorescein diacetate activity

Wheat straw and green manure practices in rice, irrespective of tillage and rice straw management practices in wheat, significantly affected fluorescein diacetate activity (FDA) in subsequent wheat at maximum tillering, flowering and harvesting stage in the surface soil layer (Fig 4.3) and at all the growth stages in the sub-surface soil layer (Fig 4.4). However, tillage and rice straw management practices in wheat, irrespective of wheat straw and green manure practices in rice, significantly affected FDA only at flowering stage in the surface soil layer and only at sowing in the sub-surface soil layer. At maximum tillering stage, FDA in surface soil layer was higher by 21% and 27.3% under PTR_{W0}+GM and PTR_{W25}+GM treatments as compared with PTR_{W0} and PTR_{W25}, irrespective of tillage and rice straw management practices in subsequent wheat. At this stage, FDA was increased by 33.3% (from 1.42 to 1.89 µg fluorescein g^{-1} hr^{-1}) in PTR_{W25}+GM as compared with PTR_{W0}. At flowering stage, in surface soil layer, FDA under ZTW_{R0} was 12.9% and 11% higher as compared with ZTW_{R0} and CTW_{R0}, respectively. Interaction effects were not significant in both surface and

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

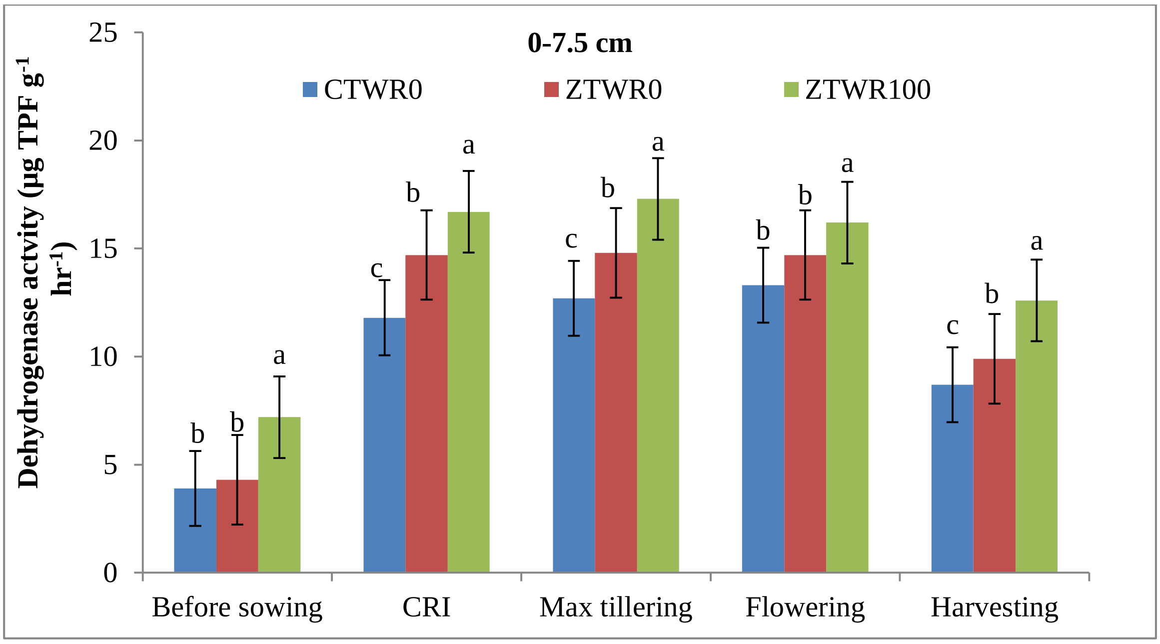
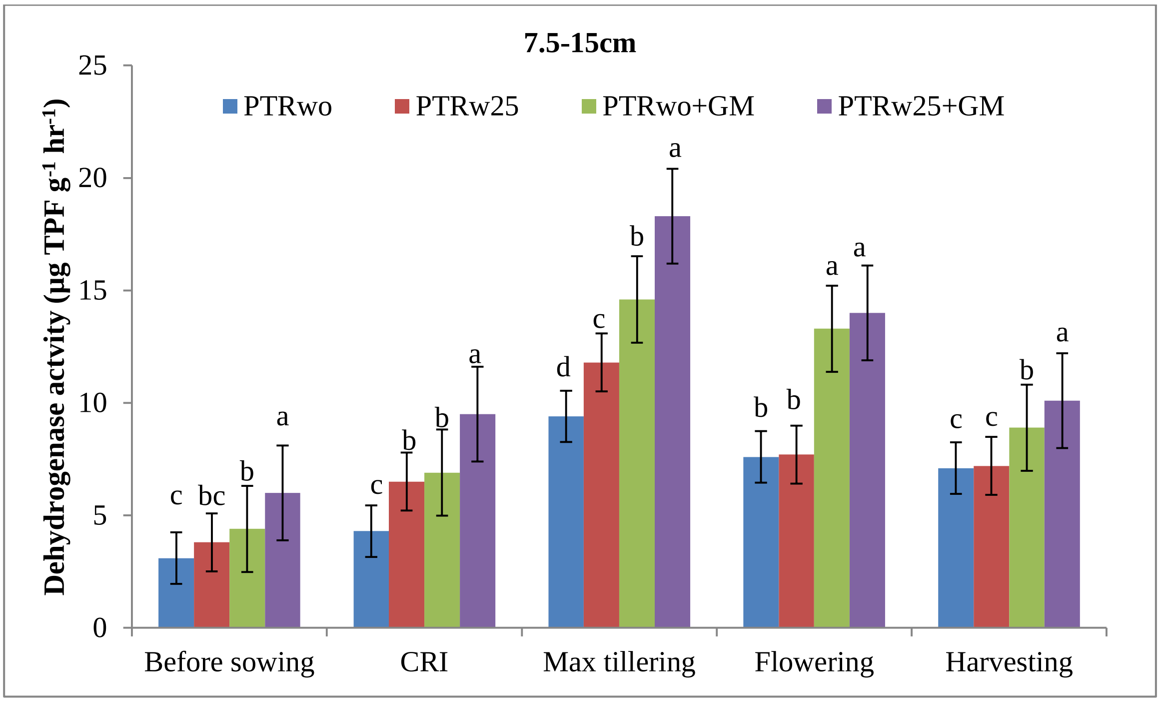


Fig. 4.1: Soil dehydrogenase activity (µg TPF g^{-1} hr^{-1}) during different growth stages of wheat in surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at p<0.05). Columns with same latter are not significantly different (p<0.05).

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

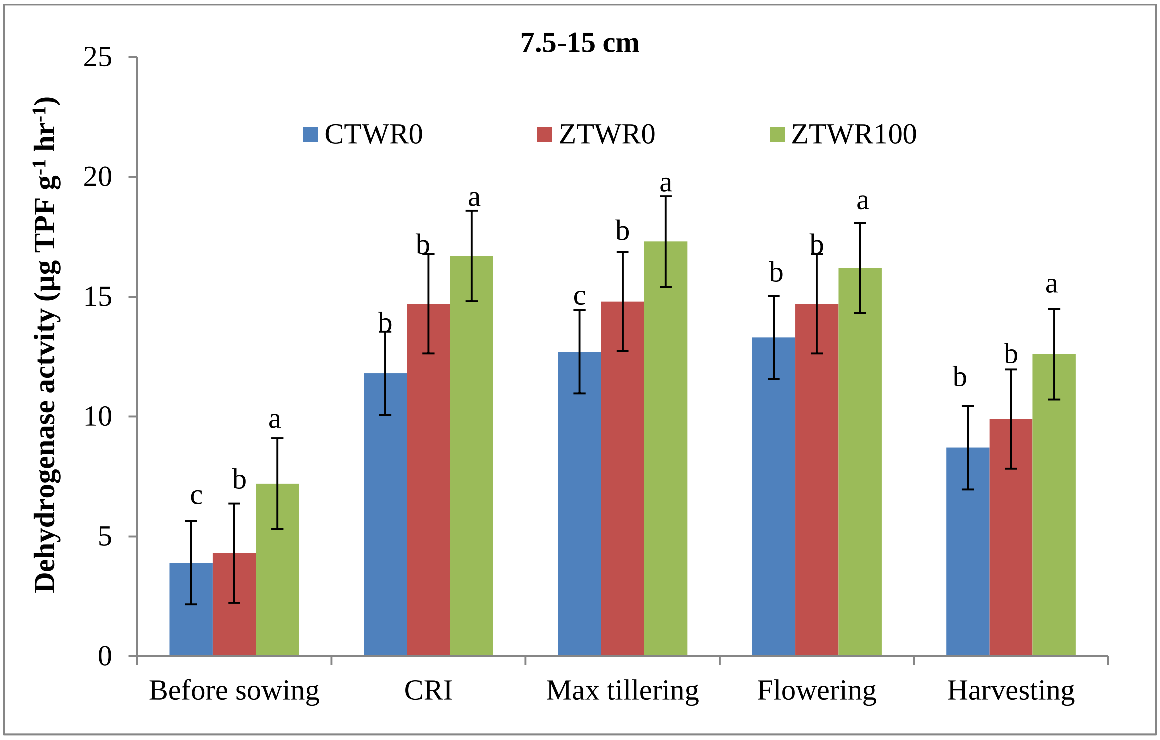


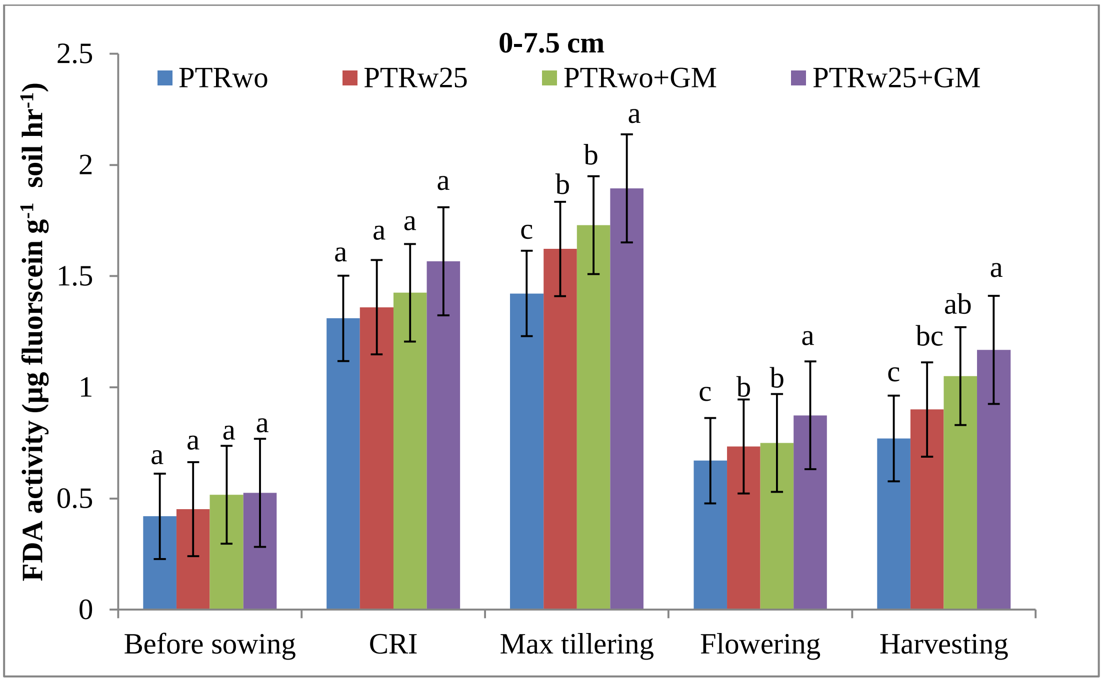
Fig. 4.2: Soil dehydrogenase activity (µg TPF g^{-1} hr^{-1}) during different growth stages of wheat in sub-surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at $p<0.05$). Columns with same latter are not significantly different ($p<0.05$).

sub-surface soil layer. FDA is hydrolysed by esterases, lipases and proteases hence depicts the hydrolytic activity of soil microorganisms and is an indicator of soil's overall biological activity (Dutta *et al* 2010) and reported to be correlated with microbial biomass, adenosine triphosphate (ATP) content and cell density (Federle *et al* 1990). FDA decreased with depth may be due to decrease in organic matter content with depth. In both the soil layers, maximum FDA was observed at maximum tillering stage followed by CRI and lowest at sowing. Li *et al* (2005) observed that FDA activity was higher at booting stage than maturity stage under NT than under CT in double rice cropping systems. Parihar *et al* (2016) observed strong relationship between MBC and FDA and 85.8% variation in FDA was explained by variation of MBC. Zero till wheat with 100% residue retention (ZTW_{R100}) produced significantly higher FDA compared to zero till without residue retention (ZTW_{R0}) and conventional tillage practices (CTW_{R0}) at all the growth stages of wheat. Gajda *et al* (2013) and Perez-Brandhan *et al* (2012) observed similar results showing significant increase (20-30%) in FDA activity under conservation tillage practices than traditional tillage practices. The increase in FDA in ZTW_{R00} might be due to combined effect of ZT and rice residue additions for increasing SOC content in the surface soil layer. Greater activity of FDA in ZTW_{R100} treatments may be ascribed to higher organic C content and the occurrence of more metabolically active microorganisms as suggested by significant positive correlation between FDA and SOC (Gaspar *et al* 2001).

4.1.3 Alkaline phosphatase activity

Wheat straw and green manure practices in rice, irrespective of tillage and rice straw management practices in wheat, significantly affected alkaline phosphatase (ALP) activity at sowing, CRI, maximum tillering and flowering stages of wheat in both the soil layers (Fig 4.5 and 4.6). However the significant effect of tillage and rice straw management practices in wheat on ALP activity, irrespective of wheat straw and green manure practices in rice was observed at all the growth stages of wheat in the surface soil layer and at sowing, CRI and maximum tillering stage in the sub-surface soil layer. The interaction effects between wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat were not significant in both the soil layers at all the growth stages of wheat. ALP activity (averaged across wheat treatments) was significantly higher under GM amended rice treatments (PTR_{W25}+GM and PTR_{W0}+GM) than no-GM treatments (PTR_{W25} and PTR_{W0}). In both the soil layers, ZT with 100% rice residue retention (ZTW_{R100}) showed significantly higher ALP activity at all growth stages of wheat as compared with ZT without rice residue retention (ZTW_{R0}) which was further reduced under CTW_{R0}. At maximum tillering stage, ALP activity (averaged across rice treatments) was significantly higher by 17.9% and 4.8% in ZTW_{R100} compared with CTW_{R0} and ZTW_{R0}, respectively. Phosphatase enzymes in soil are

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

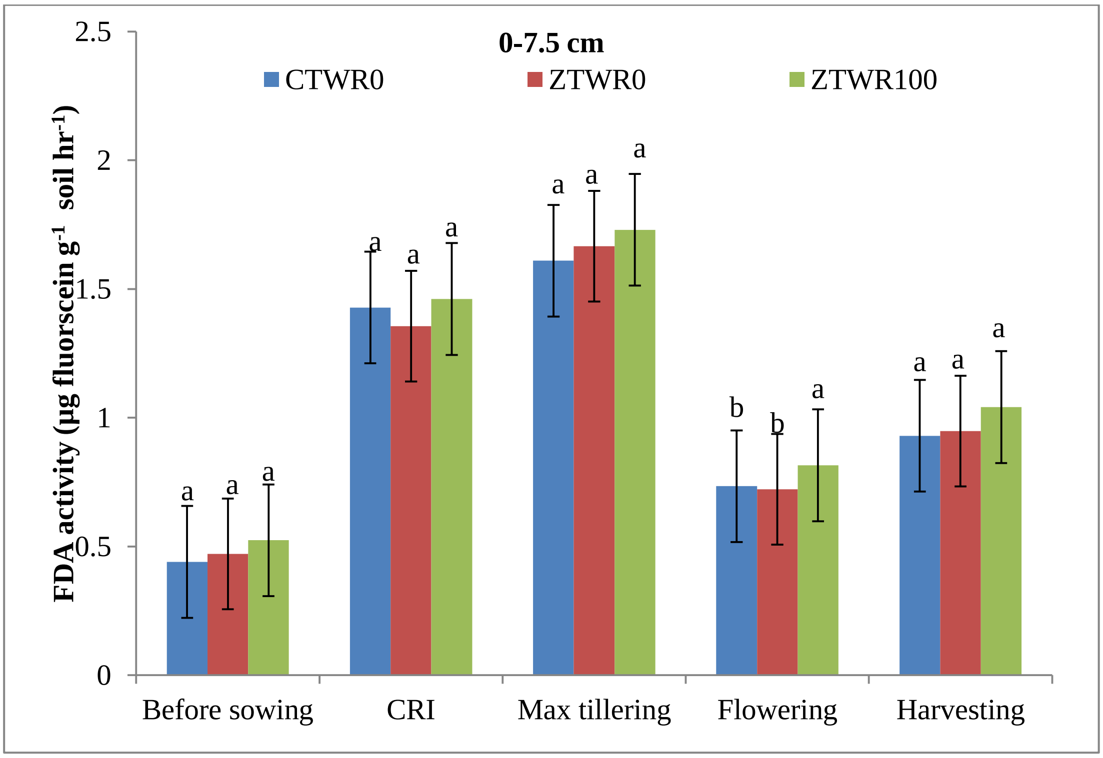
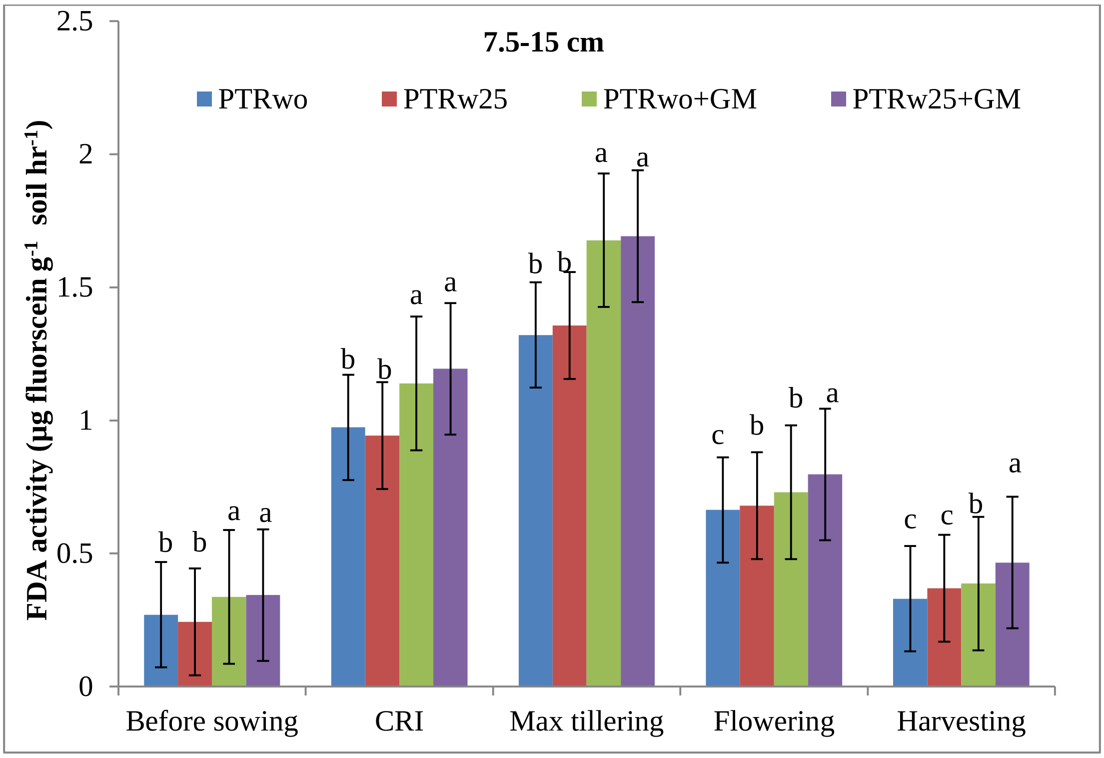


Fig. 4.3: **Soil FDA activity (µg fluorscein g^{-1} soil hr^{-1}) during different growth stages of wheat in surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at $p<0.05$). Columns with same latter are not significantly different ($p<0.05$)**

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

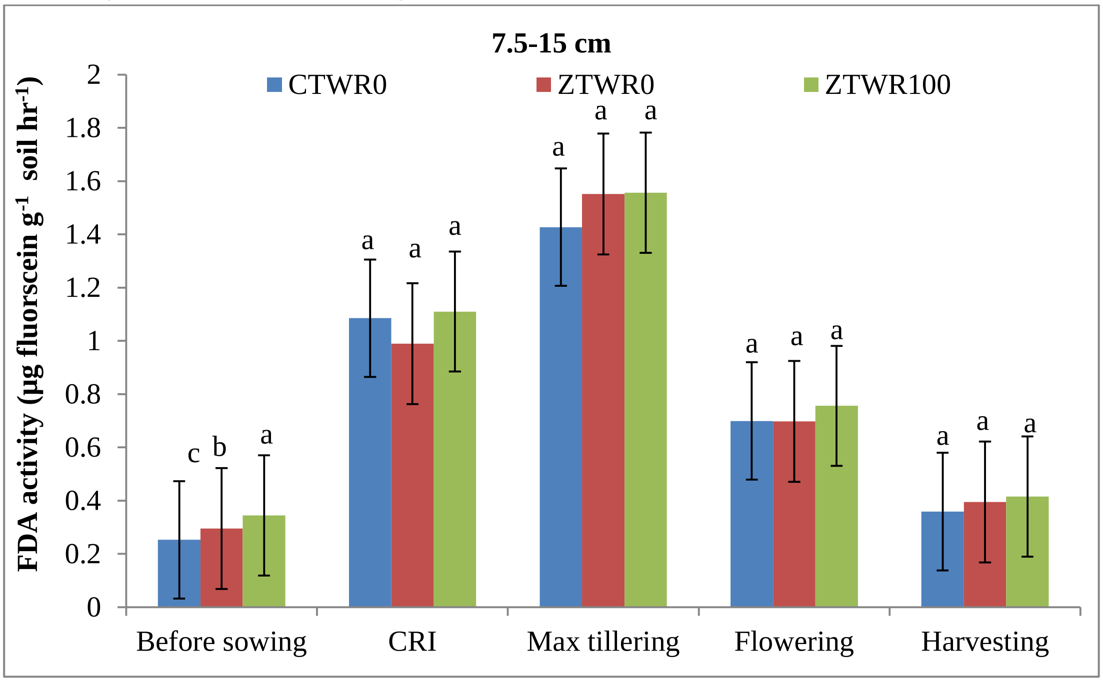
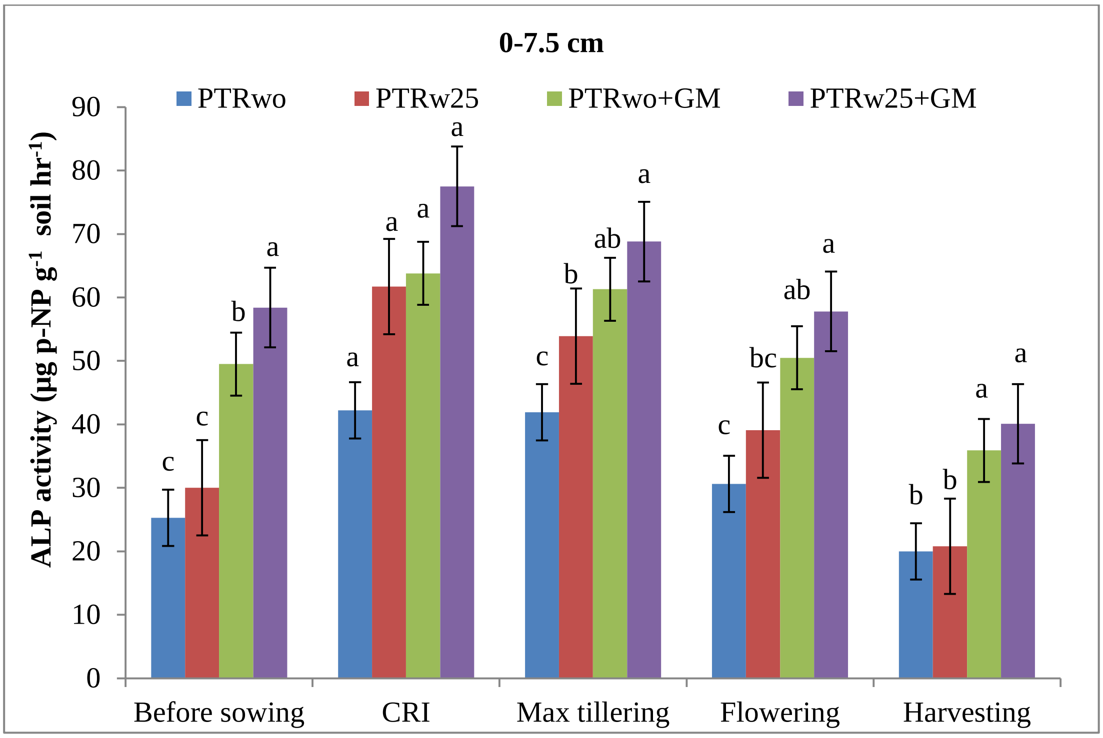


Fig. 4.4: Soil FDA activity (µg fluorscein g^{-1} soil hr^{-1}) during different growth stages of wheat in sub-surface soil layer as influenced by (a) Wheat straw and green .manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at $p<0.05$). Columns with same latter are not significantly different ($p<0.05$).

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

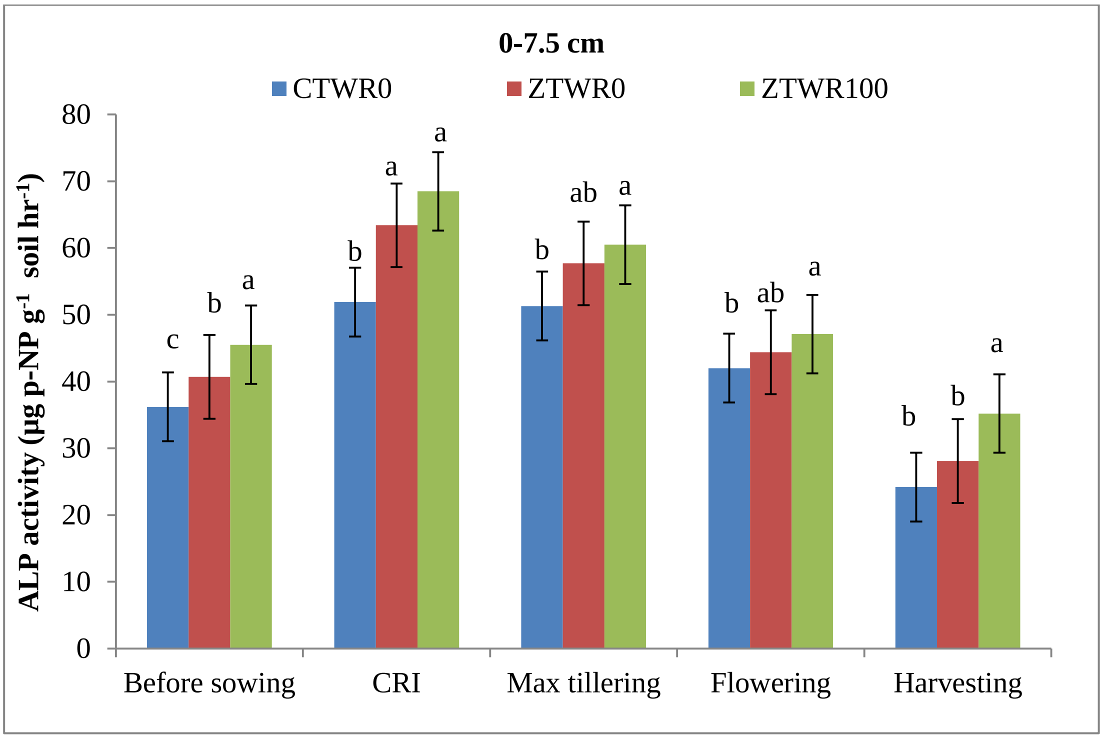
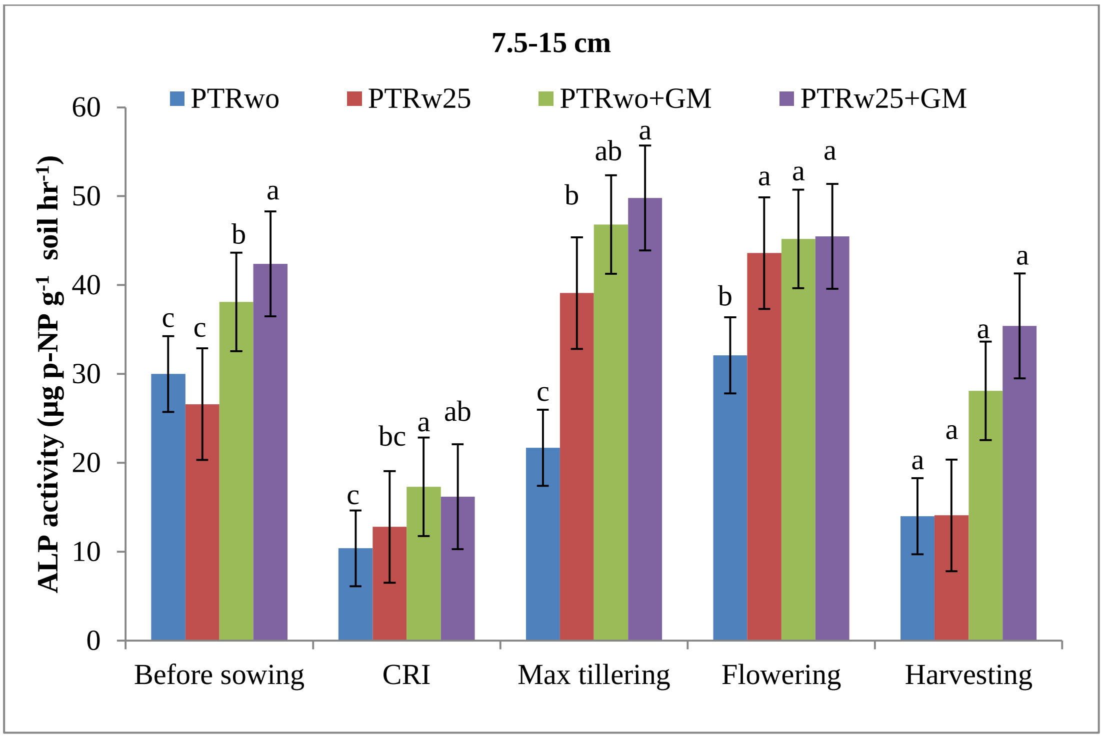


Fig. 4.5: Soil alkaline phosphatase activity (µg p-NP g^{-1} soil hr^{-1}) during different growth stages of wheat in surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at $p<0.05$). Columns with same latter are not significantly different ($p<0.05$).

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

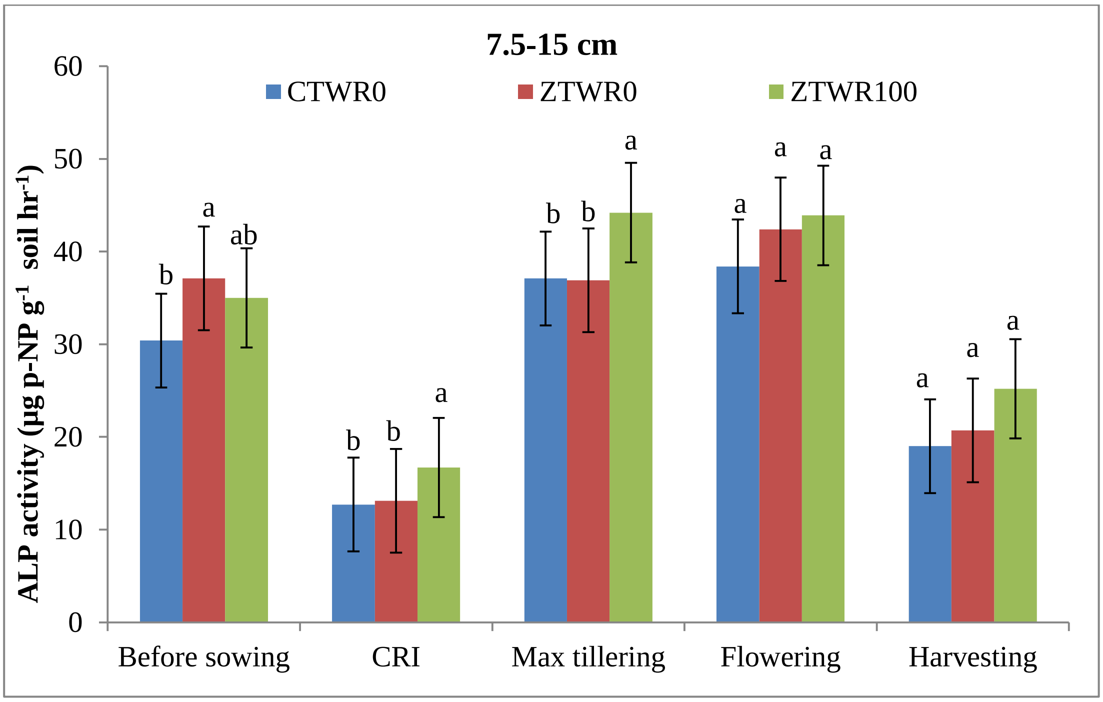


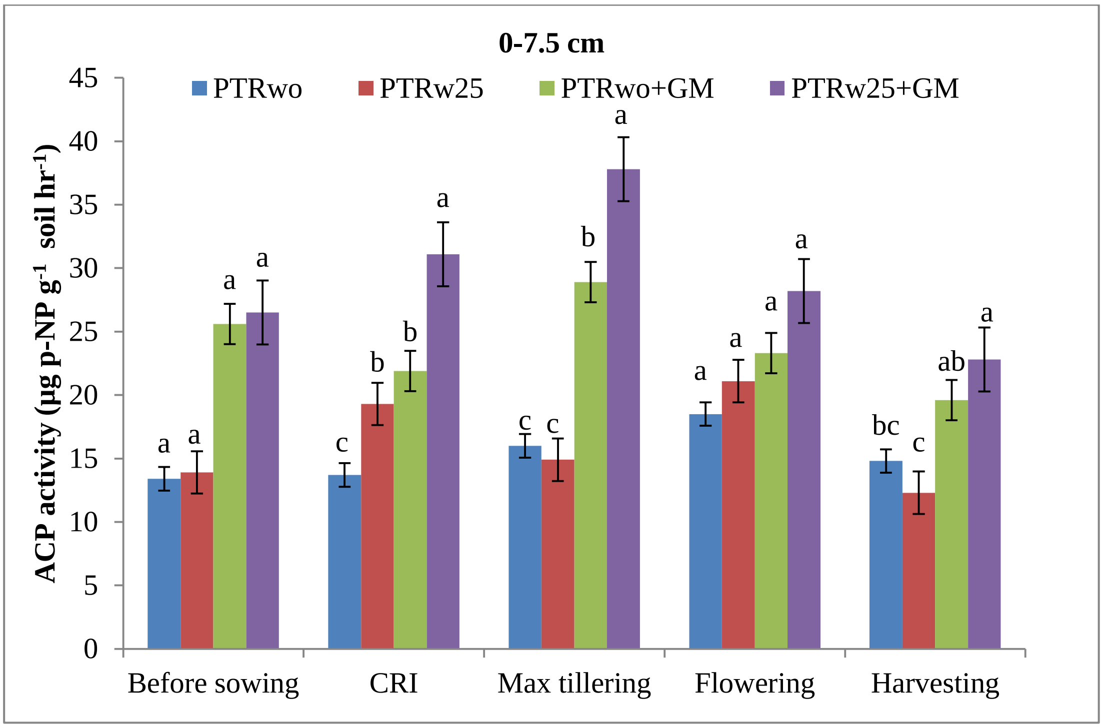
Fig. 4.6: Soil alkaline phosphatase activity (µg p-NP g^{-1} soil hr^{-1}) during different growth stages of wheat in sub-surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at p<0.05). Columns with same latter are not significantly different (p<0.05).

known to involve in breakdown of organic matter to release inorganic phosphate hence perform a crucial role in phosphorous cycle in soil ecosystem (Speir and Ross 1975). Similar finding of higher ALP activity under zero tillage than conventional tillage in maize based cropping systems was reported by Parihar *et al* (2016). In surface soil layer, maximum ALP activity was observed at CRI stage followed by maximum tillering and least at harvesting stage. However, maximum ALP activity in sub-surface soil layer was observed at flowering stage followed by maximum tillering and least at CRI stage. Luo *et al* (2013) reported that alkaline phosphatase tended to be low in activity at seedling stage, peaked at booting stage and decreased at maturing stage under rice-wheat cropping system. ALP activity was higher in surface soil layer as compared with sub-surface soil layer, which may be due to accumulation of crop residue in the surface soil layer which increases organic matter content and stimulate microbial activity in soil (Mullen *et al* 1998). Consistent with the findings of other researchers (Qin *et al* 2010, Sharma *et al* 2013) significant increase in the activities of alkaline phosphatase was observed in ZTW_{R100} compared with ZTW_{R0} and CTW_{R0}. It is also reported that nitrogen fertilization triggers phosphorous demand and hence phosphatase activity (Allison *et al* 2006). This could be the reason that phosphatase activities increased at CRI stage following urea applications as top dressing.

4.1.4 Acid phosphatase activity

Acid phosphatase activity (ACP) in the present study was lower than alkaline phosphatase activity, which might be due to slightly alkaline soil reaction. Wheat straw and green manure practices in rice, irrespective of tillage and rice straw management practices in wheat significantly affected ACP activity at CRI, maximum tillering and harvesting stage in the surface soil layer (Fig 4.7) and at sowing and CRI stage in the sub-surface soil layer (Fig 4.8). Tillage and rice straw management practices in wheat, irrespective of different wheat straw and green manure practices in rice significantly affected ACP activity at all the growth stages of wheat only in surface soil layer. The interaction between different wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was significant only at maximum tillering stage in the surface soil layer. At this stage, ACP activity was maximum in PTR with residue retention and green manure (PTR_{w25}+GM/ ZTW_{R100}) and reduced significantly in PTR_{w25}+GM/CTW_{R0}. Under PTR_{w0}+GM, ACP activity was significantly higher under ZTW_{R100} than ZTW_{R0}, which was further significantly reduced under CTW_{R0}. Under PTR_{W25}, tillage and rice straw management practices failed to cause significant difference among themselves. Under PTR_{W0}, ZTW_{R100} produced significantly higher ACP activity as compared with ZTW_{R0} and CTW_{R0}. ACP activity at this stage increased 3.8 fold in PTR_{w25}+GM/ZTW_{R100} treatment than PTR_{w0}/CTW_{R0}. Maximum ACP

(a) **Wheat straw and green manure practices in rice**



(b) **Tillage and rice straw management practices in wheat**

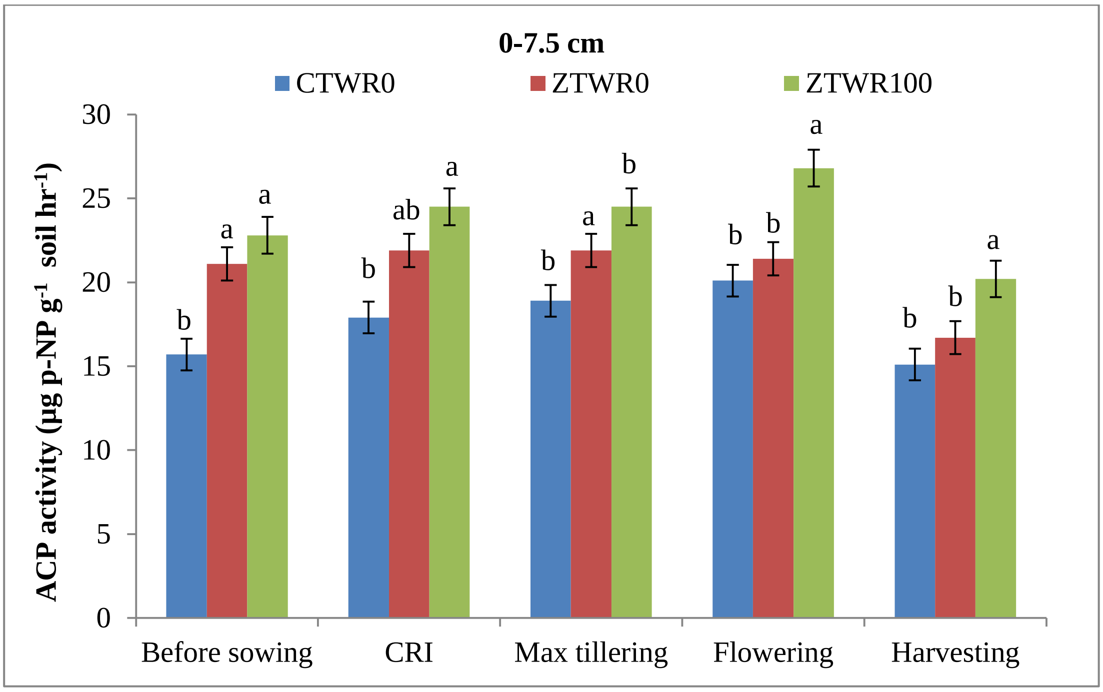
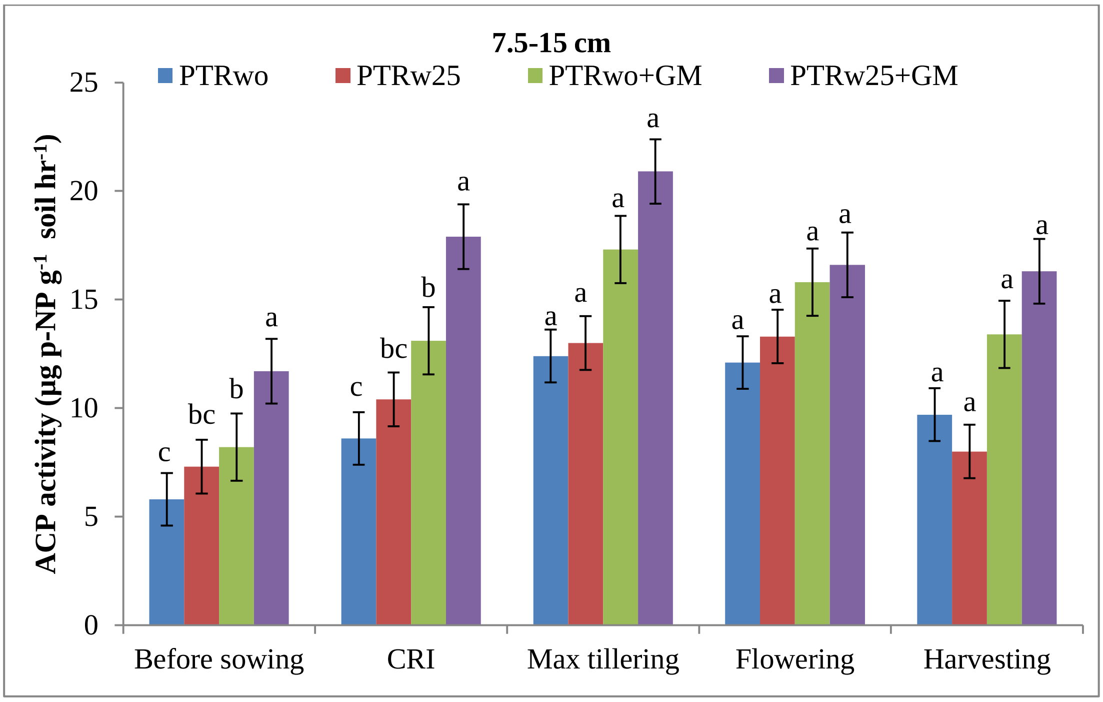


Fig. 4.7: Soil acid phosphatase activity (µg p-NP g^{-1} soil hr^{-1}) during different growth stages of wheat in surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at $p<0.05$). Columns with same latter are not significantly different ($p<0.05$).

a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

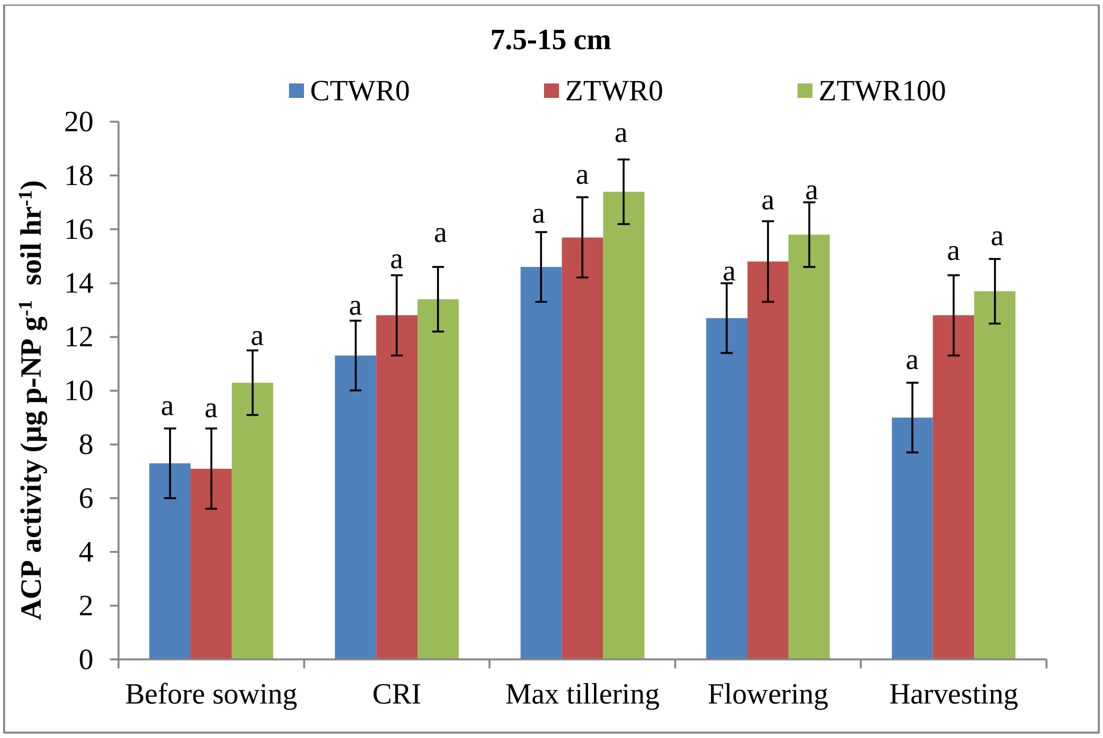
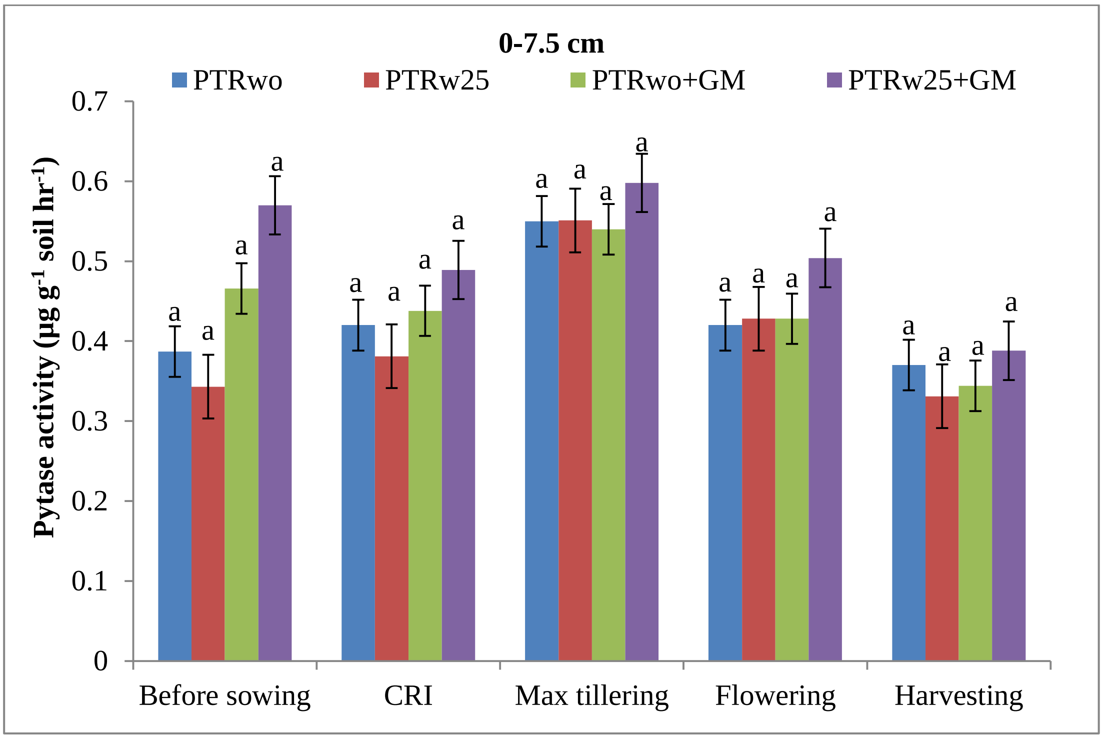


Fig. 4.8: **Soil acid phosphatase activity (µg p-NP g^{-1} soil hr^{-1}) during different growth stages of wheat in sub-surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at $p<0.05$). Columns with same latter are not significantly different ($p<0.05$).**

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

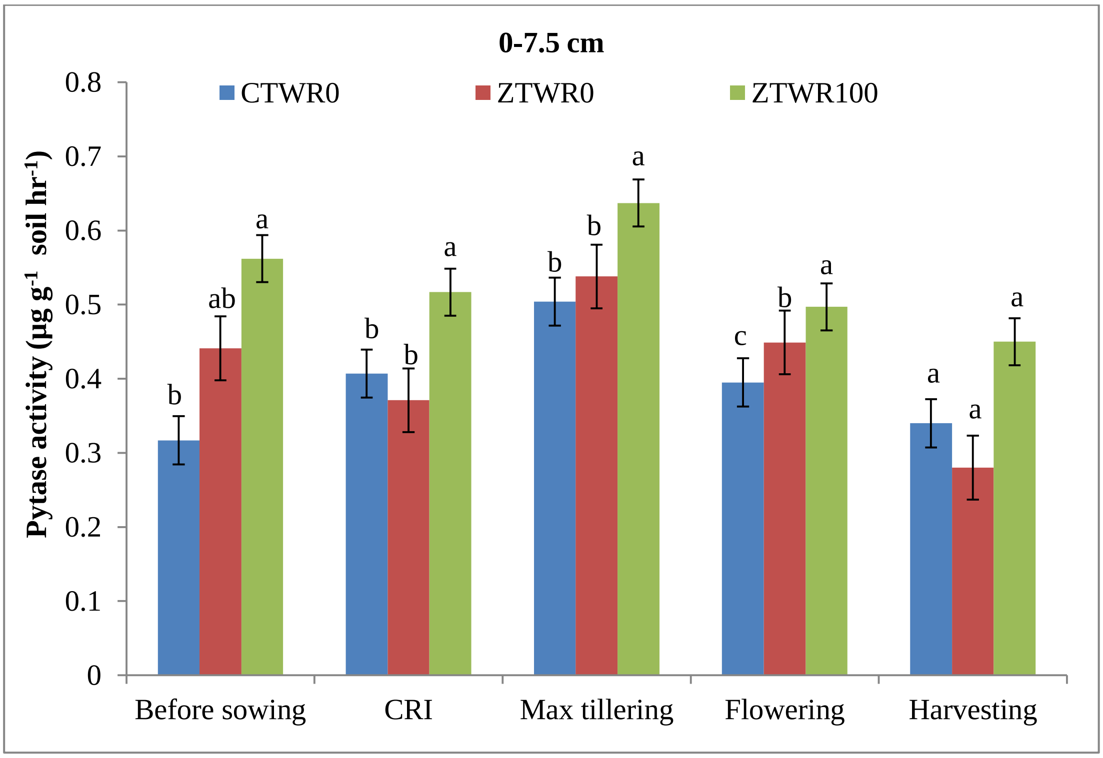
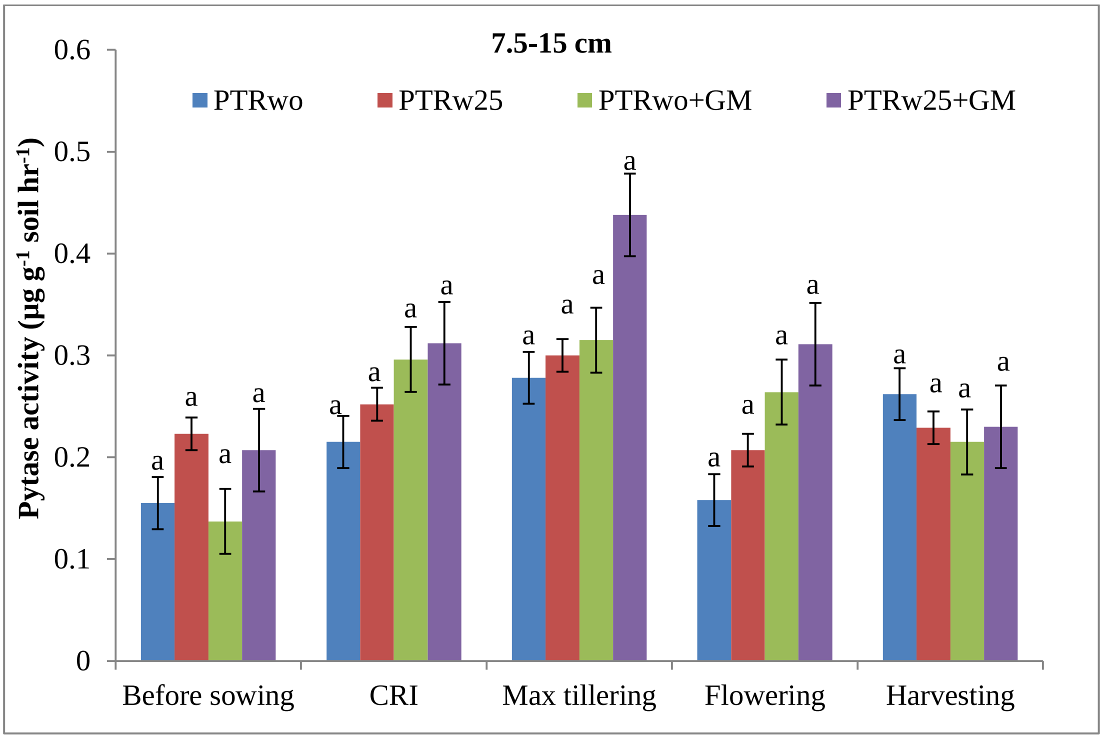


Fig. 4.9: **Phytase activity in soil (µg g^{-1} soil hr^{-1}) during different growth stages of wheat in surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at p<0.05). Columns with same latter are not significantly different (p<0.05).**

a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

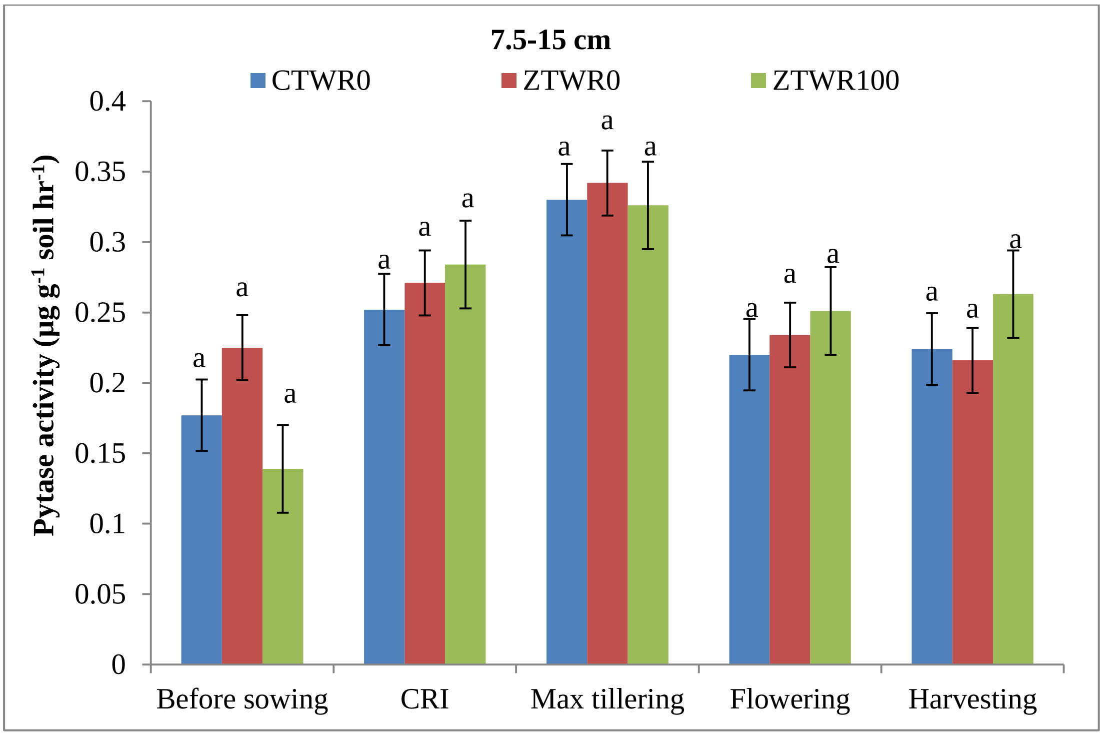


Fig. 4.10: **Phytase activity in soil (µg g^{-1} soil hr^{-1}) during different growth stages of wheat in sub-surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at p<0.05). Columns with same latter are not significantly different (p<0.05).**

activity was observed at maximum tillering followed by flowering stage in both the soil layer. It is most likely because acid phosphatase is predominantly secreted by plant roots and associated mycorrhiza and other fungi (Tarafdar and Marschner 1994), which may have attained maximum root biomass at MT stage (Mandal *et al* 2007). ACP activity was decreased in sub-surface soil layer possibly due to decrease in total organic carbon with depth. Mullen *et al* (1998) reported significant increase of ACP activity with no tillage and addition of crop residue in soil. Similarly, Roldan *et al* (2005) observed higher acid phosphatase activity under no-tillage practices as compared with soil tilled with mouldboard plough as no tillage stimulate higher microbial activity due to accumulation of high amount of crop residues in soil. Heideri *et al* (2016) recorded higher value of acid phosphatase activity in a soybean crop under no tillage than conventional tillage in a long term study in Iran.

4.1.5 Phytase activity

Tillage and rice straw management practices in wheat, irrespective of different wheat straw and green manure practices in rice, significantly affected phytase activity at all the growth stages of wheat only in the surface soil layer, except at harvesting (Fig 4.9 and 4.10). However, the effect of different wheat straw and green manure practices in rice, irrespective of tillage and rice straw management practices in wheat, failed to cause any significant effect on phytase activity at all the growth stages of wheat in both the soil layer. The interaction between different wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was not significant in both the soil layer at all the growth stages of wheat. Phytase activity was not significantly affected in subsequent wheat by wheat straw retention (25%) and incorporation of green manure in previous rice crop. But tillage and rice straw management practices in wheat significantly increased phytase activity at maximum tillering stage by 26.4% and 18.4% under ZTW_{R100} as compared with CTW_{R0} and ZTW_{R0}, respectively. In both the soil layer, maximum phytase activity was observed at maximum tillering stage followed by flowering stage and least was observed at harvesting, which might be due to higher microbial biomass at this stage. The phytase activity is mainly associated with the root cell wall and with mucilage in apical root zones (Eltrop 1993). Maximum phytase activity at maximum tillering stage may be due to alterations in the composition of the root exudates due to degradation of exudates and the release of microbial metabolites. Enhanced secretion of phytase (Li *et al* 1997) by plant roots and rhizosphere micro-organisms (Tarafdar and Marschner 1994) may contribute to inorganic P acquisition by hydrolysis of organic P esters at maximum tillering stage. Phytase activity was higher in the surface layer due to enhanced nutrition, aeration and root distribution in this layer. ZT with 100% residue retention (ZTW_{R100}) produced significantly higher phytase activity than ZT and CT without residue retention (ZTW_{R0} and CTW_{R0}), which is possibly due to organic matter build up and higher microbial activity after 5 years of rice-wheat cropping system. Kharia *et al* (2016) recorded significantly higher phytase activity under ZT with residue retention in a wheat crop after 3 years of rice-wheat cycle. Similarly, Yadav and Tarafdar (2004) reported higher phytase activities under ZTW_{R100} than CTW_{R0} which is attributed to organic matter build up and increased supply of C through crop residues for microbial activity.

4.1.6 Urease activity

Wheat straw and green manure practices in rice, irrespective of tillage and rice straw management practices in wheat significantly affected urease (URE) activity at maximum tillering stage in surface soil layer (Fig 4.11) and at flowering stage in sub-surface layer (Fig 4.12). However, the effect of tillage and rice straw management practices in wheat on urease activity, irrespective of different wheat straw and green manure practices in rice was significant at maximum tillering and harvesting stage in the surface soil layer. Urease (Urea Amidohydrolase, EC 3.5.1.5) hydrolyses non-peptide C-N bonds in linear amides (Bremner and Mulvaney 1978, Karaca *et al* 1999). Urease is a constitutive intracellular enzyme with three subunits of α, ß and γ and two nickel ions. Urease catalyzes the hydrolysis of urea and amides to carbon dioxide and ammonia. The interaction between different wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was not significant at all the growth stages of wheat in both the soil layer. PTR_{w25}+GM treatment produced significantly higher urease activity than other treatments. Urease activity increase with the incorporation of leguminous plant in soil, as they have the potential for N fixation and this could have stimulated the enzymes involved in N mineralization. Roldan *et al* (2003) observed increase of urease activity in proportion to addition of crop residues in soil, suggesting that crop residue are good source of carbon and energy for soil microflora. Urease activity was highest at CRI stage than other growth stages. Such a trend in urease activity in wheat rhizosphere after incorporation of rice stubbles and ZT was reported by Banerjee and Aggarwal (2013), who observed urease activity in wheat rhizosphere was significantly higher at CRI stage followed by tillering, internode elongation and least at harvesting stage. Highest urease activity at CRI than at the other growth stages might be due to the application of urea at sowing. Urease activity was significantly higher under ZTW_{R100} as compared with the ZTW_{R0} or CTW_{R0}. Our findings comply with the observation made by Qin *et al* (2010) and they observed significant increase of urease activity under no tillage than reduced tillage, which was significantly higher than traditional tillage practices. Likewise, Dick (1984) observed significantly higher urease activity under ZT than CT. Bandick and Dick (1999) observed significant increase of urease activity under straw application with straw manure and legume than application of fertiliser nitrogen. In a rice–wheat/oilseed rape cropping system, Gao *et al* (2004) observed that soil urease activity was higher under NT than under CT at rice tillering stage.

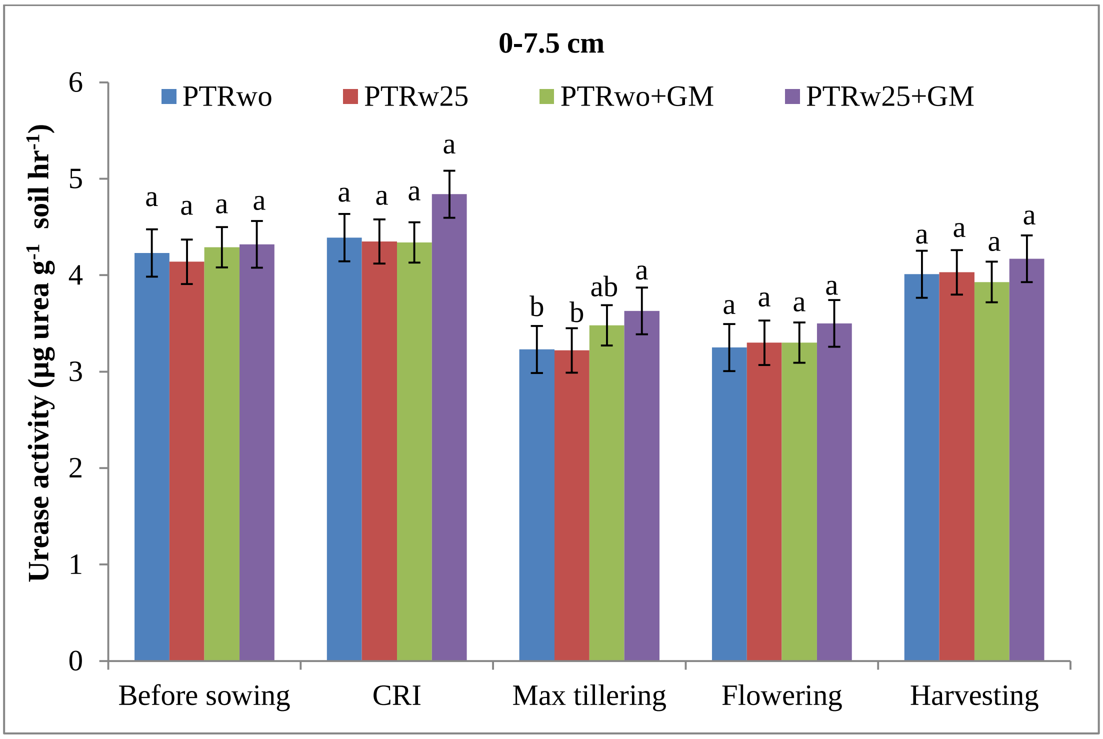
4.1.7 L-asparaginase activity

During fifth wheat crop, wheat straw and green manure practices in rice, irrespective of tillage and rice straw management practices in subsequent wheat, significantly affected L-asparaginase (ASP) activity at maximum tillering, flowering and harvesting stage of wheat in the surface soil layer (Fig 4.13). Likewise, the effect of tillage and rice straw management practices in subsequent wheat, on ASP activity, irrespective of different wheat straw and green manure practices in rice was significant at all growth stages of wheat in the surface soil layer. The interaction between different wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was significant only at flowering stage of wheat. At this stage, PTR_{w25}+GM/ZTW_{R100} exhibits maximum ASP activity, which was 2.7 fold higher than PTR_{W0}/$CTW_{R0.}$ Under PTR_{W0} and PTR_{w25}+GM, ZTW_{R100} produced maximum ASP activity as compared to ZTW_{R0} and CTW_{R0}. Maximum ASP activity was recorded at maximum tillering stage (41.3% higher than before sowing) followed by harvesting stage and lowest value was observed at CRI stage, which may be attributed to higher root exudation and biomass at maximum tillering stage. L-asparaginase enzyme is associated with nitrogen cycling in soil. It acts on C-N bonds except peptide bond in linear amides, which leads to release of ammonia. Amidohydrolase activity is sensitive to changes in soil quality resulting from tillage practices (Ekenler and Tabatabai 2004). The results of the present study comply with the previous findings of Deng and Tabatabai (1996b) showing that tillage and residue management significantly affected ASP activity. They observed maximum activity of ASP under no-till/double mulch as compared to mouldboard or chisel plough without mulching. PTR with green manuring practices produced significantly higher ASP activity compared to PTR without green manure. This may be due to stimulating effect of legume on N cycle enzymes. Hamido and Kpomblekou (2009) observed significantly higher ASP activity in plots preceded by crimson clover than that of plots preceded by black oat.

4.1.8 β-glucosidase activity

Wheat straw and green manure practices in rice, irrespective of tillage and rice straw management practices in subsequent wheat, significantly affected β-glucosidase (β-glu) activity after 5 year of rice-wheat cropping at all the growth stages of wheat in both the soil

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

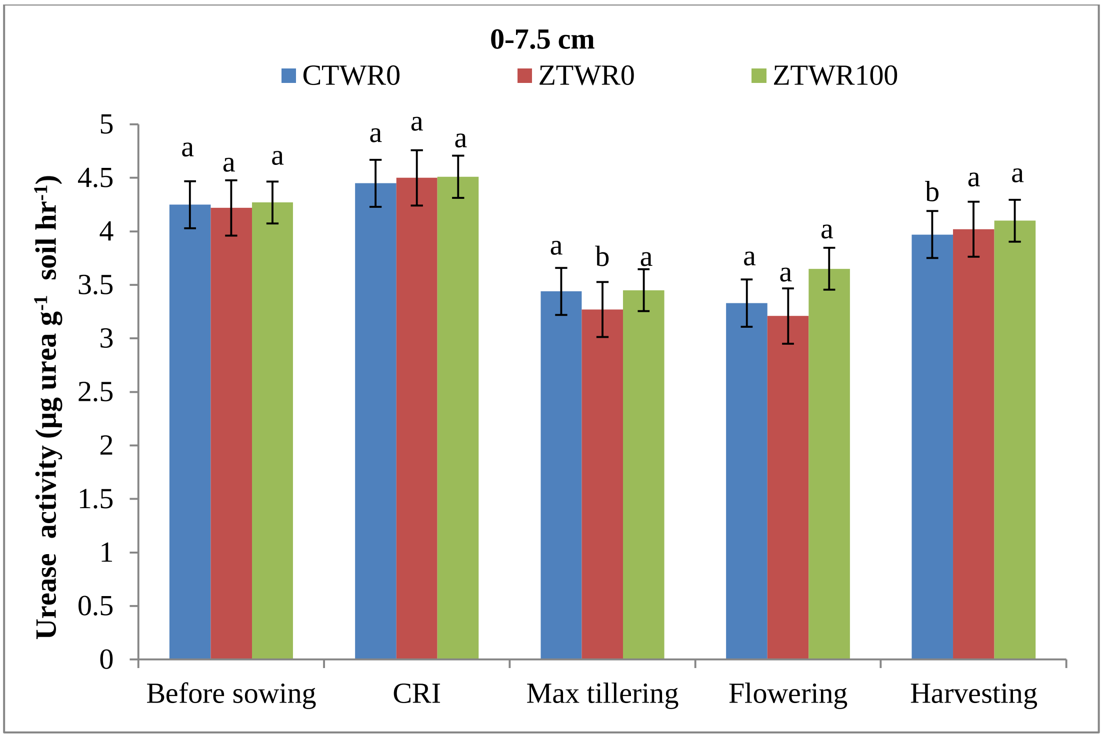
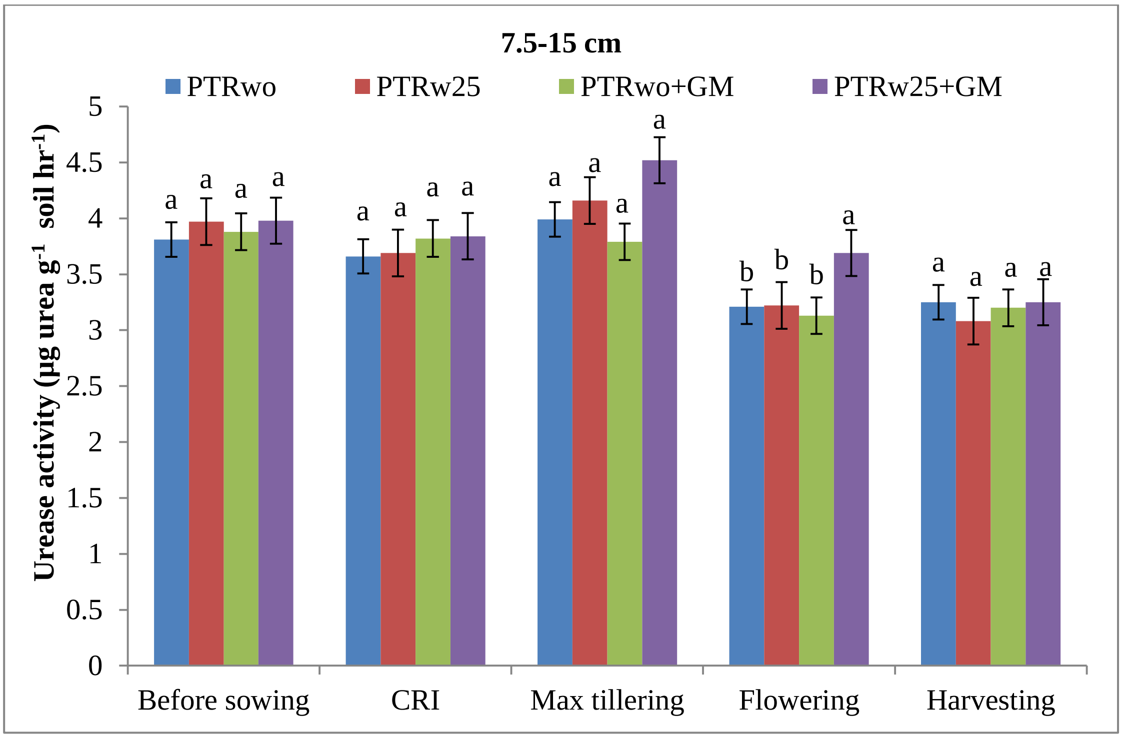


Fig. 4.11: Urease activity in soil (µg urea g^{-1} soil hr^{-1}) during different growth stages of wheat in surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at $p<0.05$). Columns with same latter are not significantly different ($p<0.05$)

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

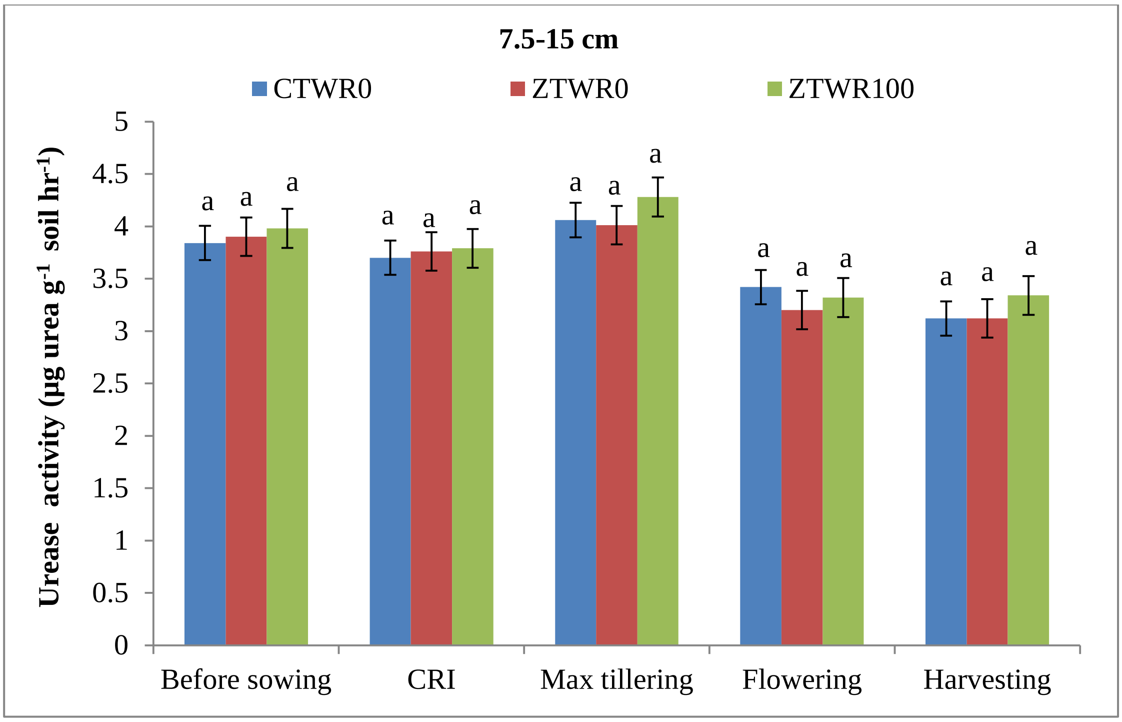
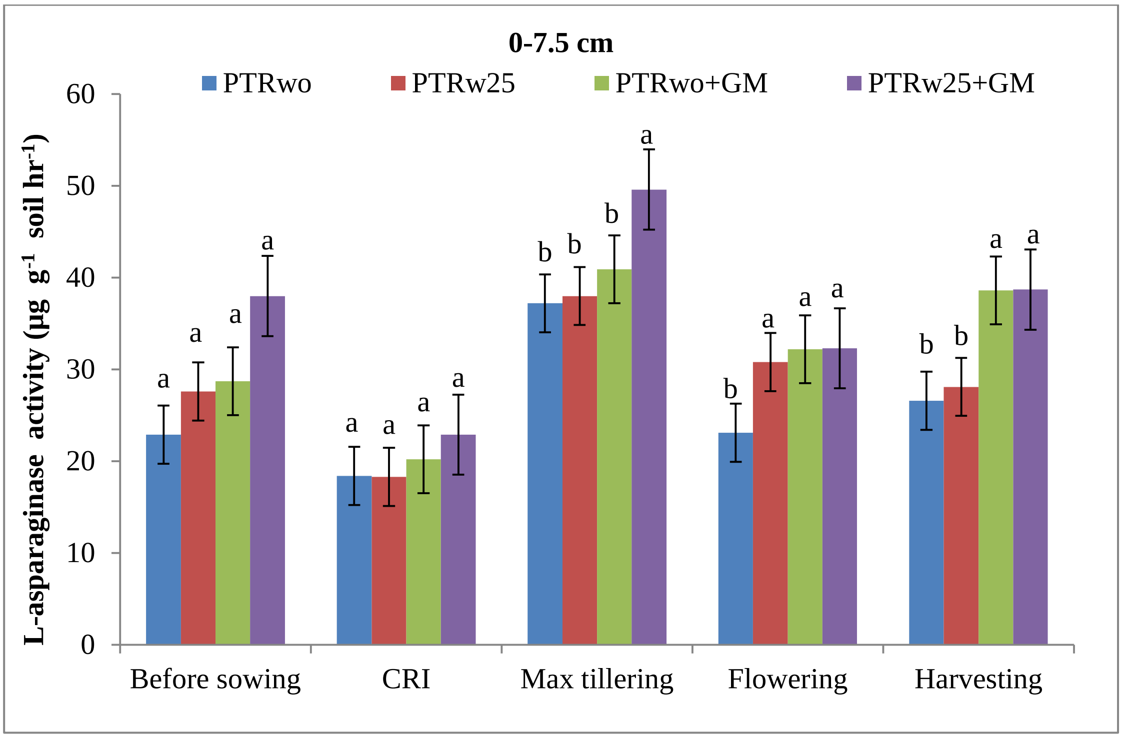


Fig. 4.12: Urease activity in soil (µg urea g^{-1} soil hr^{-1}) during different growth stages of wheat in sub-surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at $p<0.05$). Columns with same latter are not significantly different ($p<0.05$)

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

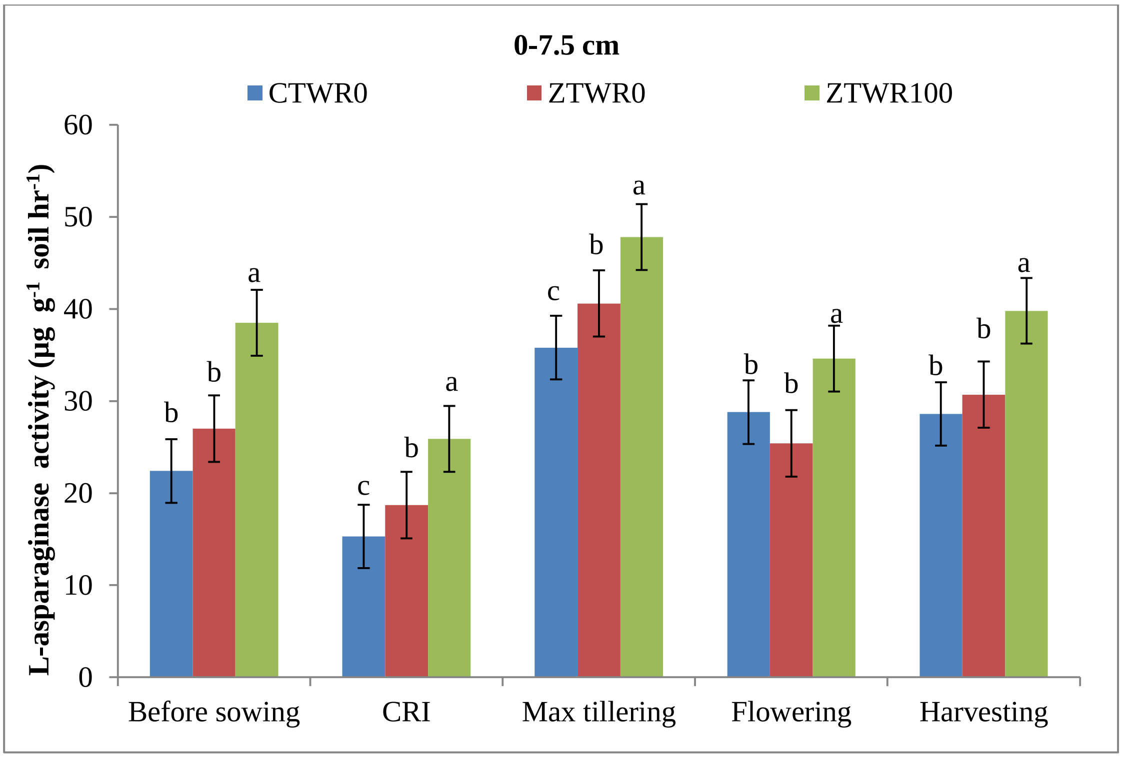


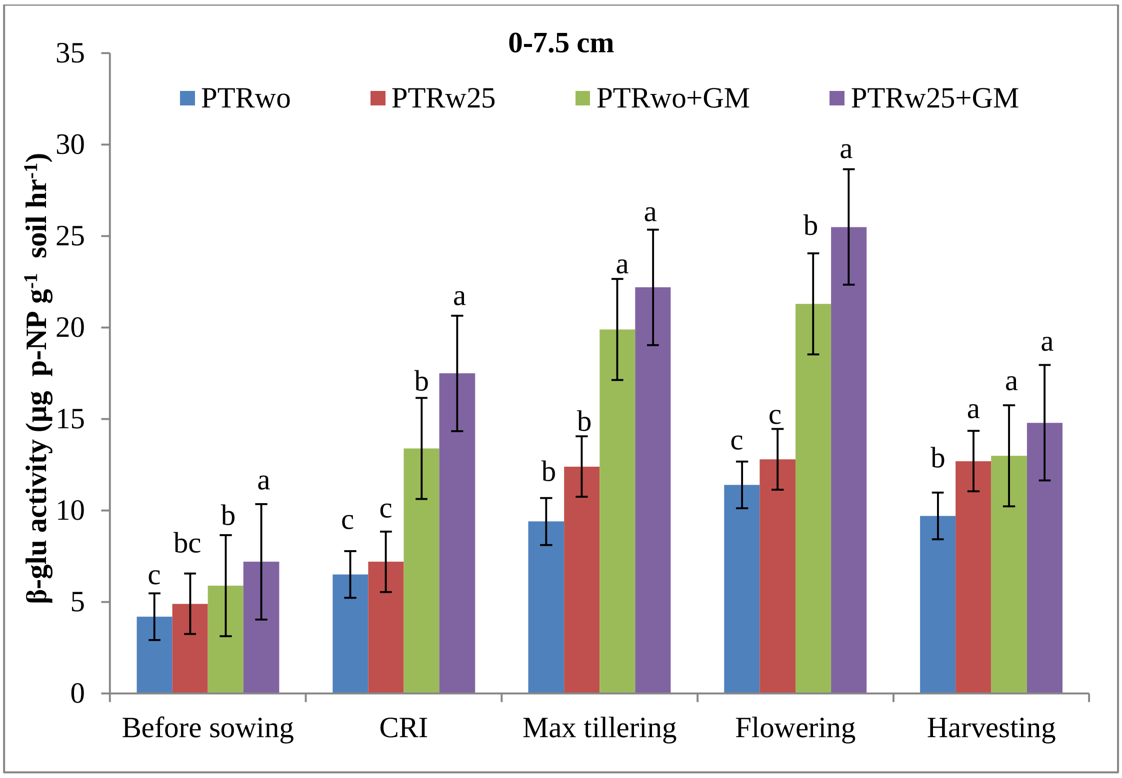
Fig. 4.13: L-asparaginase activity (µg g^{-1} soil hr^{-1}) during different growth stages of wheat in surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at $p<0.05$). Columns with same latter are not significantly different ($p<0.05$).

layer (Fig 4.14 and 4.15). However, the effect of tillage and rice straw management practices in subsequent wheat on β-glu activity, irrespective of different wheat straw and green manure practices in rice was significant at sowing, maximum tillering and flowering stage in surface soil layer and at sowing, CRI, maximum tillering and flowering stage in the sub-surface soil layer. β-glucosidase can decompose labile cellulose and other carbohydrate polymers into low molecular weight compounds (Liang *et al* 2014). The interaction between different wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was significant at sowing, maximum tillering and flowering stage in both the soil layer. At sowing, in both the soil layer, maximum β-glu activity was obtained under PTR_{W0}+GM/ZTW_{R100} treatment, which was statistically at par with PTR_{W25}+GM/ZTW_{R100} treatment. At maximum tillering stage, PTR_{W25}+GM/ZTW_{R100} treatment produced maximum of β-glu activity, which was significantly higher than PTR_{W25}+GM/CTW_{R0} treatment. At flowering stage, PTR_{W25}+GM/ZTW_{R100} produced maximum β-glu activity in both the soil layer. ZTW_{R100} produced significantly higher β-glu activity than ZTW_{R0} and CTW_{R0}. Maximum β-glu activity was recorded at flowering stage followed by maximum tillering stage in the surface soil layer and at maximum tillering followed by flowering stage in the sub-surface soil layer. Lowest activity was recorded at sowing for both the soil layer. At flowering stage, in the surface soil layer, β-glu activity under PTR_{W0}+GM and PTR_{W25}+GM was 1.8 and 2 times higher than PTR_{W0} and PTR_{W25}. β-glu activity was higher in surface soil layer than sub-surface soil layer possibly due to higher total organic carbon in the former layer. Pandey *et al* (2014) reported that no tillage before both rice and wheat, in a rice-wheat system potentially increased the activity of β-glu in soil. No-tillage significantly increased β-glu activity as compared with reduced tillage and conventional tillage, which may be associated with the increase of organic matter content under no-tillage (De la Horra *et al* 2003). Sharma *et al* (2013) observed higher (54.5%) β-glu activity under conservation tillage, possibly due to minimum soil disturbance and incorporation of crop residue in the surface layer.

4.1.9 Xylanase activity

During fifth rice-wheat cycle, wheat straw and green manure practices in rice, irrespective of tillage and rice straw management practices in wheat significantly affected xylanase activity at CRI, flowering and harvesting stage in surface soil layer (Fig 4.16). Likewise, the effect of tillage and rice straw management practices in wheat on xylanase activity, irrespective of different wheat straw and green manure practices in rice, was significant at all the growth stages of wheat in the surface soil layer, except at maximum

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

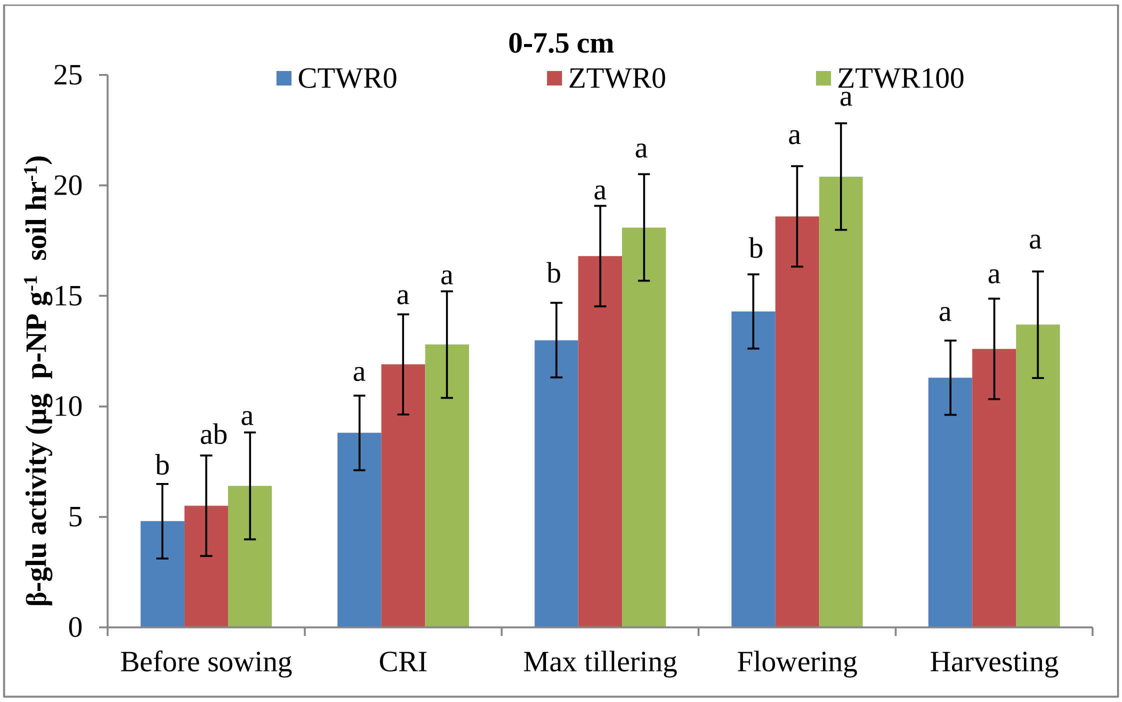
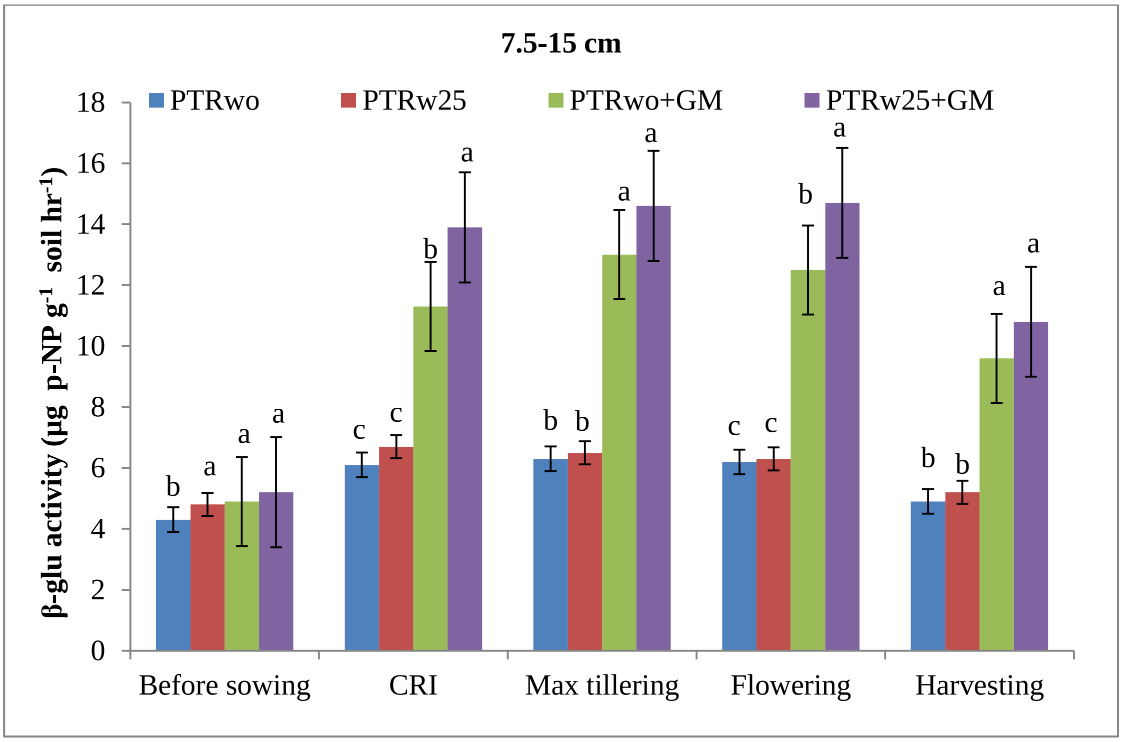


Fig. 4.14: β-glucosidase (β-glu) activity (µg p-NP g^{-1} soil hr^{-1}) during different growth stages of wheat in surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at $p<0.05$). Columns with same latter are not significantly different ($p<0.05$).

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

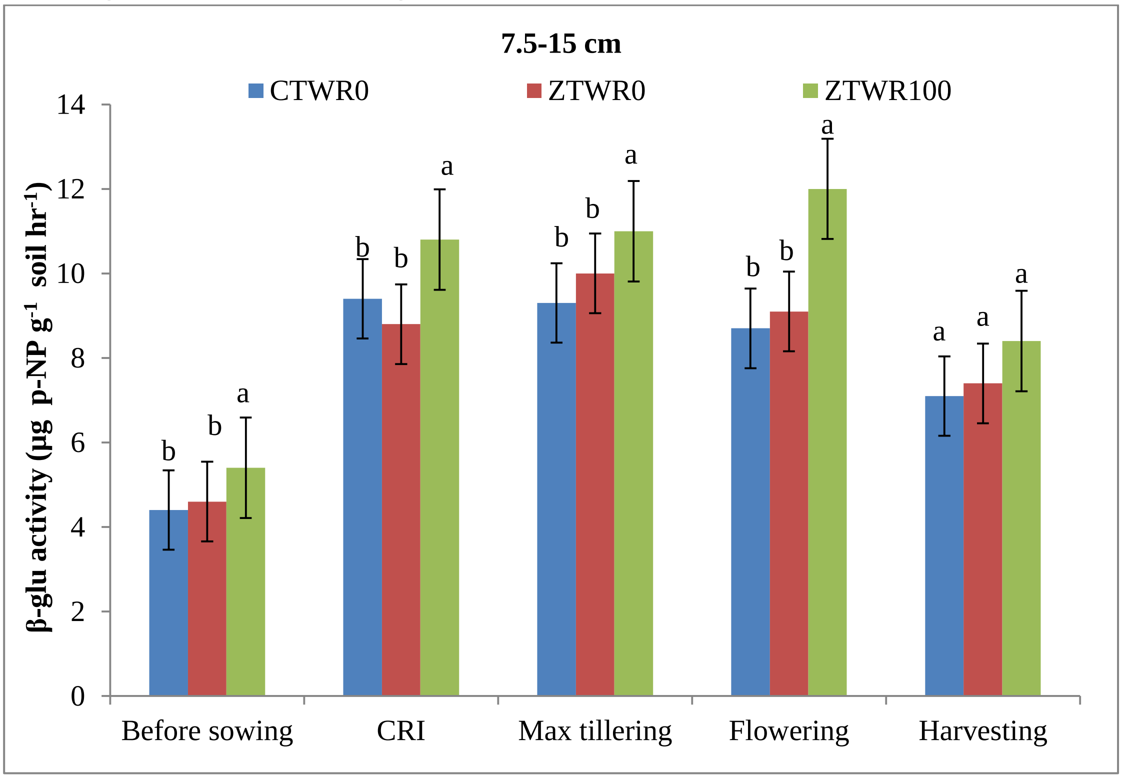
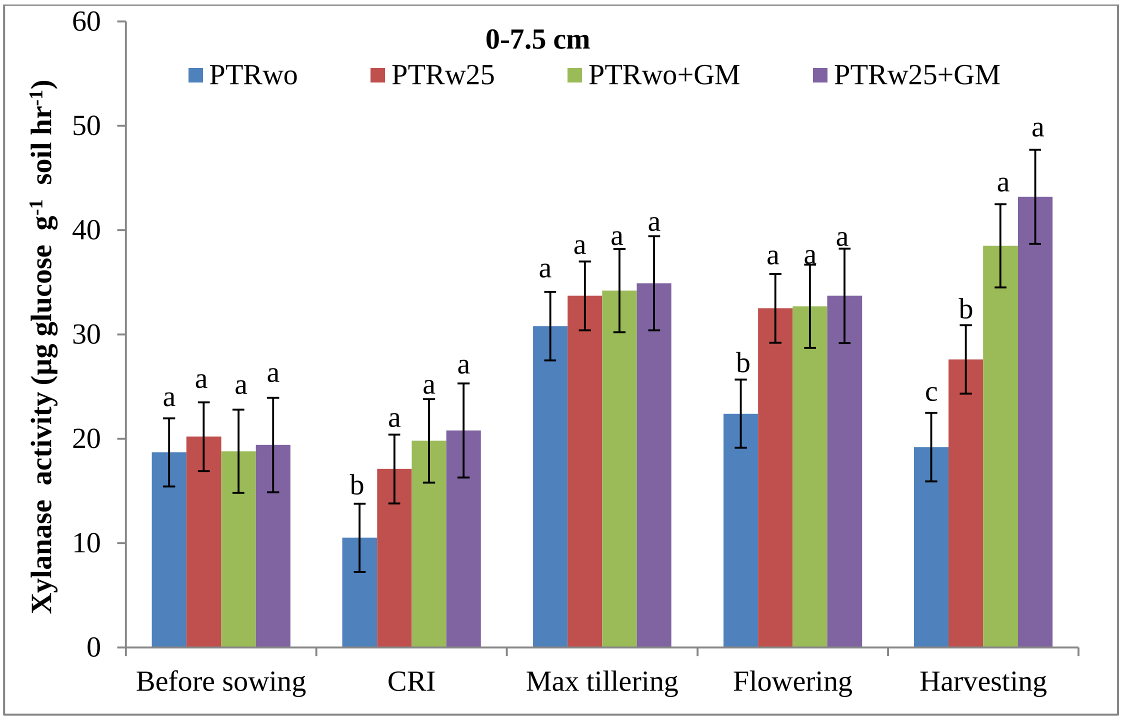


Fig. 4.15: **β-glucosidase (β-glu) activity (μg p-NP g^{-1} soil hr^{-1}) during different growth stages of wheat in sub-surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at p<0.05). Columns with same latter are not significantly different (p<0.05).**

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

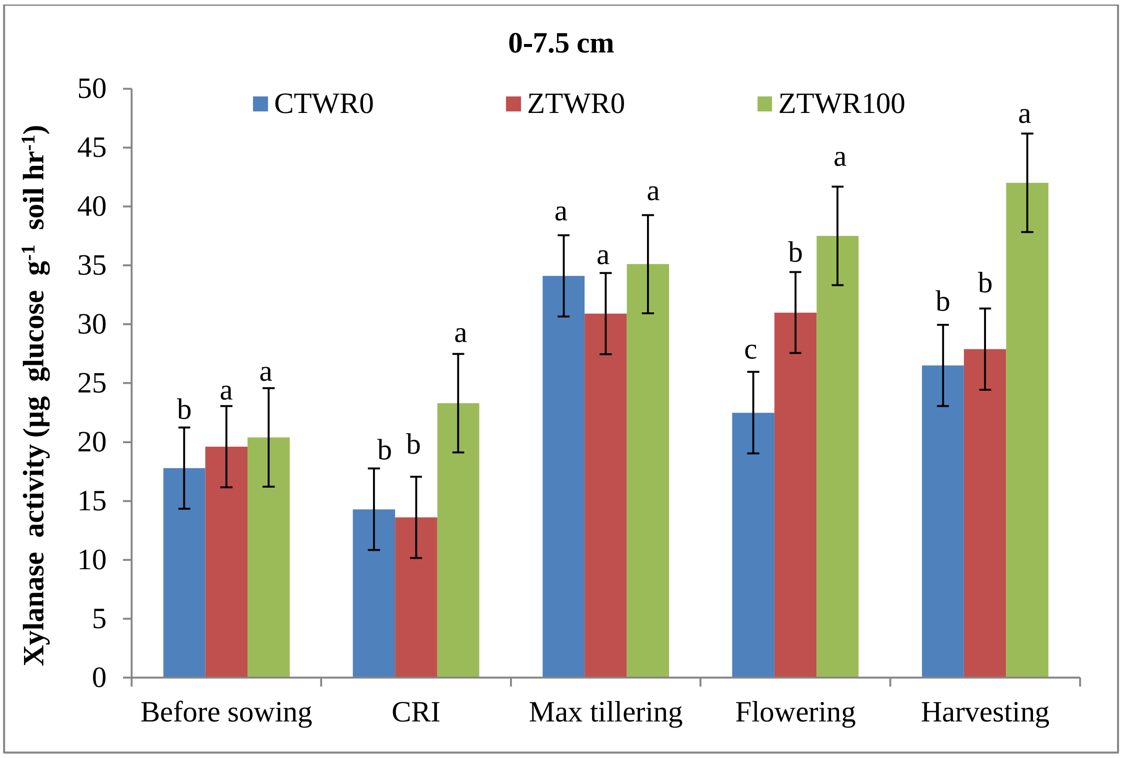


Fig. 4.16: **Xylanase activity in soil (µg glucose g^{-1} hr^{-1}) during different growth stages of wheat in surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at $p<0.05$). Columns with same latter are not significantly different ($p<0.05$).**

tillering. The interaction between different wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was significant at flowering and harvesting stage in the surface layer. At flowering stage, PTR_{w25}+GM/ZTW_{R100} exhibits maximum xylanase activity as compared with PTR_{w25}+GM/ZTW_{R0} and PTR_{w25}+GM/CTW_{R0}. Under PTR_{w0}+GM, ZTW_{R100} produced significantly higher xylanase activity as compared with ZTW_{R0} which was further reduced significantly under CTW_{R0}. At this stage, xylanase activity under PTR_{w25}+GM/ZTW_{R100} was 1.6 times higher than PTR_{w0}/CTW_{R0}. Similarly, at harvesting stage, under PTR_{W25}, PTR_{w0}+GM and PTR_{w25}+GM main treatments, ZTW_{R100} sub treatment produced significantly higher xylanase activity as compared with ZTW_{R0} and CTW_{R0}. At this stage, xylanase activity under PTR_{w25}+GM/ZTW_{R100} was 2.6 times higher than PTR_{w0}/CTW_{R0}. Maximum xylanase activity was recorded at maximum tillering stage followed by harvesting stage and lowest at CRI stage due to higher root exudation and biomass at maximum tillering stage. Xylanases (4-xylanhydrolase, E.C. 3.2.1.8) are the group of enzymes that catalyse hydrolysis of xylan (hemicelluloses) to xylooligosaccharide (Prade 1996). Xylanase is an extracellular enzyme, which is produced and released to a great extent by saprophytic fungi in the aerobic environment. Xylanase activity is mainly influenced by the quality and quantity of the residues and the amount of below-ground plant biomass. Previous findings by Kandeler and Bohm (1996) suggest that xylanase activity is significantly affected by tillage practices. Minimum tillage and reduced tillage significantly increased activity of the enzyme than conventional tillage as intensive tillage practices decrease organic matter content in coarse fraction (>200 µm) of soil, which is possibly the reason for decrease of xylanase activity under conventional tillage. Espana *et al* (2011) suggested that xylanase activity increase with addition of soybean residue as compared to maize residue. Mangalassery *et al* (2015) reported 38% higher xylanase activity under zero tillage as compared with conventional tillage after 7 year under wheat-rapeseed cropping system. Lesser disturbance of soil under zero tillage creates a less oxidative environment. This is possibly the reason for greater stability of extracellular soil enzyme such as xylanase under zero tillage (Melero *et al* 2009).

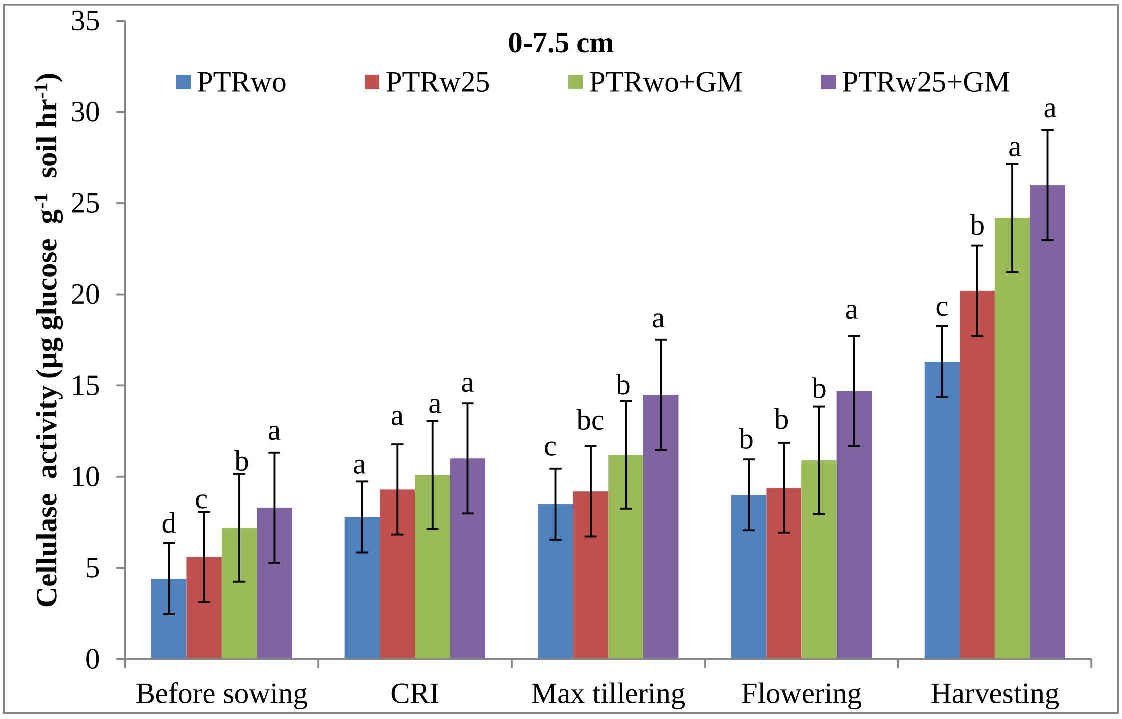
4.1.10 Cellulase activity

Wheat straw and green manure practices in rice, irrespective of tillage and rice straw management practices in subsequent wheat, significantly affected cellulase activity at sowing, maximum tillering, flowering and harvesting stage in the surface soil layer (Fig 4.17) and at maximum tillering and harvesting stage in the sub-surface soil layer (Fig 4.18). Likewise, the effect of tillage and rice straw management practices in subsequent wheat on cellulase activity, irrespective of different wheat straw and green manure practices in rice was significant at all the growth stages of wheat in both the soil layer. Cellulase activity in soil is recognized as essential regulators to control SOC decomposition (Sinsabaugh 1994, Grandy *et al* 2009), which breaks cellulose down to cellobiose, fructose and glucose (Wickings *et al* 2012). The interaction between different wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was significant at sowing and flowering stage in the surface soil layer and at maximum tillering stage in sub-surface soil layer. In the surface soil layer, at sowing and flowering stage maximum cellulase activity was observed under PTR_{W25}+GM/ZTW_{R100} treatment, which was significantly higher than PTR_{W25}+GM/ZTW_{R0} and PTR_{W25}+GM/CTW_{R0}. At sowing, cellulase activity under PTR_{W25}+GM/ZTW_{R100} treatment was 3 times higher than PTR_{W0}/CTW_{R0} treatment. Similarly, at flowering stage, cellulase activity under PTR_{W25}+GM/ZTW_{R100} was 3.1 times higher than PTR_{W0}/CTW_{R0}. At maximum tillering stage, in the sub-surface soil layer, under $PTR_{W0,}$ PTR_{W25} and PTR_{W25}+GM main treatments, ZTW_{R100} sub treatment produced higher cellualse activity than ZTW_{R0} and CTW_{R0}. At this stage, cellulase activity under PTR_{W25}+GM/ZTW_{R100} treatment was 3.1 time higher than PTR_{W0}/CTW_{R0} treatment. Among different tillage and rice straw management practices, ZTW_{R100} significantly improved cellulase activity in soil. This was probably because rice straws are lignocellulosic materials which are degraded by cellulases resulting in the production of reducing sugars as the end products. Cellulases play a major role in the initial phases of decomposition of organic C compounds and degrade cellulolytic material. The stimulation of cellulase enzyme activity probably increased the decomposition of SOM and input of C through crop residues could have led to net increase in SOC stocks. The results of this study showing greater cellulase activity under zero tillage supports the previous finding of Balota *et al* (2004). They observed 90% higher cellulase activity under no-tillage than conventional tillage. Increase of cellulase activity under no-tillage is possibly because of increase in fungal population due to less soil disturbance, as fungi is the main source of this enzyme in soil (Deng and Tabatabai 1996a). Celluase activity under ZTW_{R100} continuously increases from sowing to harvesting stage (3.4 fold in surface soil layer and 3.19 fold in sub-surface soil layer). Li *et al* (2016) observed that cellulase activity was significantly higher under straw application than application of mineral fertilizer at maturity stage of wheat. Ou *et al* (2010) also reported that soil respiration and cellulose decomposition rates were lower at tillering, booting, and grain-filling stages but higher at maturity stage under NT as compared CT in paddy soil.

4.1.11 Polyphenol oxidase activity

In the surface soil layer polyphenol oxidase activity was significantly affected by wheat straw and green manure practices in rice at all the growth stages of fifth wheat crop except at CRI stage (Fig 4.19). Similarly, tillage and rice straw management practices in

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

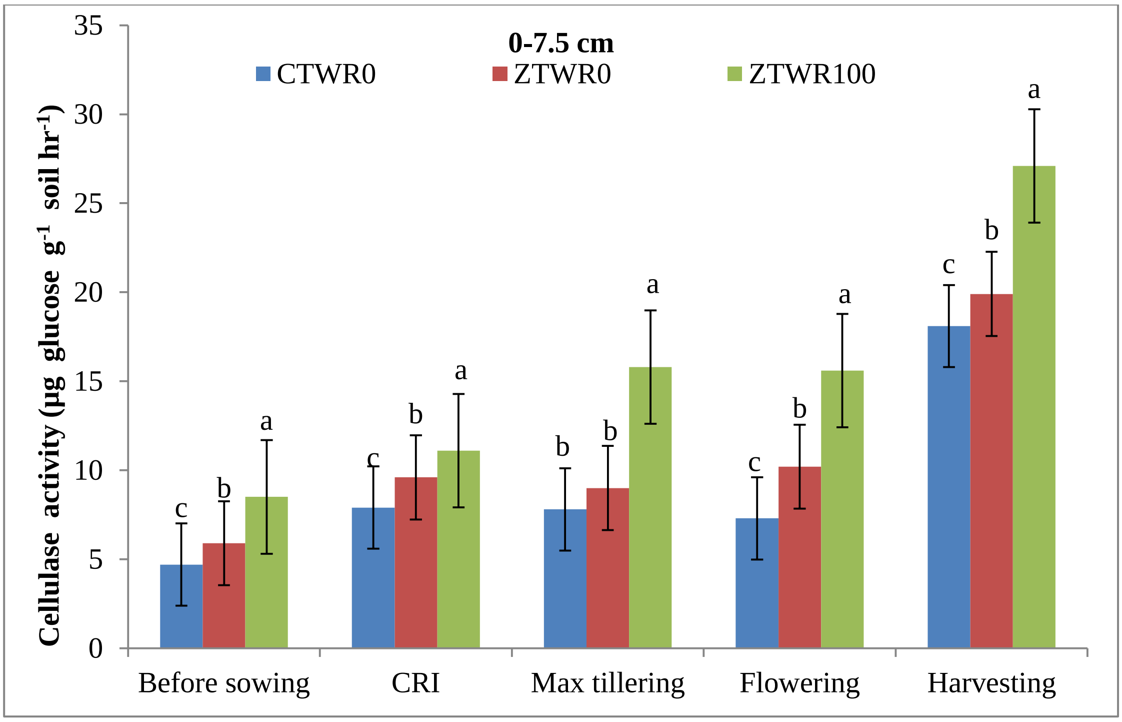
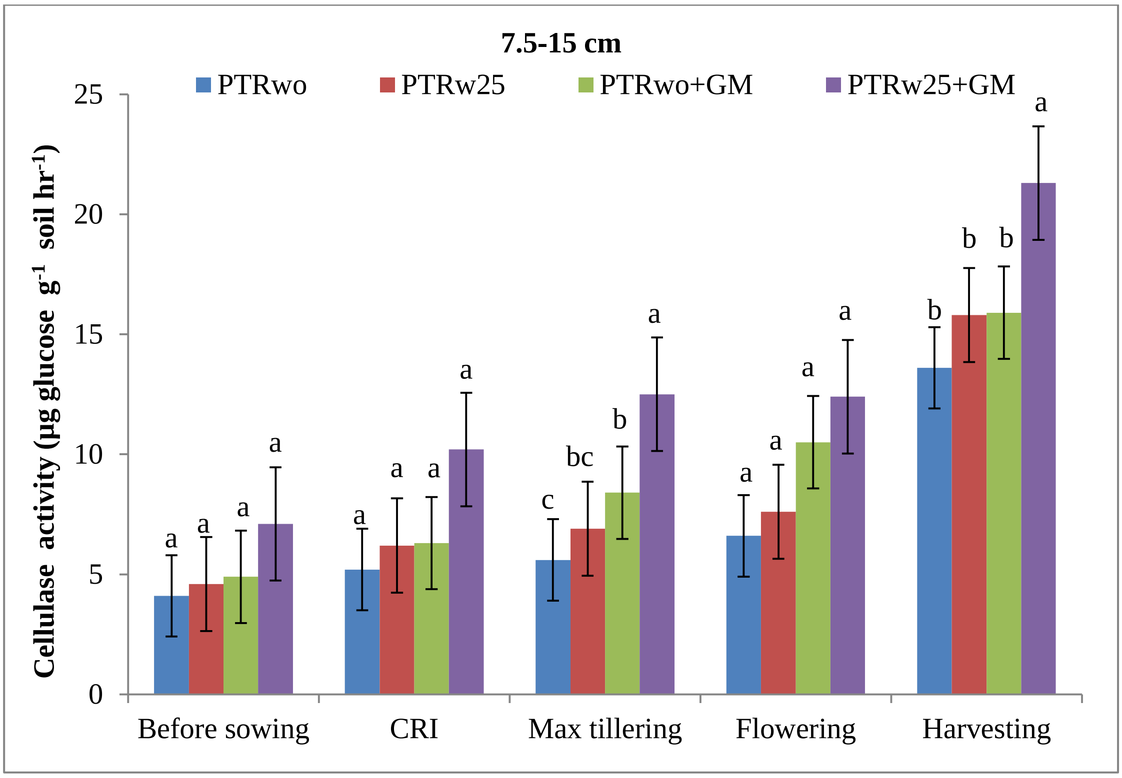


Fig. 4.17: Cellulase activity in soil (µg glucose g^{-1} hr^{-1}) during different growth stages of wheat in surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at $p<0.05$). Columns with same latter are not significantly different ($p<0.05$).

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

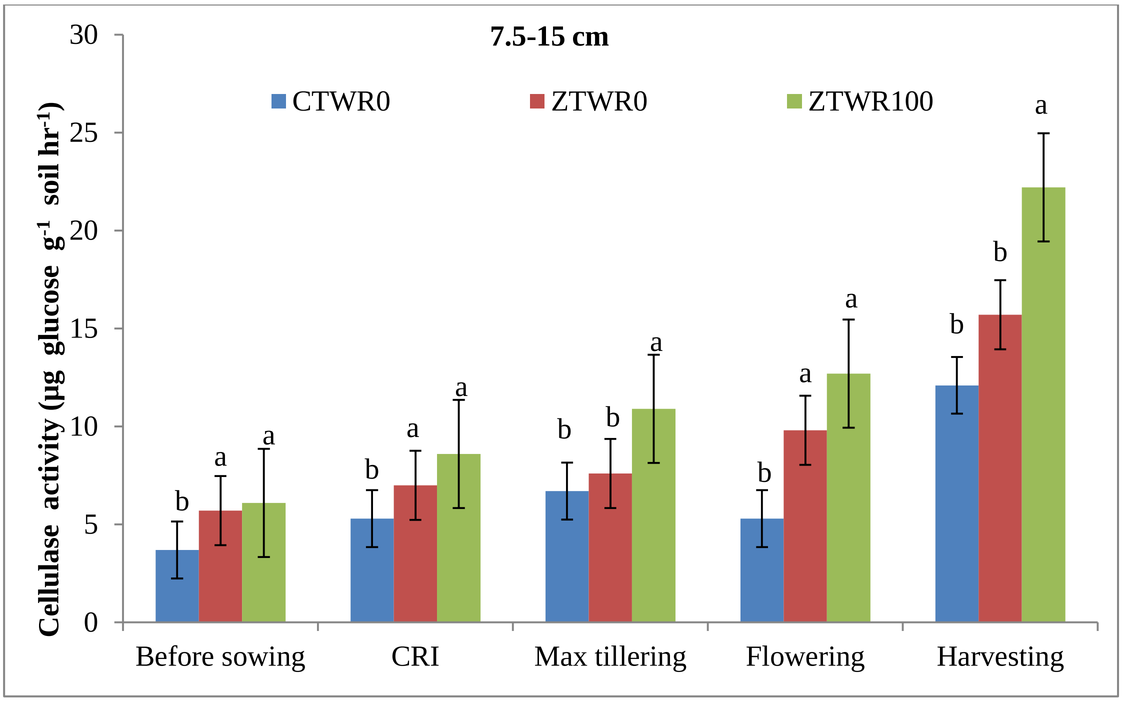
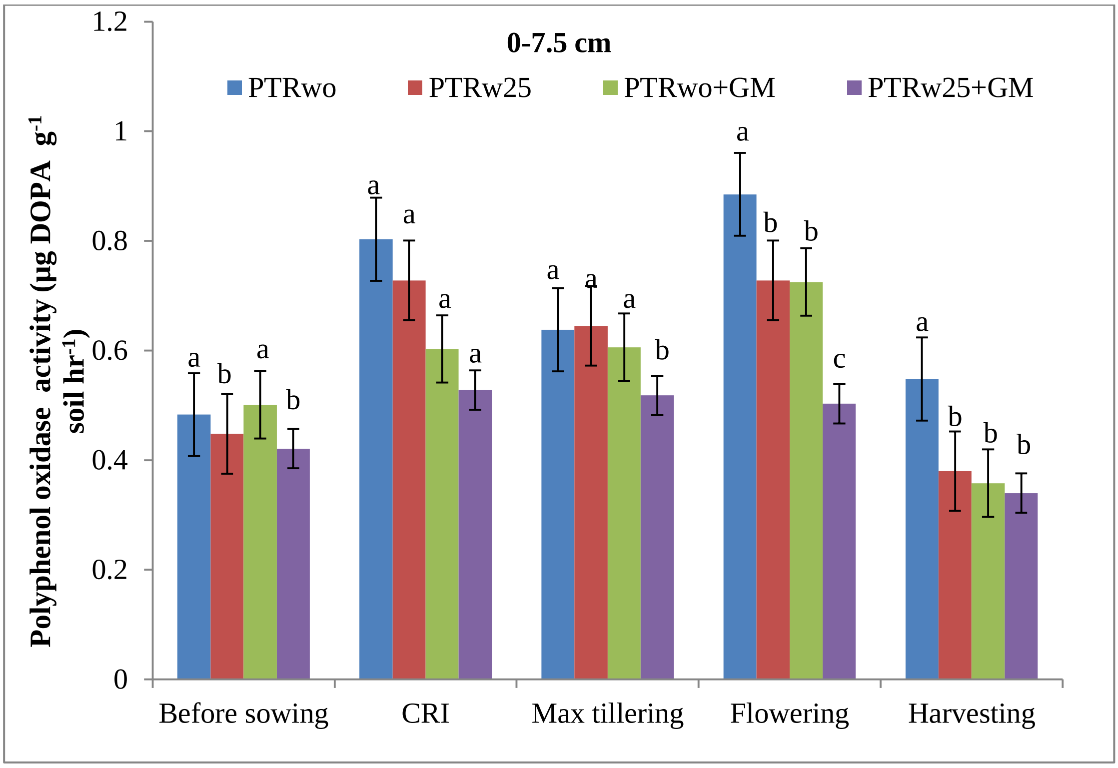


Fig. 4.18: Cellulase activity in soil (µg glucose g^{-1} hr^{-1}) during different growth stages of wheat in sub-surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at $p<0.05$). Columns with same latter are not significantly different ($p<0.05$).

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

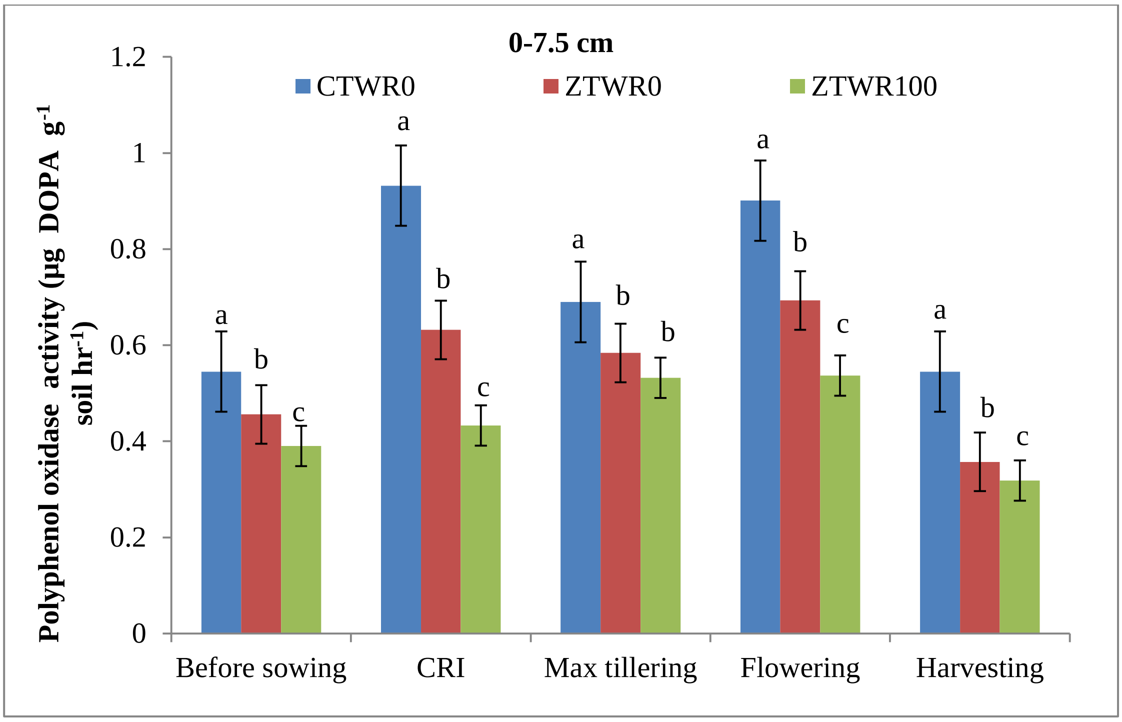


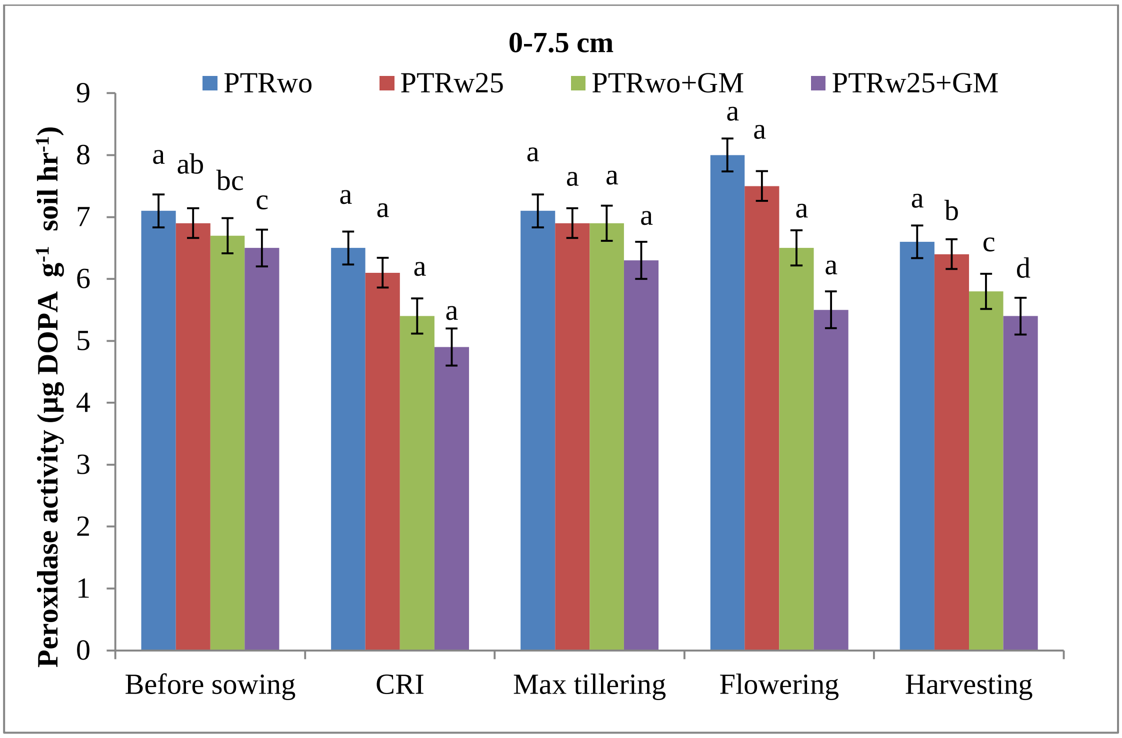
Fig. 4.19: Polyphenol oxidase activity (µg DOPA g^{-1} soil hr^{-1}) during different growth stages of wheat in surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at $p<0.05$). Columns with same latter are not significantly different ($p<0.05$).

subsequent wheat, irrespective of different wheat straw and green manure practices in rice significantly affected polyphenol oxidase activity at all the growth stages of wheat in the surface soil layer. Soil phenol oxidase is proposed as an ‘enzymatic latch’ to protect SOC by phenolic-containing organics in oxygen-restricted ecosystems (Freeman *et al* 2001). Because low phenol oxidase activity is conducive for the accumulation of soluble phenolics and inhibits the activity of hydrolytic enzymes, thus benefits soil carbon sequestration (Zibilske and Bradford 2007, Sinsabaugh 2010). These enzymes include fungal laccases and prokaryotic laccase-like enzymes that typically have multiple copper (Cu) atoms at the reaction center (Baldrian 2006, Hoegger *et al* 2006). The potential phenol oxidase activity in soils is typically measured as the rate of oxidation of a model substrate added to soil suspensions (German *et al* 2011, Burns *et al* 2013). The interaction between different wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was significant at flowering and harvesting stage. At these stages, maximum polyphenol oxidase activity was observed under PTR_{W0}/CTW_{R0}. Under all wheat straw and green manure practices in rice, CTW_{R0} exhibited significantly higher polyphenol oxidase activity than ZTW_{R0} and ZTW_{R100}. PTR_{W0} produced higher activity of polyphenol oxidase than other treatments. At flowering and harvesting stage, PTR_{W0}/CTW_{R0} produced 2.6 and 3.5 times higher polyphenol oxidase activity than PTR_{W25}+GM/ZTW_{R100}. Activity of polyphenol oxidase was highest at flowering stage followed by crown root initiation and least value was observed at harvesting stage. Melero *et al* (2009) observed higher activity of polyphenol oxidase under traditional tillage than no-tillage after 3 year in a wheat-sunflower-pea cropping system. Pandey *et al* (2014) observed significantly higher polyphenol oxidase activity under conventional tillage than no-tillage in a rice-wheat system. This is likely due to highly aerobic conditions prevail in conventionally tilled soil than no-tilled soil, which provides favourable condition for expression of this enzyme. Polyphenol oxidase activity is inversely related to amount of soil organic matter (Sinsabaugh *et al* 2008).

4.1.12 Peroxidase activity

In the surface soil layer peroxidase activity was significantly affected by wheat straw and green manure practices in rice at sowing and harvesting stages of wheat (Fig 4.20). Tillage and rice straw management practices in wheat, irrespective of different wheat straw and green manure practices in rice, significantly affected peroxidase activity at all the growth stages of wheat in the surface soil layer. Peroxidase, an extracellular enzyme produced by bacteria, fungi, plants and animals (Passardi *et al* 2007). It is an oxidative enzyme, which utilizes H_2O_2 as final electron acceptor and act as catalysts for biological reactions (Martinez 2002, Passardi *et al* 2007). Peroxidase activity is measured as the rate of substrate oxidation in the presence of added H_2O_2 (Burns *et al* 2013). It is involved in the degradation of lignin,

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

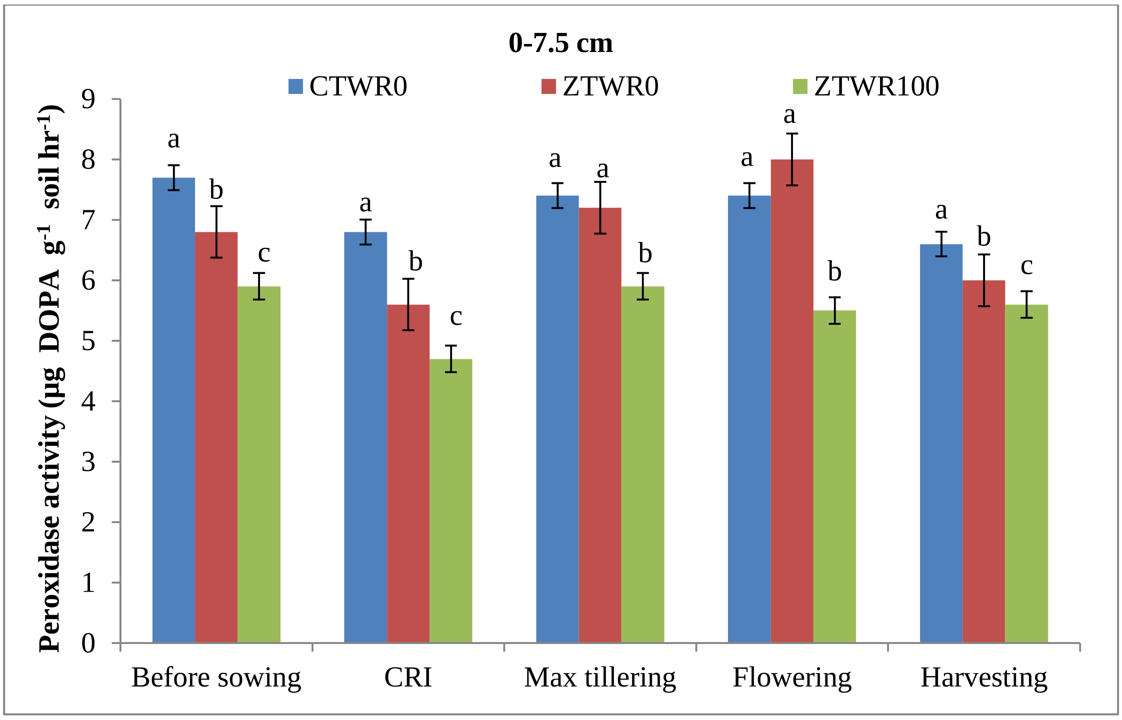


Fig. 4.20: Peroxidase activity (µg DOPA g^{-1} soil hr^{-1}) during different growth stages of wheat in surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at $p<0.05$). Columns with same latter are not significantly different ($p<0.05$).

removal of hydrogen peroxide within the cell and oxidation of toxic substances (O'Brien 2000, Erman and Vitello 2002). The interaction between different wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was significant at sowing and flowering stage. At sowing, maximum peroxidase activity was observed under PTR_{W0}/CTW_{R0}, which was 1.5 times higher than PTR_{W25}+GM/ZTW_{R100}. Similarly, at flowering stage PTR_{W0}/ZTW_{R0} produced the maximum value of peroxidase activity, which was 1.7 times higher than PTR_{W25}+GM/ZTW_{R100}. Under different wheat straw and green manure practices in rice, PTR_{W0} produced significantly higher peroxidase activity as compared to the treatments with green manure and residue retention (PTR_{W0}+GM and PTR_{W25}+GM). Similarly, conventional tilled soil (CTW_{R0}) produced higher peroxidase activity than zero tilled soil (ZTW_{R0} and ZTW_{R100} treatments). Peroxidase activity was maximum at flowering stage of wheat growth followed by maximum tillering stage and lowest value was observed at CRI stage. Our results are consistent with Chu *et al* (2016), reported increase of peroxidase activity under conventional tillage than no tilled plot. Soil with high oxygen availability stimulates the activity of peroxidase enzyme, which leads to lower accumulation of SOM. This may be a possible reason for increase of peroxidase activity under conventional tillage practices. Sinsabaugh (2010) and Li *et al* (2015) also showed that peroxidase and phenol oxidase activities increased with the loss of SOC, which was in agreement with our finding that the peroxidase and phenol oxidase activities were higher under conventional tillage practices than treatments with green manure and residue retention, and they had a significantly negative correlation with SOC.

4.1.13 Total polysaccharide carbon

Total polysaccharide carbon (TPC) content in soil was significantly affected by wheat straw and green manure practices in rice at flowering stage in the surface soil layer (Fig 4.21) and at CRI and maximum tillering stage of wheat in the sub-surface soil layer (Fig 4.22). Whereas, tillage and rice straw management practices in subsequent wheat, irrespective of different wheat straw and green manure practices in rice significantly affected TPC content at CRI stage of wheat in surface soil layer and at sowing, CRI and maximum tillering stage in the sub-surface soil layer. Polysaccharides are of plant or microbial origin, it accounts for a considerable part of the labile carbon pool and are important binding agent necessary for stabilizing soil aggregates (Jolivet *et al* 2006). The interaction between different wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was significant at CRI and maximum tillering stage of wheat only in the sub-surface soil layer. At both the stages, PTR_{W25}+GM/ZTW_{R100} exhibits maximum TPC content in soil. At CRI and maximum tillering stage, total polysaccharide carbon under PTR_{W25}+GM/ZTW_{R100}

was 3.4 and 2.6 times higher than $PTR_{W0}/CTW_{R0.}$ Among different wheat straw and green manure practices, TPC content was significantly higher under PTR_{W0}+GM and PTR_{W25}+GM than other treatments. Among different tillage and rice straw management practices in wheat, ZTW_{R100} and ZTW_{R0} produced significantly higher TPC content in soil as compared with conventional tillage (CTW_{R0}). TPC content in soil was maximum at flowering stage followed by harvesting stage in surface soil layer and at CRI followed by flowering stage in sub-surface layer. Total polysaccharide content in soil responds to changes in land use or management practices (such as tillage and residue management) because of its labile nature. Martin *et al* (2009) illustrated that soil cropped with maize under no-tillage in a tropical climate exhibits higher dilute acid extractable polysaccharide content, which constitutes about 86-94% of total polysaccharide in aggregates with diameter of 6.30–2.00 mm. Yuan *et al* (2012) reported that intensive tillage practices enhanced the degradation of labile form of SOM, which reduce the microbial population in soil. This might be a reason for reduction of microbial polysaccharide production under conventional tillage practices. They also concluded that higher total polysaccharide content under zero tilled soil may be attributed to its higher aggregate stability. Sandeep *et al* (2016) observed that conservation tillage practices preserved more total polysaccharides in soil as compared with conventional tillage practices in a maize-wheat cropping system.

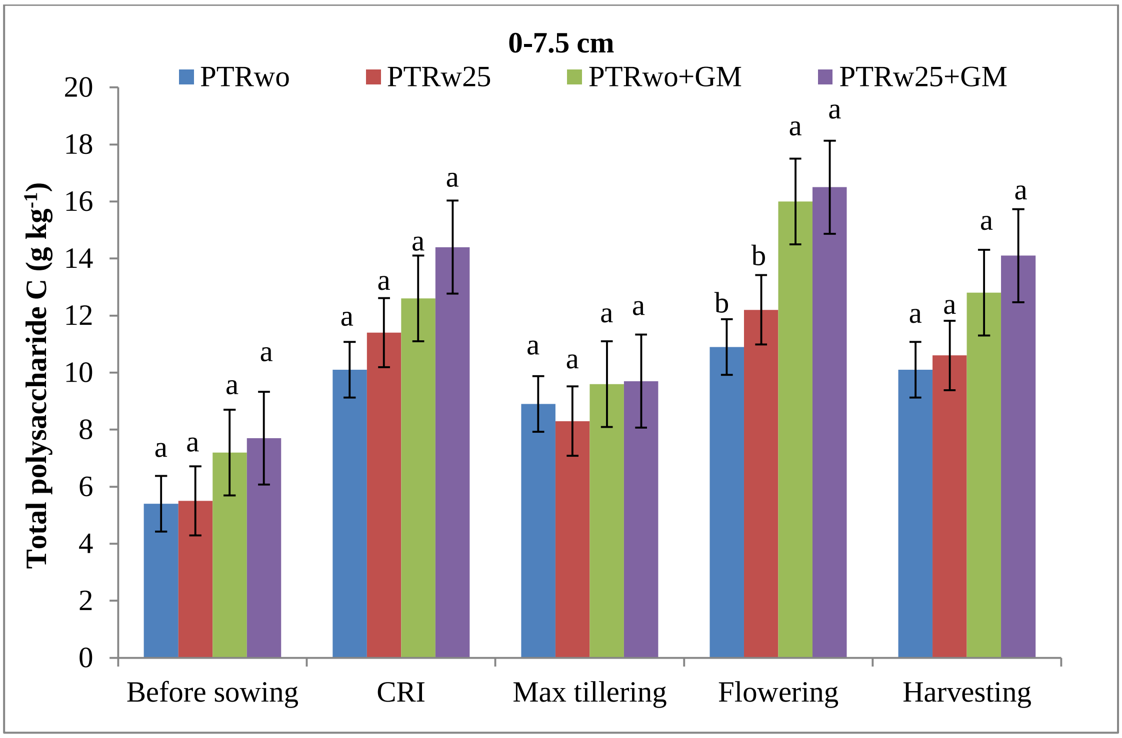
4.1.14 Total carbohydrate carbon

During fifth wheat crop of rice-wheat cycle, significant effect of wheat straw and green manure practices in rice on total soil carbohydrate carbon (TCHO) content was observed at all growth stages of wheat in both the soil layer, except before sowing in the surface layer (Fig 4.24) and harvesting stage in the sub-surface layer (Fig 4.23). Tillage and rice straw management practices in subsequent wheat significantly affected TCHO content in soil at sowing, CRI, maximum tillering and flowering stage of wheat in surface soil layer and at sowing and CRI stage in the sub-surface soil layer. Soil carbohydrates are crucial part of intermediate labile C pool which is strongly influenced by management practices. It constitutes about 5-25% of SOM (Schmitt and Glaser 2011). Due to fast turnover rates of soil carbohydrates, any changes in C input to the soil can easily influences its content in soil. The interaction between different wheat straw and green manure practices in rice and tillage and rice straw management practices in subsequent wheat was not significant at all the growth stages of wheat in both the soil layer. Higher TCHO in soil was observed at CRI stage followed by flowering stage in surface soil layer, whereas, maximum total carbohydrate content was observed at flowering stage of wheat growth in the sub surface soil layer. At CRI stage, total carbohydrate content under ZTW_{R100} was 21.2% and 27.4% higher as compared with ZTW_{R0} and CTW_{R0}, respectively in the surface soil layer. Similarly, TCHO content under ZTW_{R100} was 7% and 9.1% higher at flowering stage as compared with ZTW_{R0} and CTW_{R0}, respectively in the sub-surface soil layer. Arshad *et al* (1999) reported 21% greater carbohydrate concentration in a sandy loam soil under no-tillage than conventional tillage. Soil organic C decomposition is restricted under no tilled soil as SOC is protected within macroaggregates (Franzluebbers and Arshad 1997), which is likely be the reason for grater carbohydrate content under zero tillage than conventional tillage. Hazarika *et al* (2009) observed that reduced tillage practices such as chisel plough or no till along with straw incorporation increased the abundance of soil carbohydrates for microorganisms. They also reported negative correlation of hot water soluble carbohydrate with bulk density but positive correlation with MBC, β-glucosidase and acid phosphatase enzyme. Hue *et al* (1997) also observed that soil carbohydrate content can be increased by alteration of conventional tillage practices to reduced tillage practices. TCHO content was higher in the surface soil layer than the sub-surface soil layer. Decrease of carbohydrate content in sub-surface soil layer might be related to the decrease in amount of organic matter in the sub-surface soil layer.

4.1.15 Total and easily extractable glomalin related soil protein

During fifth wheat crop of rice-wheat cycle, wheat straw and green manure practices in rice, irrespective of tillage and rice straw management practices in subsequent wheat significantly affected easily extractable glomalin content (EEG) in the surface soil layer at sowing, CRI and flowering stages (Fig 4.25) of wheat growth and total glomalin (TG) content at CRI and flowering stage (Fig 4.26). Significant effect of tillage and rice straw management practices in subsequent wheat on EEG was observed at CRI, flowering and harvesting stage and for TG at sowing, CRI, flowering and harvesting stage of wheat growth. However, the interaction between different wheat straw and green manure practices in rice and tillage and rice straw management practices in subsequent wheat was not significant at all the growth stages of wheat in the surface soil layer. Glomalin, an insoluble N-linked glycoprotein with 37% C and 3-5 % N, contributed to C pools by slowing the decomposition speed of SOC in the soils (Lovelock *et al* 2004, Rillig 2004). TG and EEG content were significantly higher in PTR_{W0}+GM and PTR_{W25}+GM as compared with PTR_{W0} and PTR_{W25}. Similarly, TG and EEG content in soil were higher under ZTW_{R100} than ZTW_{R0} which was further reduced under CTW_{R0} at all the growth stages of wheat. Higher Glomalin content in ZT with residues

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

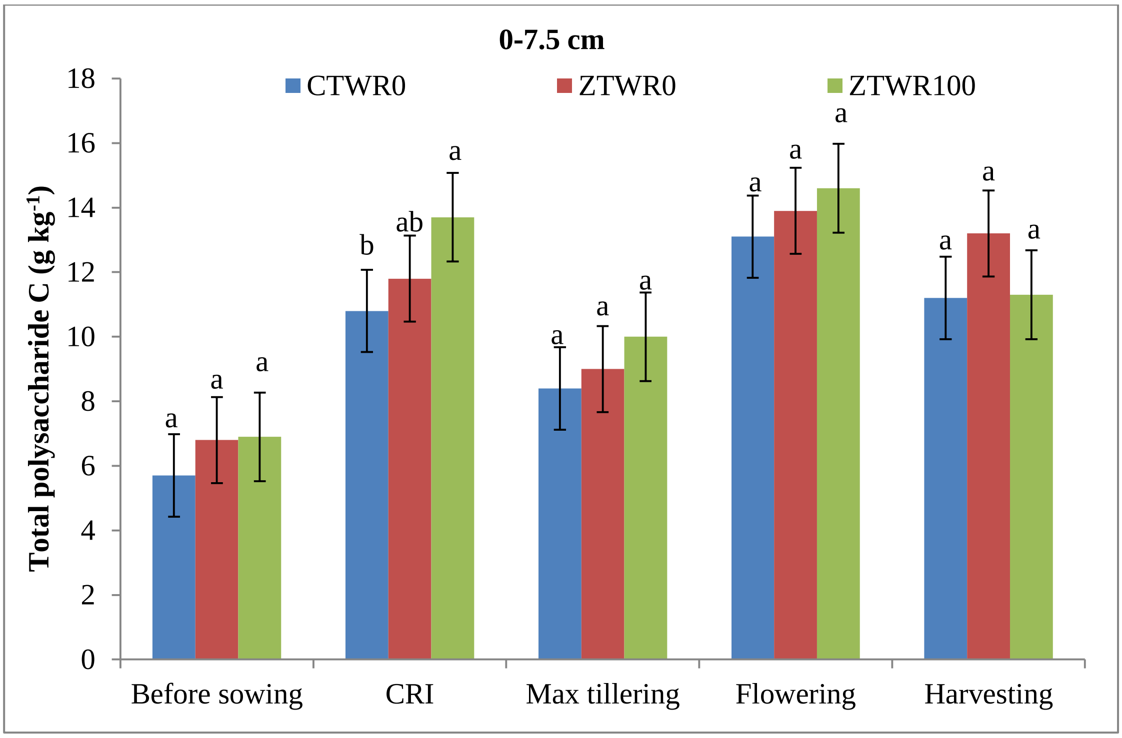
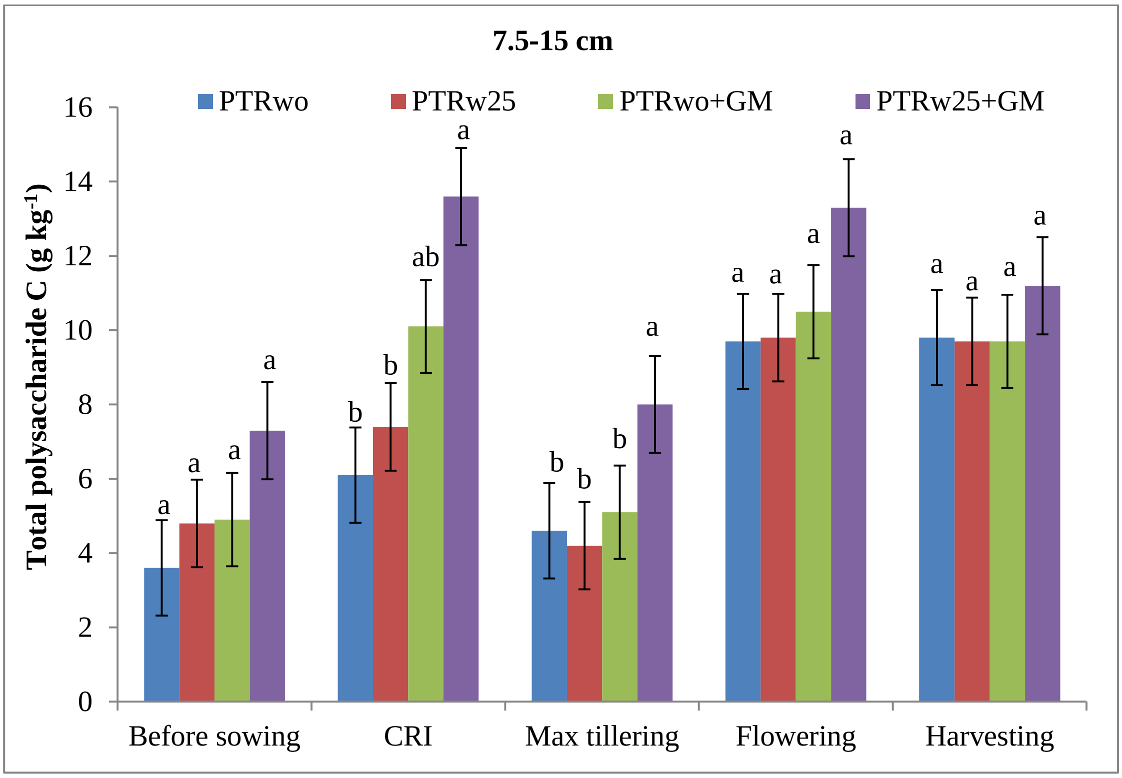


Fig. 4.21: Total polysaccharide carbon (g kg^{-1}) during different growth stages of wheat in surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at $p<0.05$). Columns with same latter are not significantly different ($p<0.05$).

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

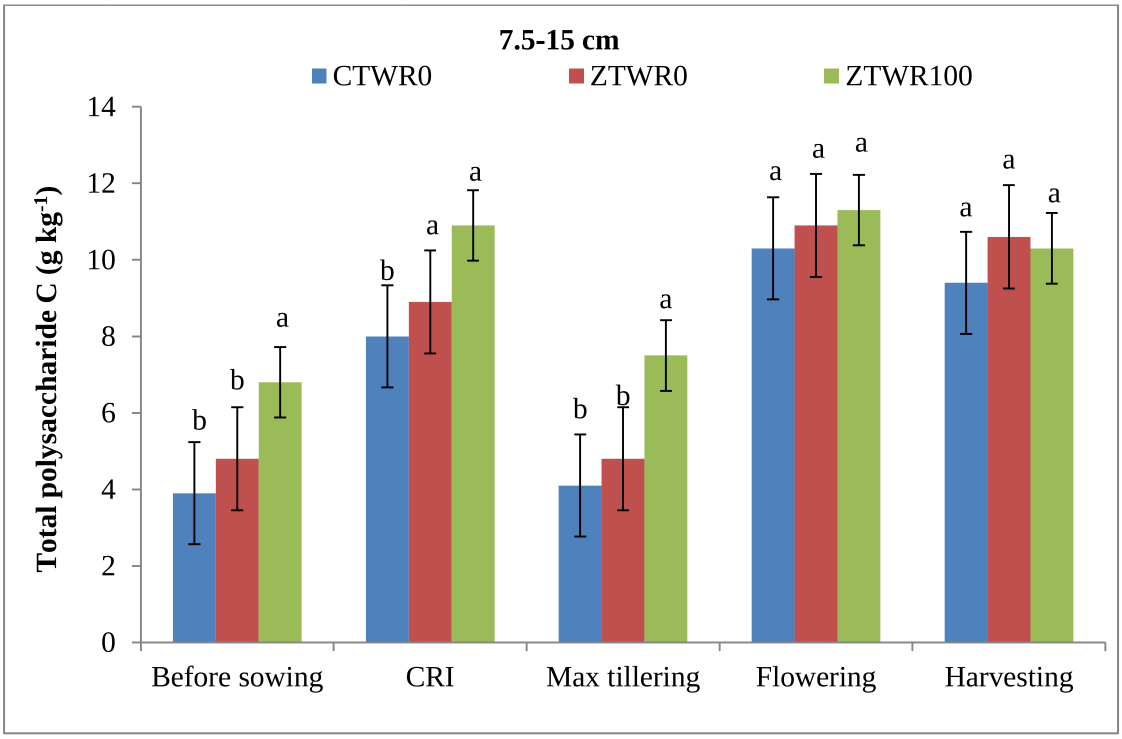
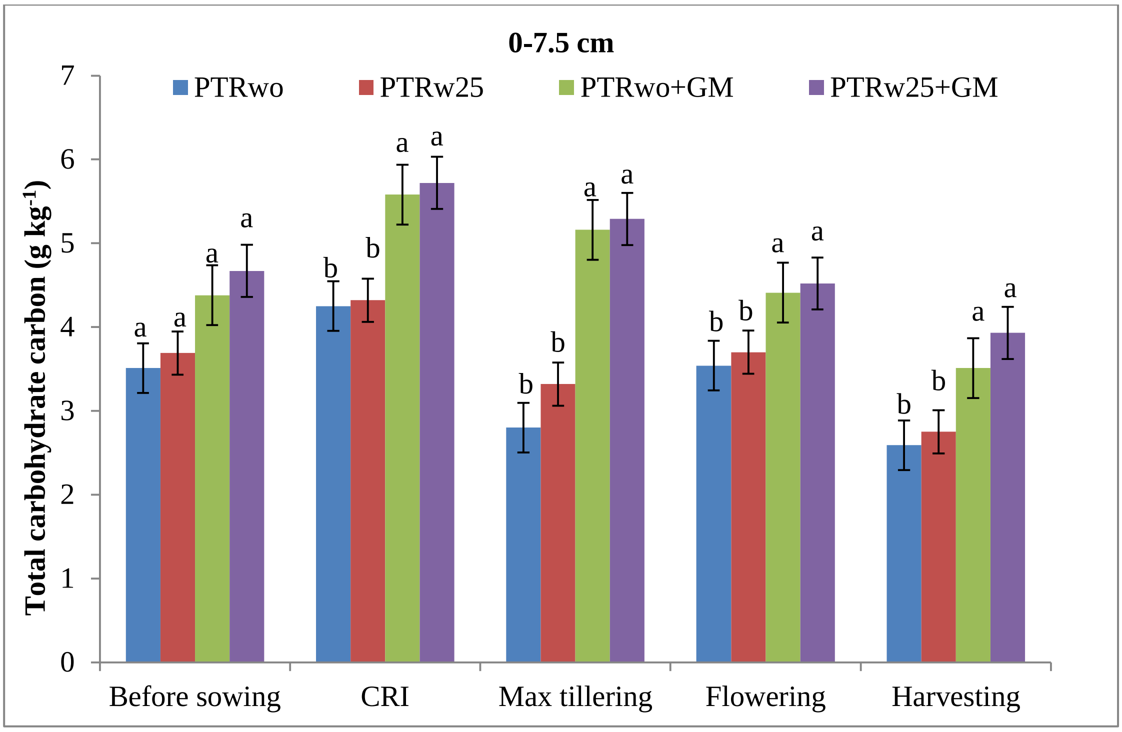


Fig. 4.22: Total polysaccharide carbon (g kg^{-1}) during different growth stages of wheat in sub-surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at p<0.05). Columns with same latter are not significantly different (p<0.05).

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

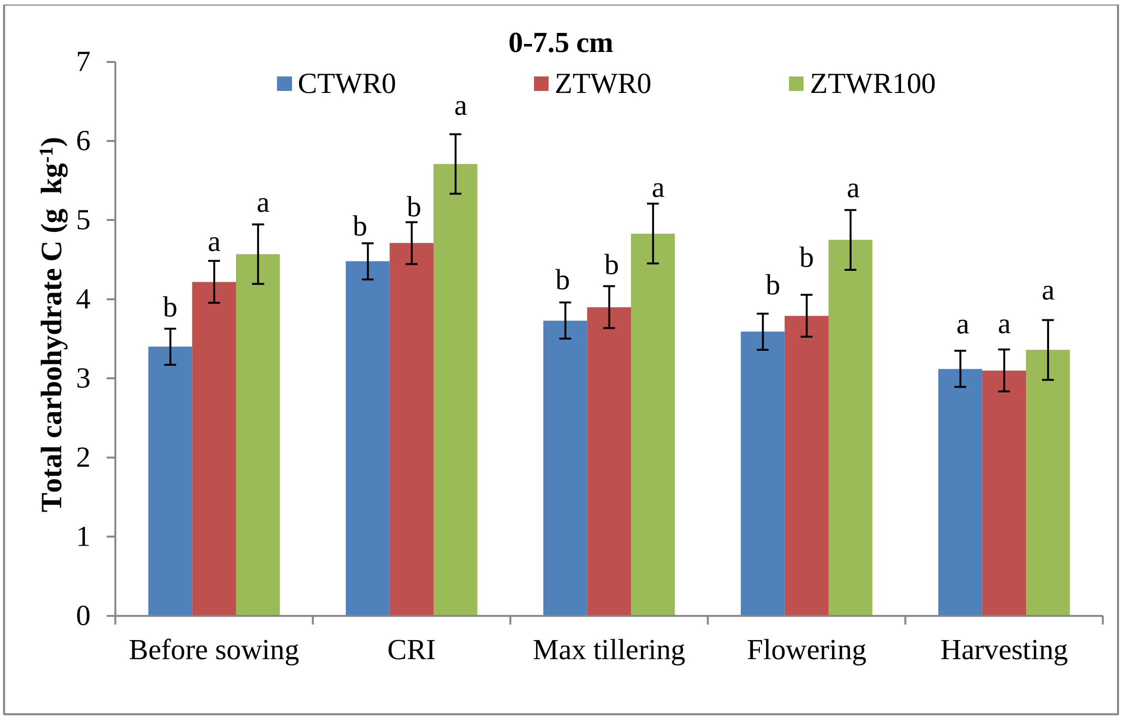
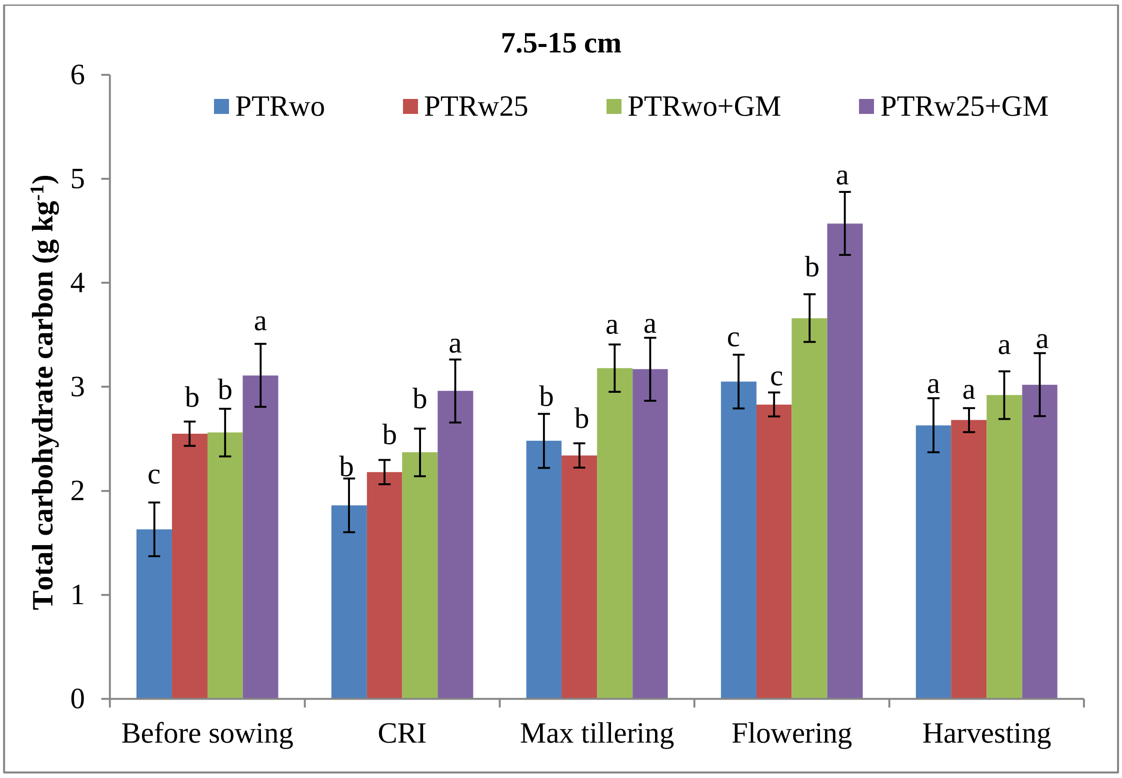


Fig. 4.23: **Total carbohydrate carbon (g kg^{-1}) during different growth stages of wheat in surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at $p<0.05$). Columns with same latter are not significantly different ($p<0.05$).**

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

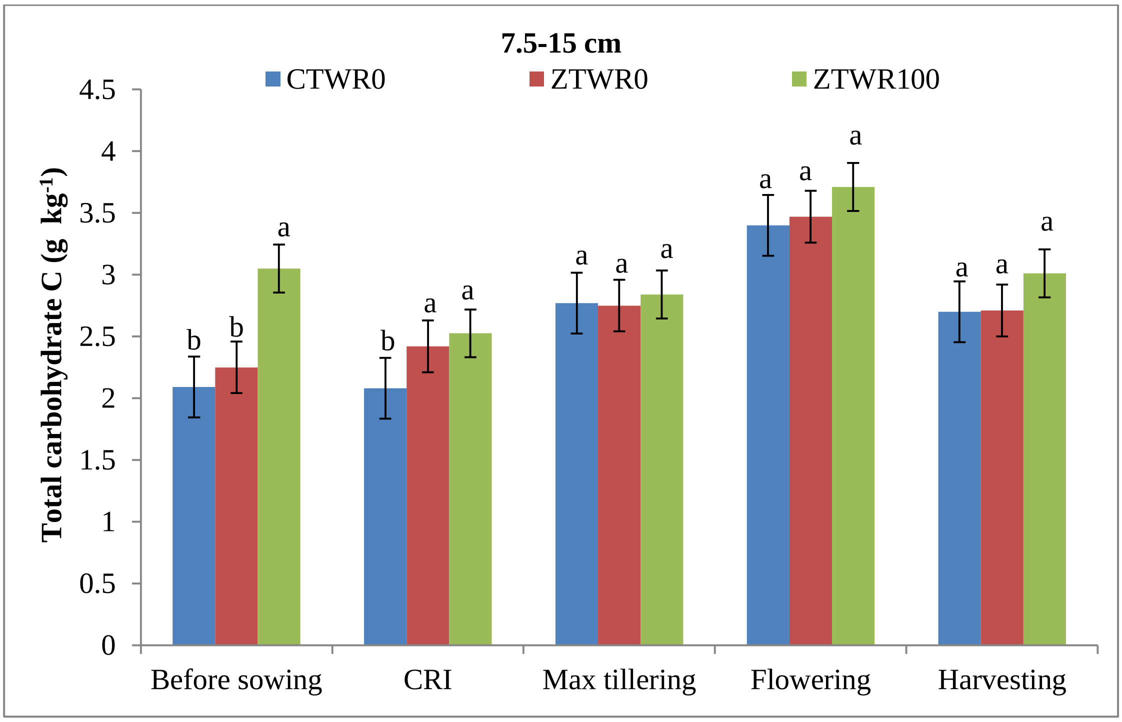
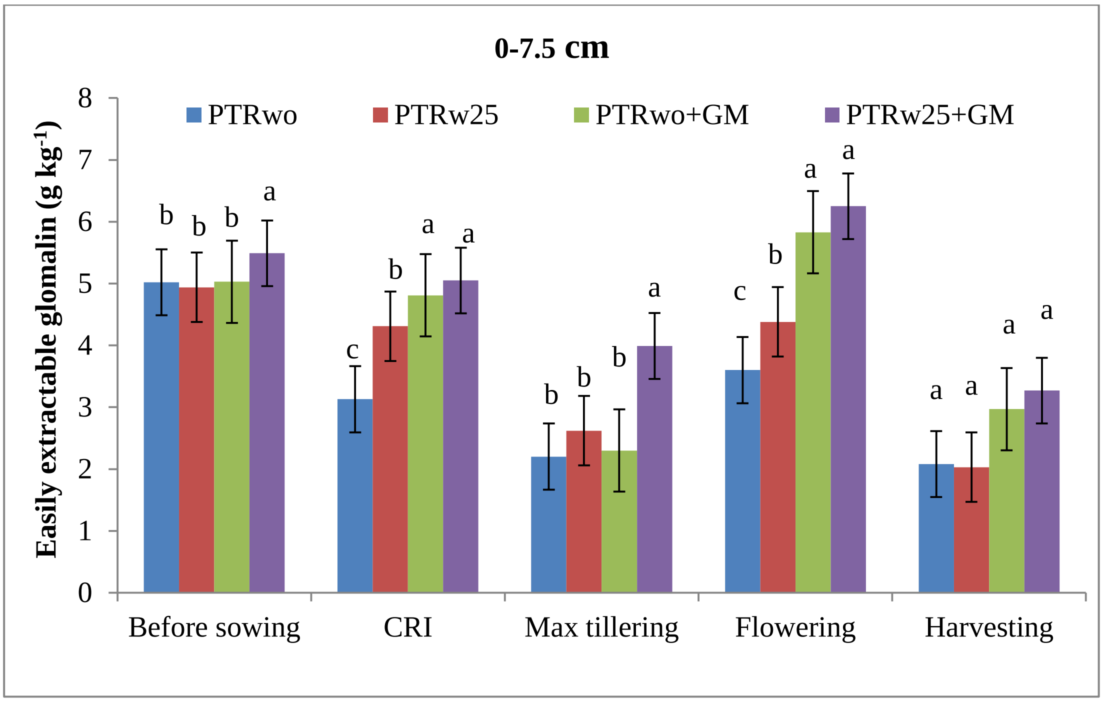


Fig. 4.24: Total carbohydrate carbon (g kg^{-1}) during different growth stages of wheat in sub-surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at p<0.05). Columns with same latter are not significantly different (p<0.05).

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

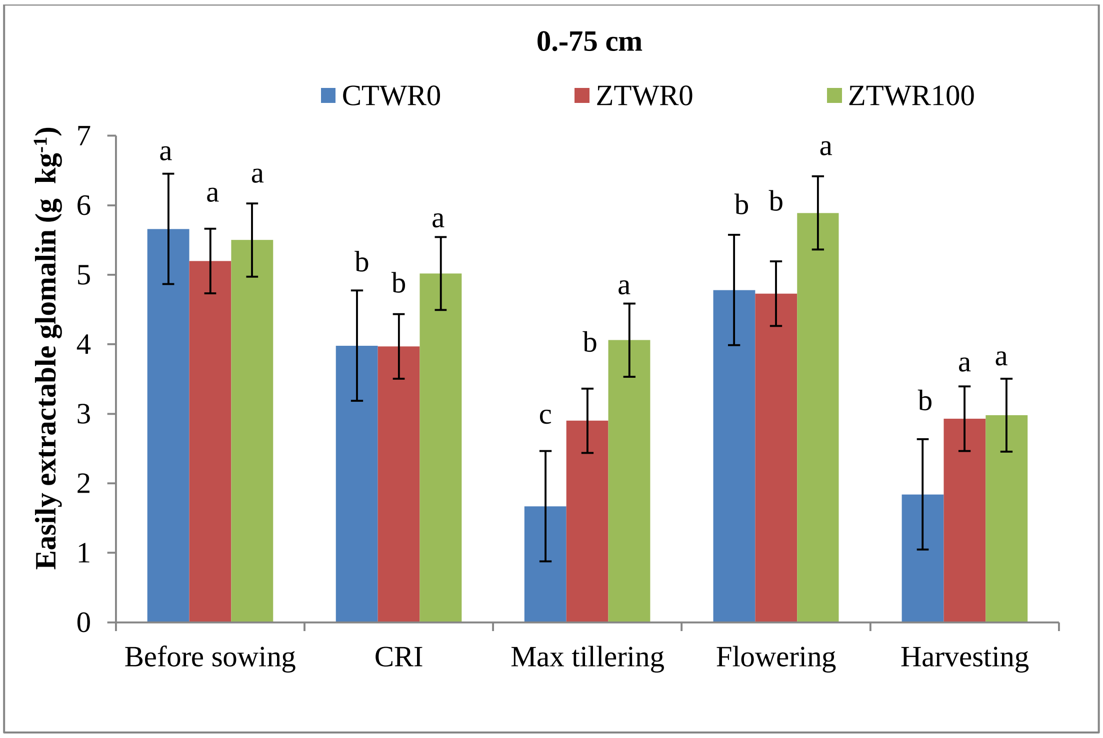
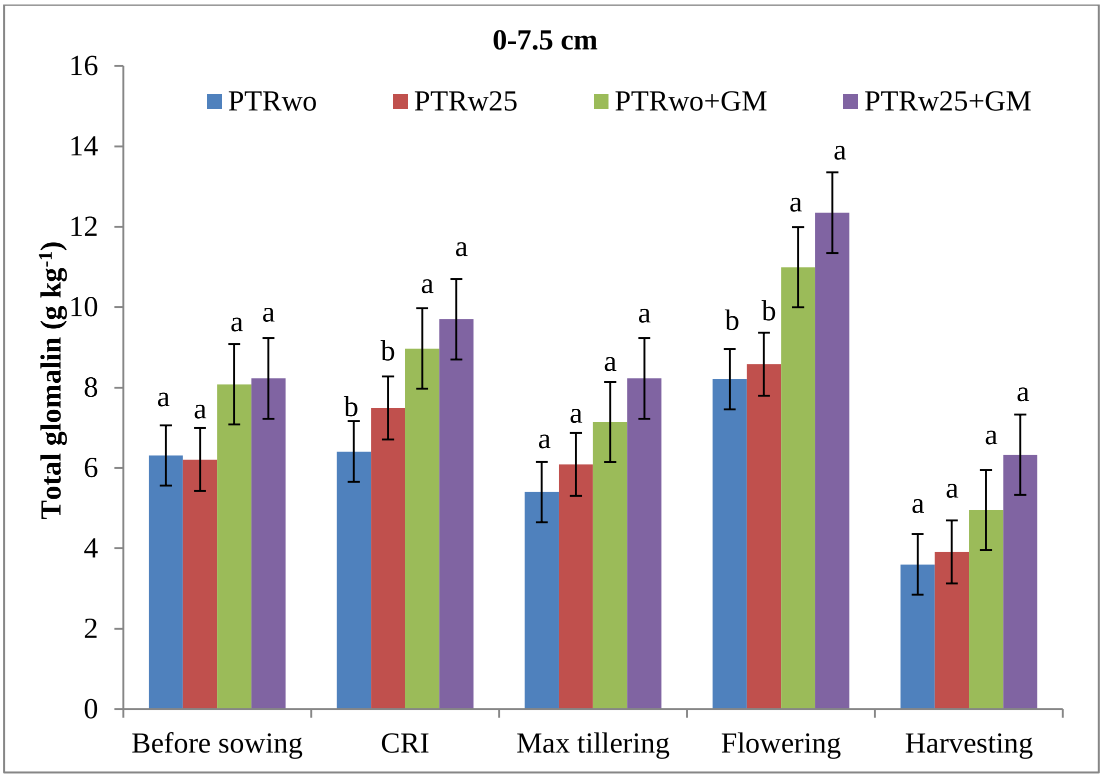


Fig. 4.25: Easily extractable glomalin content (g kg^{-1}) during different growth stages of wheat in surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at p<0.05). Columns with same latter are not significantly different (p<0.05).

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

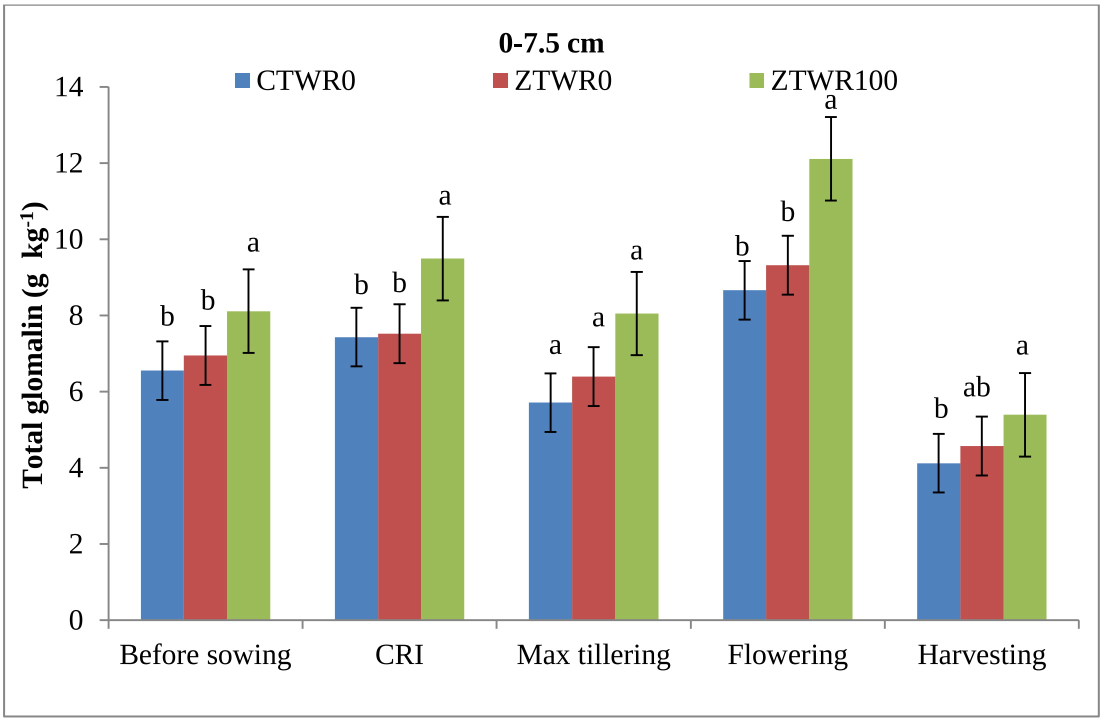


Fig. 4.26: Total glomalin content (g kg^{-1}) during different growth stages of wheat in surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at p<0.05). Columns with same latter are not significantly different (p<0.05).

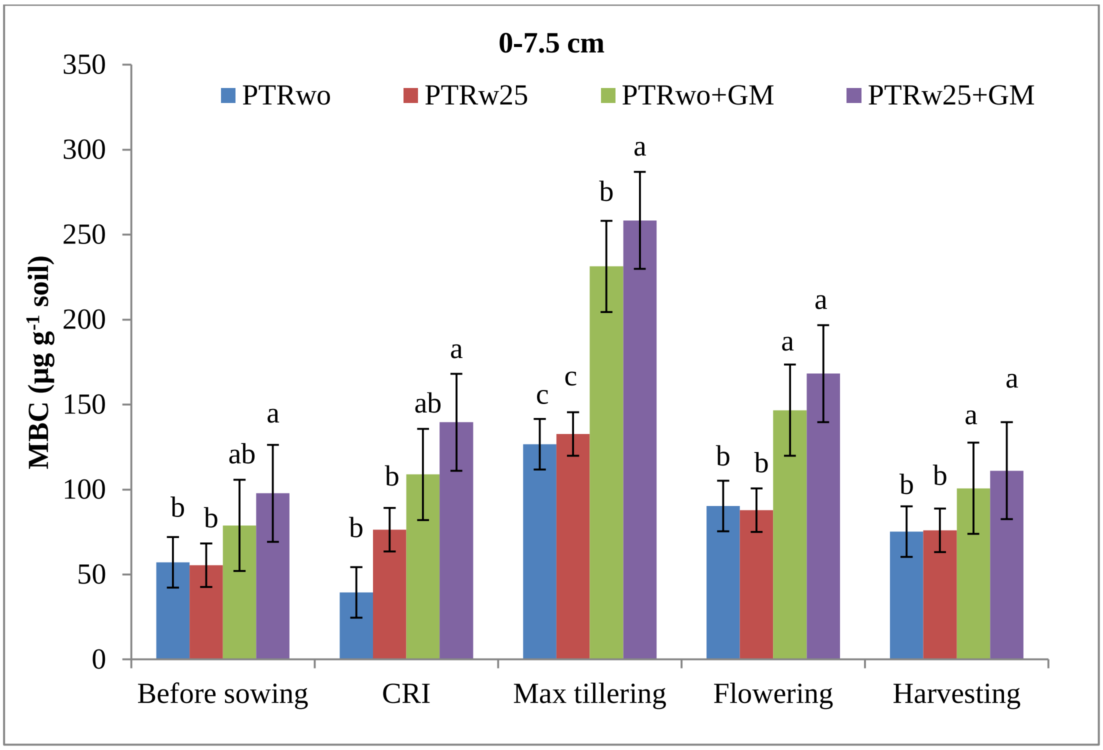
retention treatment is may be because of remarkable increase in organic matter, which represented a more stable Soil-C fraction than other Soil-C deriving from residues and fine root turnover (Rillig *et al* 2003). Maximum value of TG and EEG content in soil was recorded at flowering stage of wheat growth. Cornejo *et al* (2009) observed that tillage practices significantly influenced mycorrhizal activity, microbial diversity and glomalin production in soil. Sandeep *et al* (2016) reported significant increase of glomalin content in soil under bed planting system as compared with conventional tillage in a maize-wheat system. Curaqueo *et al* (2010) reported significant increase in content of TG and EEG under no tilled soil than conventional tilled soil; this may be related to less soil disturbance in no till system accounts for higher activity of arbuscular mycorrhizal hyphae in soil. Similar work by Curaqueo *et al* (2011) demonstrated higher content of TG and EEG in no tilled plots than conventional tillage under spring wheat-maize cropping system. Wright *et al* (1999) reported that the content of glomalin in soil was 1.5 times higher under no tillage than conventional tilled soil. The length of mycelia and root colonisation is high under no tilled than conventional tilled soil (Borie *et al* 2006) which resulted in greater glomalin content under no tilled soil. Clune (2010) observed higher content of TG and EEG under no tillage with maize residue retention than mouldboard plough without retention of maize residue in a long term study in Northern New York. The thermo stable protein glomalin, perceived to be produced from the hyphal wall (Rillig *et al* 2002) which is found to be positively correlated with soil aggregate stability (John *et al* 2005) and net primary productivity (Treseder and Turner 2007) could enlighten us more about soil carbon dynamics. Thus, it is generally hypothesized that more the glomalin in a soil better would be the soil quality (Vaidya *et al* 2011), hence reflects the better health of a soil ecosystem.

4.1.16 Microbial biomass carbon

Microbial biomass carbon (MBC) was significantly affected by wheat straw and green manure practices in rice at all the growth stages of wheat, except at CRI stage in the sub-surface soil layer (Fig 4.27 and 4.28). Similarly, the effect of tillage and rice straw management practices in subsequent wheat, on MBC was significant at all growth stages of wheat in surface soil layer and at sowing, CRI and flowering stage in the sub-surface soil layer. The interaction between different wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was significant at maximum tillering, flowering and harvesting stage in the surface soil layer and at flowering stage of wheat growth in the sub-surface soil layer. At these growth stages, PTR_{W25}+GM/ZTW_{R100} produced maximum MBC as compared with the other treatments. Among different wheat straw and green manure practices in rice, MBC was higher under PTR_{W0}+GM and PTR_{W25}+GM compared to PTR_{W0} and $PTR_{W25.}$ At maximum tillering stage, in the surface layer, MBC was

82.5-94.7% higher in PTR_{W0}+GM and PTR_{W25}+GM as compared with PTR_{W0} and $PTR_{W25.}$ At all the growth stages studied, MBC was higher under ZTW_{R100} than $ZTW_{R0,}$ which was further reduced under CTW_{R0}. At maximum tillering stage, MBC was 17.1% higher under ZTW_{R100} than $ZTW_{R0,}$ which was 9.7% higher than $CTW_{R0.}$ MBC was higher in surface soil layer than the sub-surface soil layer, which is presumably due to higher organic matter content at this layer. In both the soil layer, MBC was higher at maximum tillering stage followed by flowering stage and least was observed at harvesting stage. MBC is an important component of labile carbon pool used as sensitive soil quality indicator. It is intimately linked to nutrient transformations in soil, acting as both a sink and a source of nutrients (Gregorich *et al* 2000). It was reported that NT could increase soil microbial biomass carbon in a wheat cropping system (Wang *et al* 2008), in wheat–pea cropping systems (Chan *et al* 2008, Bi *et al* 2009) and in wheat–maize (Yang *et al* 2010, Wang *et al* 2012). Consistently, in rice-upland cropping systems, such as rice–wheat and rice–oilseed rape, it was observed that NT had higher soil microbial biomass carbon and nitrogen than CT (Gao *et al* 2004, Jiang *et al* 2011, Li *et al* 2012). Prasad *et al* (2016) reported significant increase of MBC under minimum tillage practices with application of organic source of nitrogen than intensive tillage practices with application of inorganic source of nitrogen. Microbial decomposition of SOC in no tilled soil is restricted due to greater stability of micro and macro aggregate which act as physical barrier between SOM and decomposers (Tripathi *et al* 2014). This provides congenial environment for microbial proliferation in soil which is possibly the reason for higher MBC under no tillage. Crop residue retention potentially increases MBC in soil than their removal or burning (Mandal *et al* 2007). Sun *et al* (2016) observed that MBC was significantly affected by tillage practices and sampling time, higher value was observed under no tilled soil than soil tilled with mouldboard plough. Similar results were reported by Spedding *et al* (2004) suggesting that sampling time may have larger impact on the effect of tillage and management practices on soil microbial community, as seasonal crop growth strongly influences the quantity and spatial distribution of organic matter in soil. The MBC was maximum at maximum tillering stage of wheat due to higher root exudation, biomass and vigorous vegetative growth. Tamilselvi *et al* (2015) recorded maximum MBC at active vegetative growth stage of maize crop, which is further decreased at the later growth stages. This may be ascribed to increase in C and other nutrient input from rhizosphere due to active rhizodeposition (Kumar *et al* 2014). Leon *et al* (2017) reported significant increase of MBC at surface soil layer (0-5 cm) under NT along with Ca-amendment application than CT in a degraded acidic soil of Spain.

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

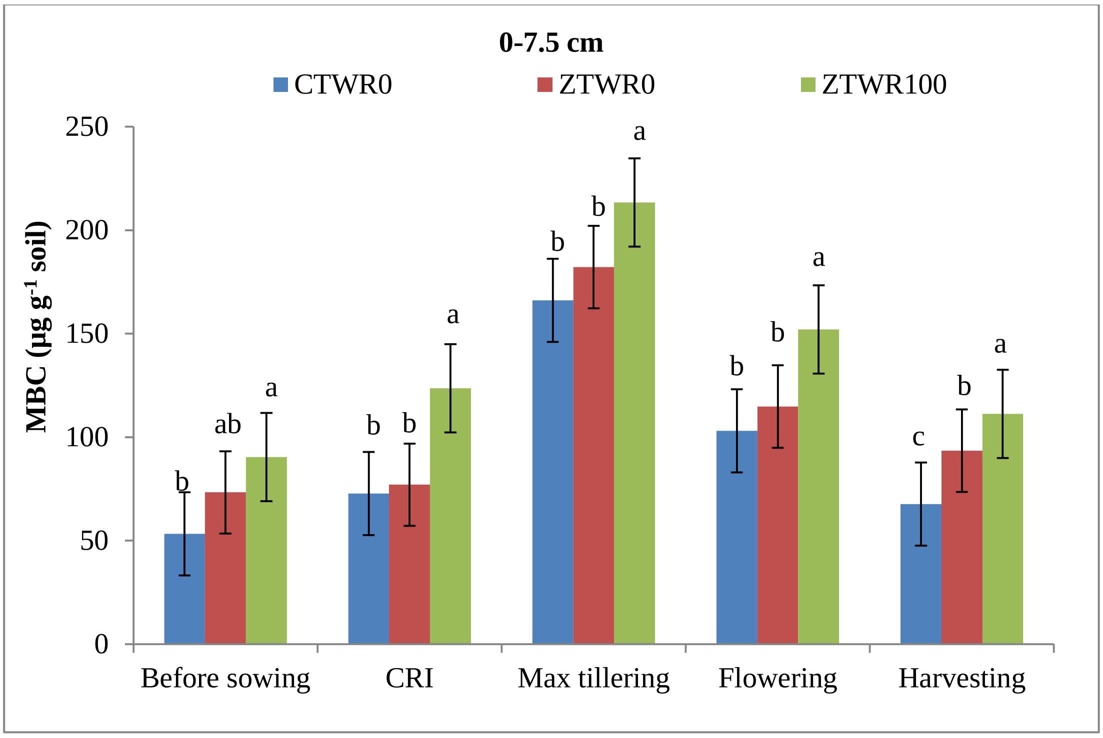
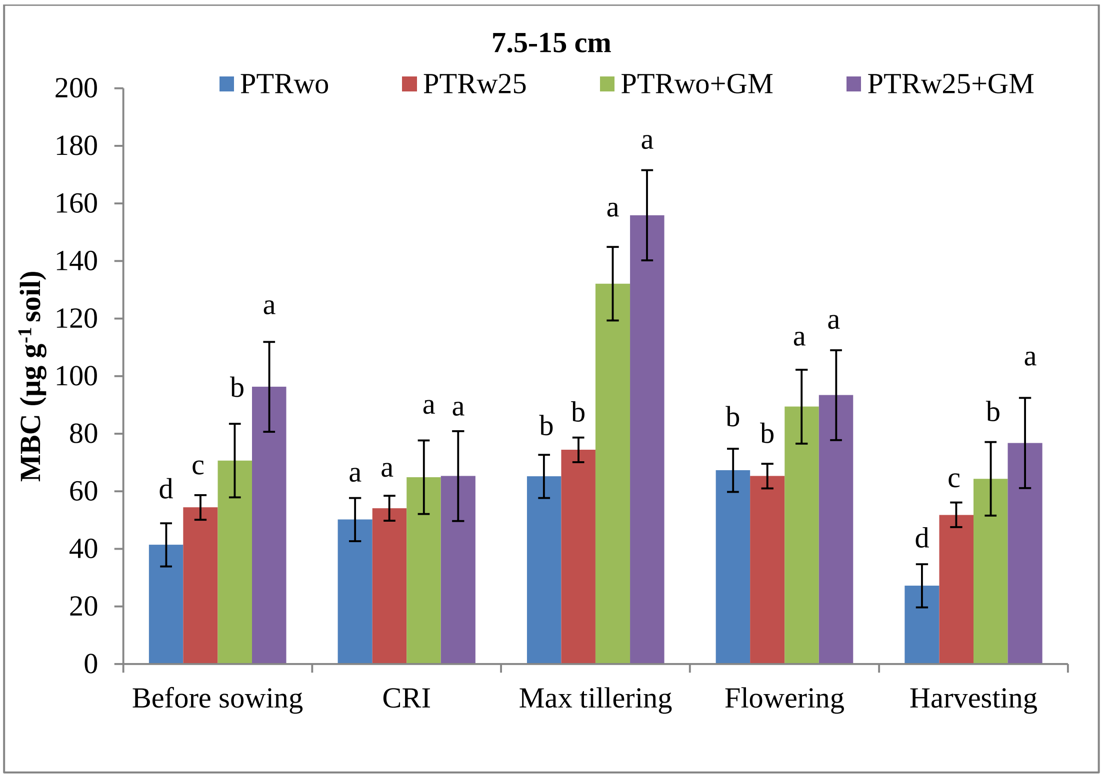


Fig. 4.27: **MBC (µg g^{-1} soil) during different growth stages of wheat in surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at p<0.05). Columns with same latter are not significantly different (p<0.05).**

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

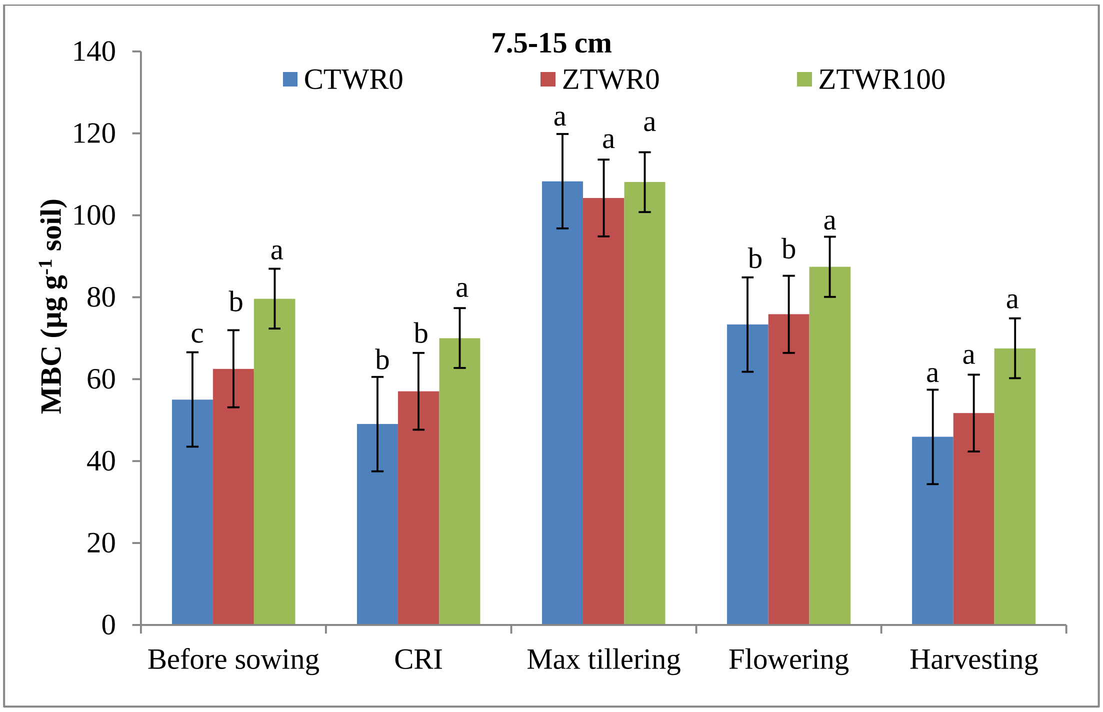
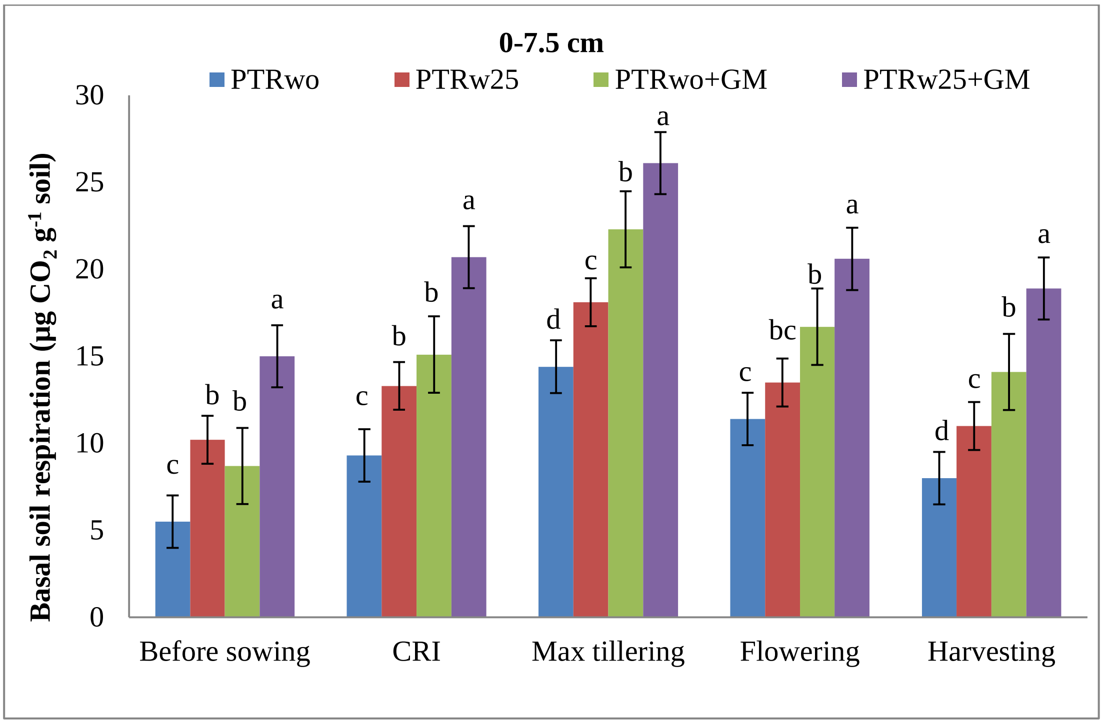


Fig. 4.28: MBC (µg g^{-1} soil) during different growth stages of wheat in sub-surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at $p<0.05$). Columns with same latter are not significantly different ($p<0.05$).

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

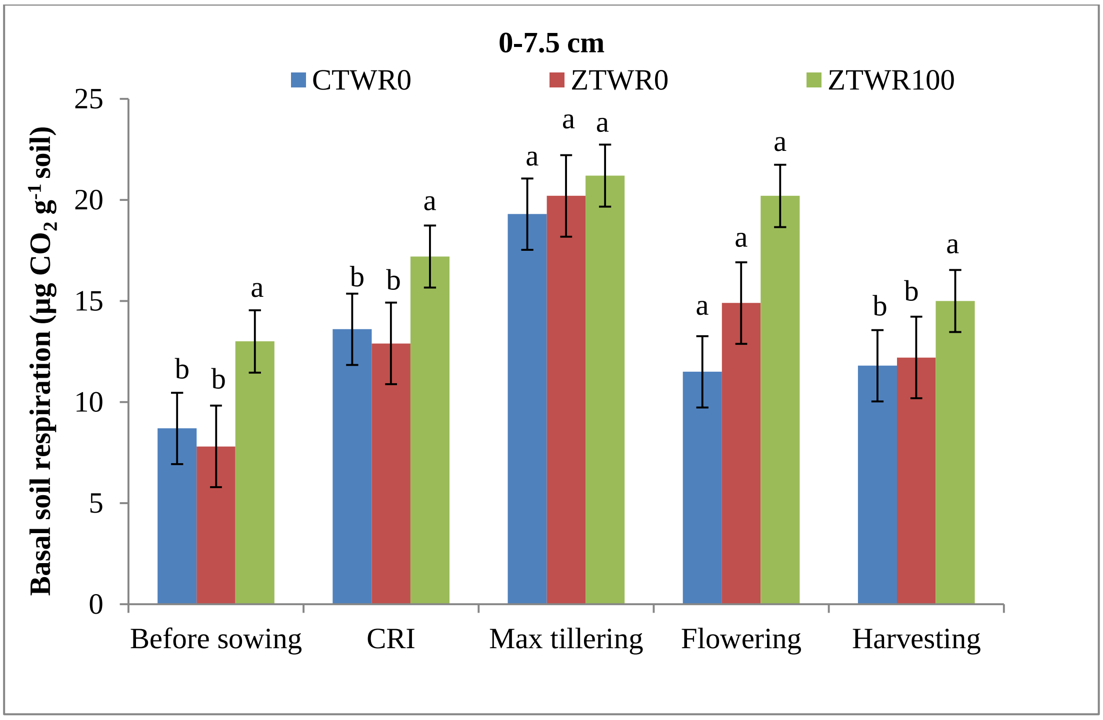
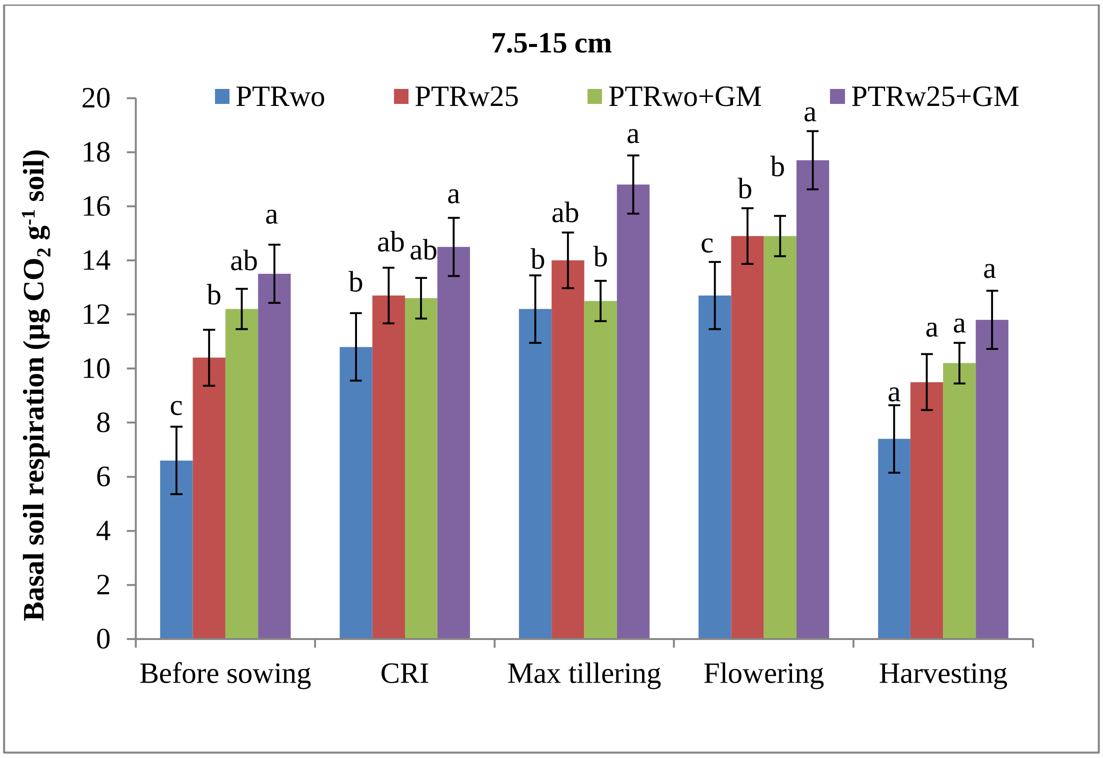


Fig. 4.29: Basal soil respiration (µg CO_2 g^{-1} soil) during different growth stages of wheat in surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at $p<0.05$). Columns with same latter are not significantly different ($p<0.05$).

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

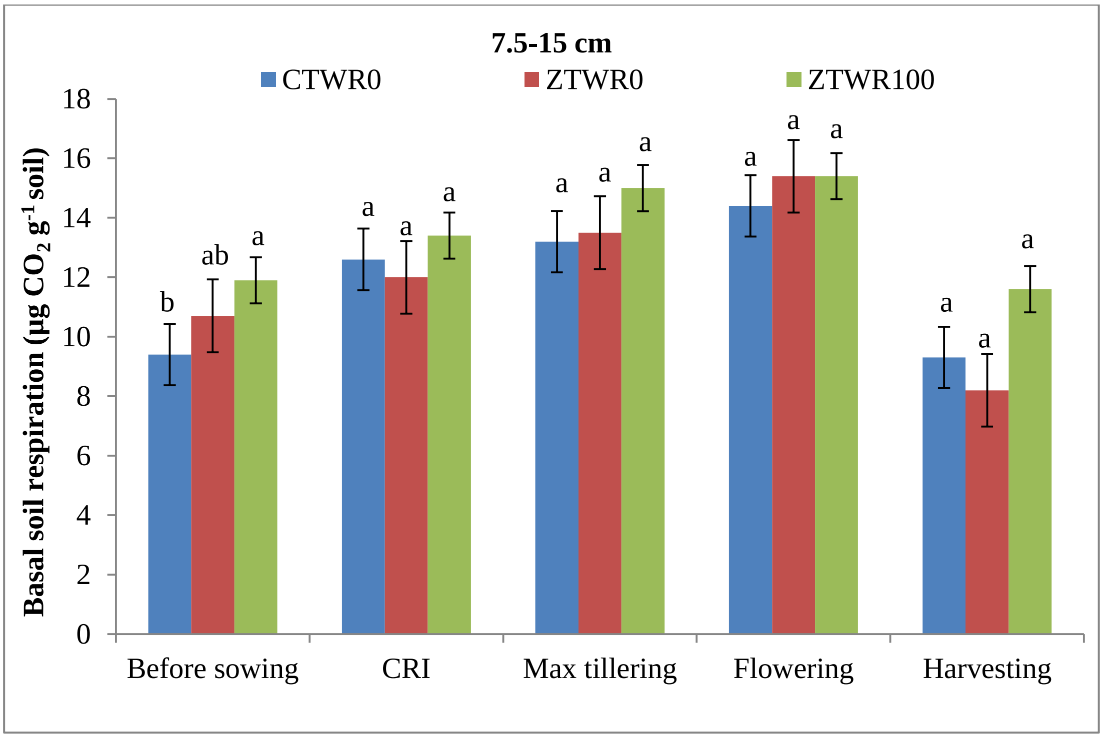


Fig. 4.30: Basal soil respiration (µg CO_2 g^{-1} soil) during different growth stages of wheat in sub-surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at $p<0.05$). Columns with same latter are not significantly different ($p<0.05$).

4.1.17 Basal soil respiration

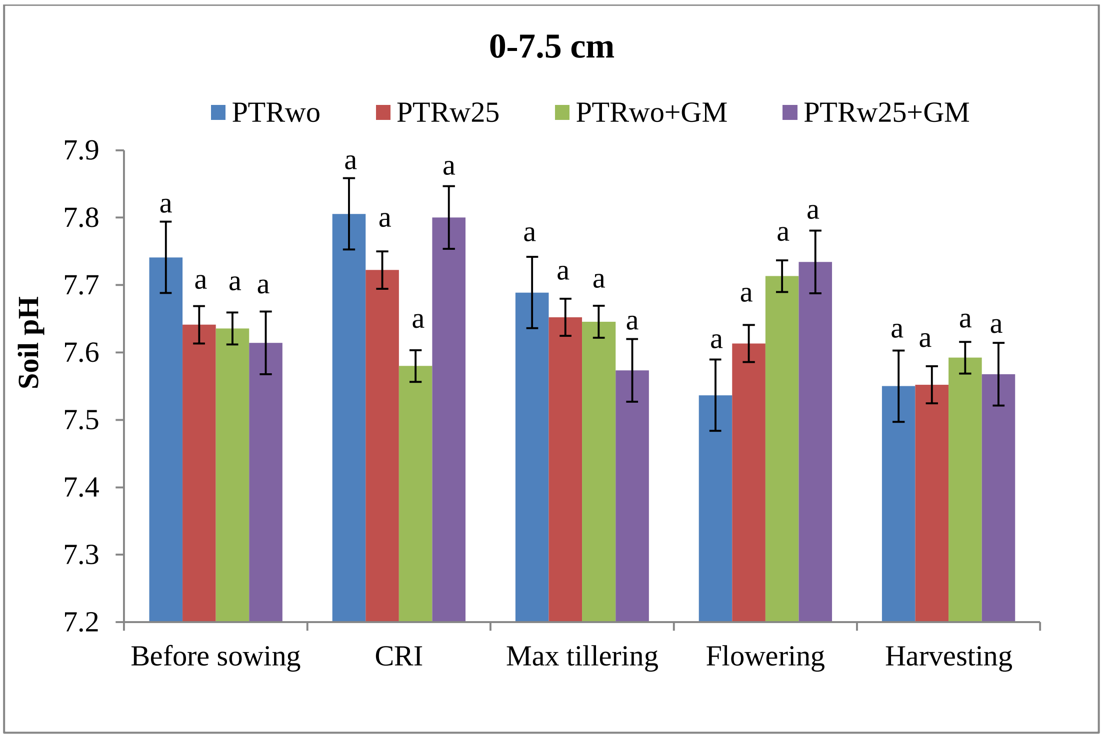
Wheat straw and green manure practices in rice, irrespective of tillage and rice straw management practices in subsequent wheat, significantly affected Basal soil respiration (BSR) at all the growth stages of wheat except at harvesting stage in the sub-surface soil layer (Fig 4.29 and 4.30). The significant effect of tillage and rice straw management practices in subsequent wheat was observed at sowing, CRI and harvesting stage of wheat in the surface soil layer and at sowing in the sub-surface soil layer. The interaction between different wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was not significant at any of the growth stage of wheat studied. Application of wheat residue and green manure substantially improved BSR as compared with the treatments without application of residue and green manure. Soil respiration refers to the overall process by which bacteria and fungi in the soil decompose C and release it into the atmosphere in the form of CO_2. Basal soil respiration was higher under ZTW_{R100} as compared with ZTW_{R0} and CTW_{R0}. Maximum BSR was recorded at maximum tillering stage of wheat followed by flowering stage in the surface soil layer and flowering stage followed by maximum tillering stage in the sub-surface soil layer. Least value of BSR was recorded at sowing in both the soil layer. At maximum tillering stage, in the surface soil layer, BSR under PTR_{W0}+GM and PTR_{W25}+GM treatment was 54.6% and 44.2% higher than PTR_{W0} and PTR_{W25} treatments. Basal soil respiration is ascribed as a bio-indicator of soil quality (Dutta *et al* 2010), which is linked to carbon availability in applied biomass. Kessavalou *et al* (1998) observed higher BSR at maximum growth of the wheat crop in a wheat-fallow cropping system. BSR is higher in surface soil layer under no tillage than conventional tillage because of higher population and activity of microorganism at this layer (Gajda and przewoka 2012). BSR decreased with depth possibly due to decrease of organic matter with depth. Kainiemi *et al* (2015) observed increase in soil respiration under shallow tillage with residue placement at soil surface as compared to residue incorporation into soil with mouldboard plough. Gajda *et al* (2013) recorded 21-25% higher soil respiration in 0-15 cm soil layer under no tilled soil than traditional tillage in a wheat based cropping system in a long term study.

4.2 Effect of wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat on soil chemical properties

4.2.1 Soil pH and EC

The effect of different wheat straw and green manure practices in rice and tillage and rice straw management practices in subsequent wheat and their interaction was not significant on soil pH (Fig 4.31, 4.32) and EC (Fig 4.33, 4.34) at all the growth stages of wheat in both soil layer. Thomas *et al* (2007) observed similar findings suggesting that soil pH and EC was not influenced by tillage practices at all the soil depth studied. Kumar *et al* (2004) observed

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

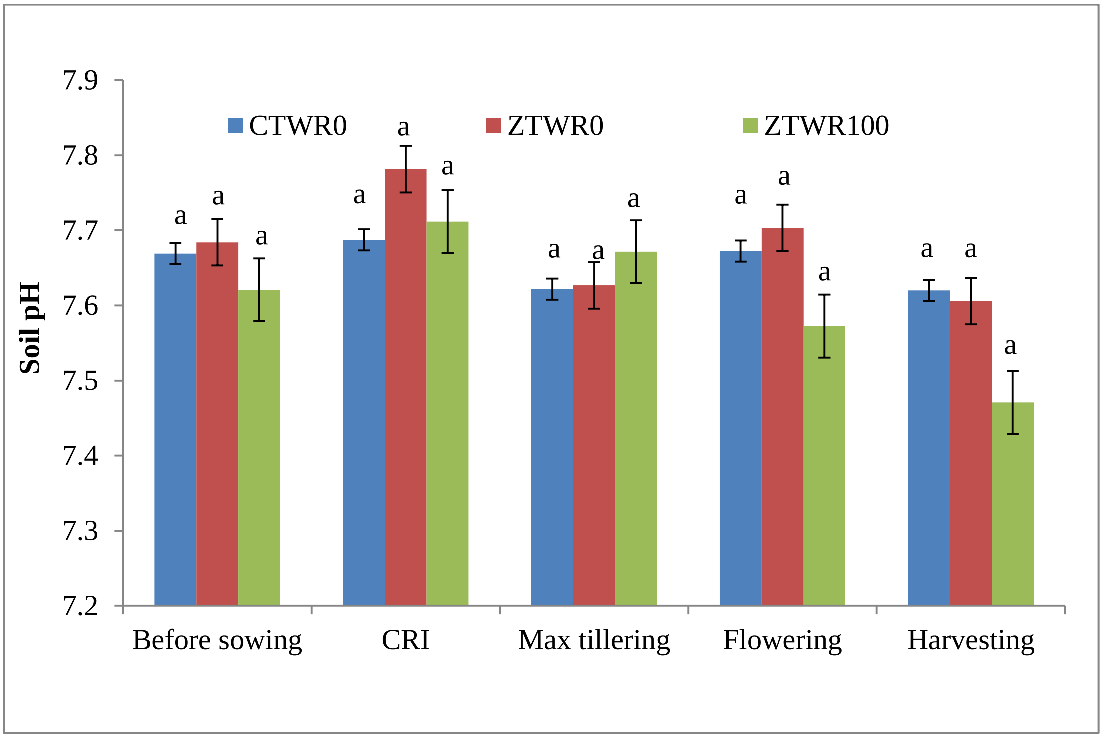
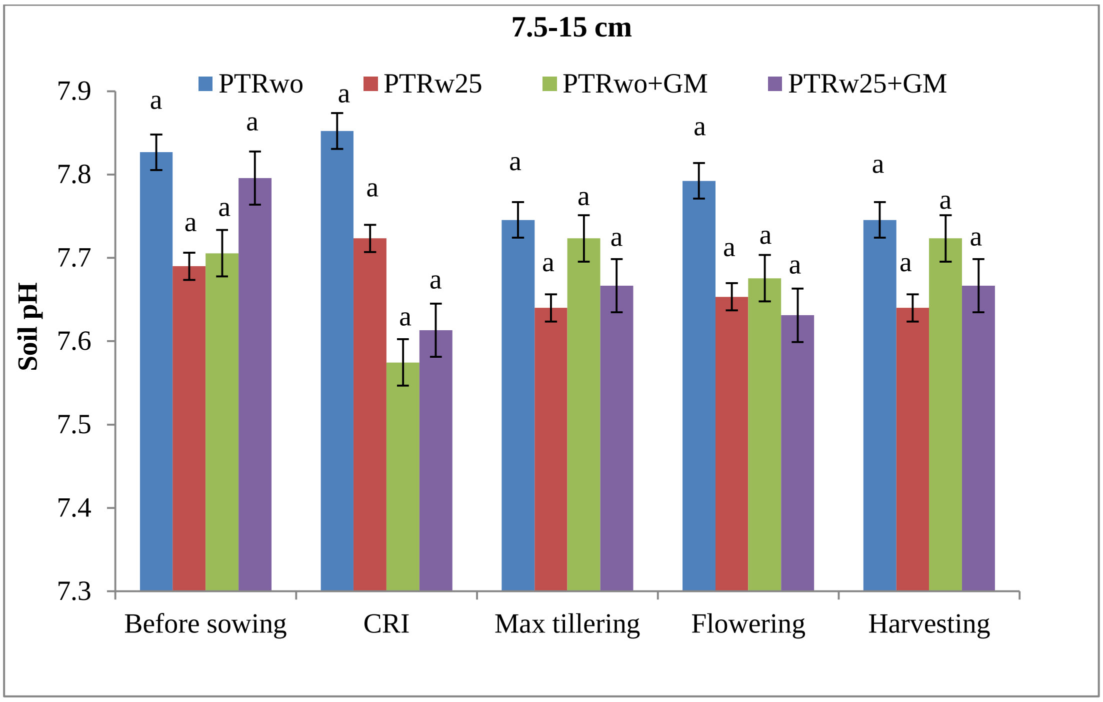


Fig. 4.31: Soil pH during different growth stages of wheat in surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at p<0.05). Columns with same latter are not significantly different (p<0.05).

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

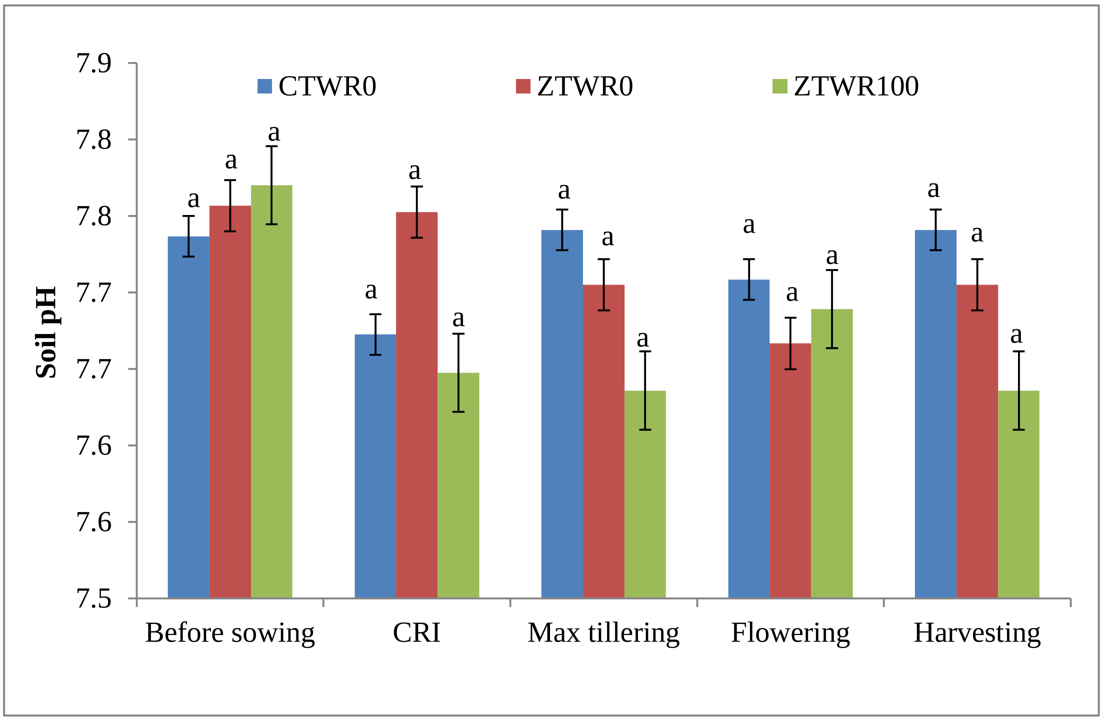
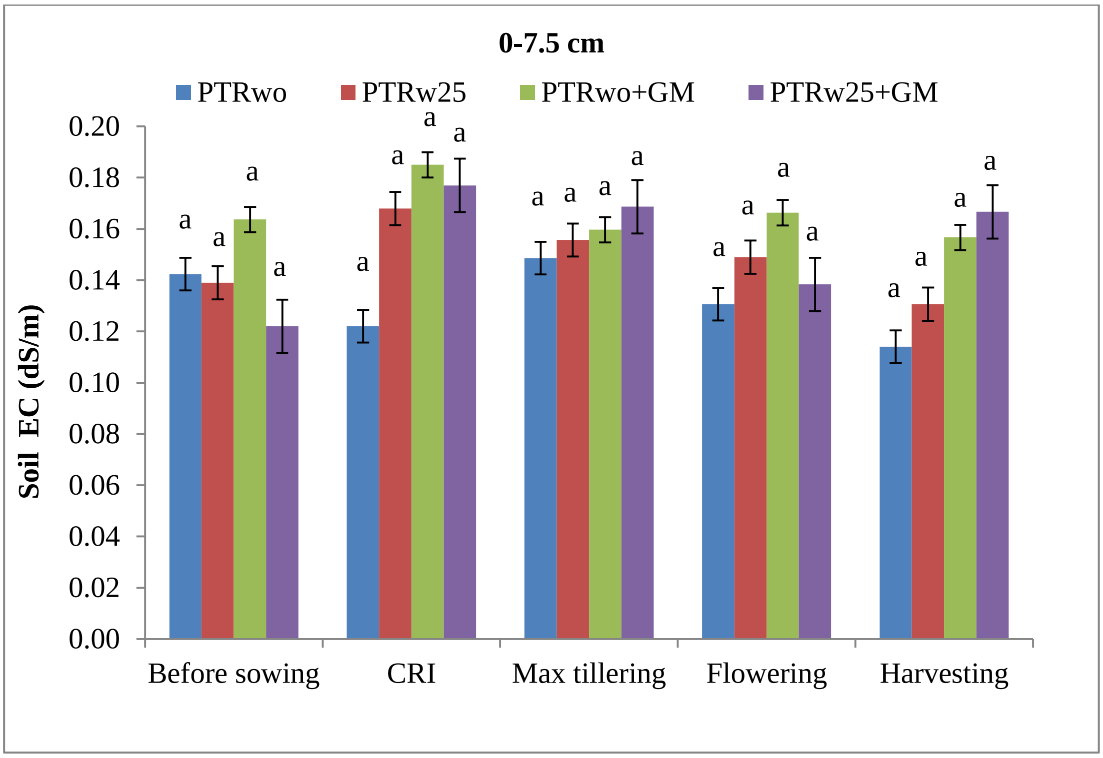


Fig. 4.32: Soil pH during different growth stages of wheat in sub-surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at p<0.05). Columns with same latter are not significantly different (p<0.05).

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

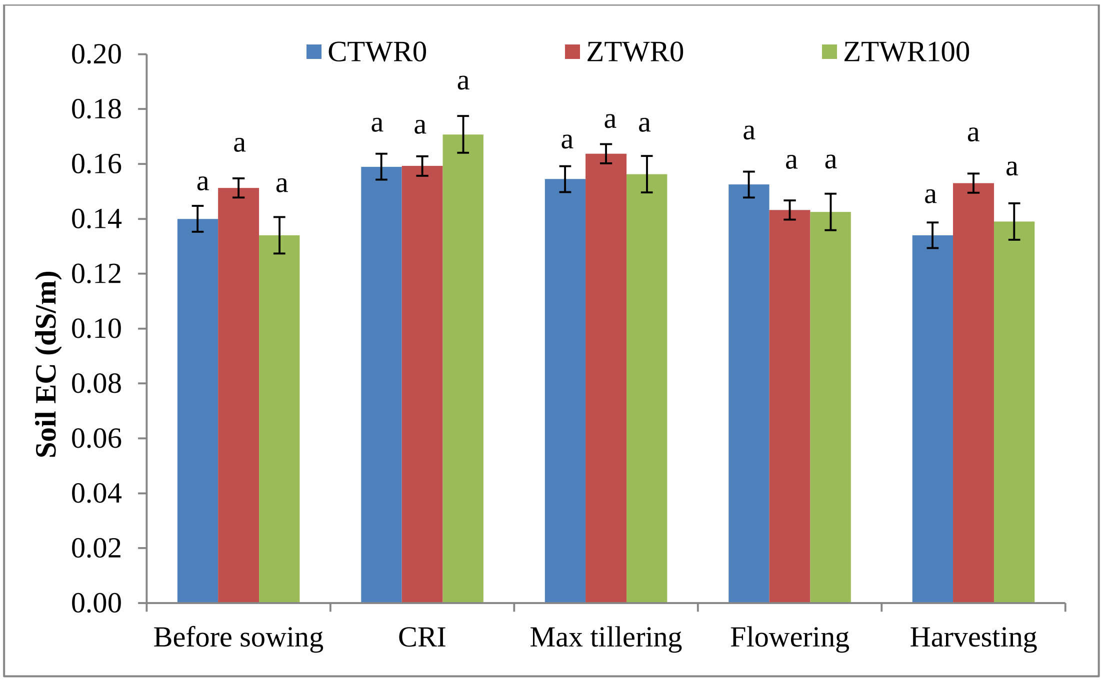
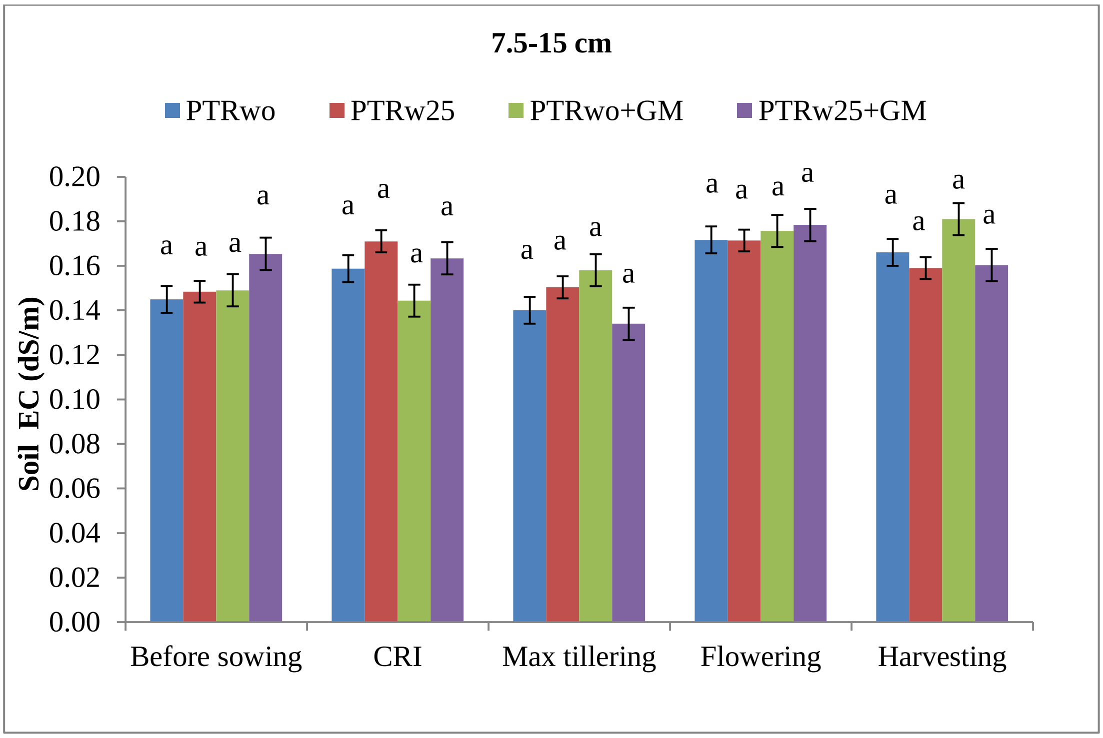


Fig. 4.33: Soil EC during different growth stages of wheat in surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at $p<0.05$). Columns with same latter are not significantly different ($p<0.05$).

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

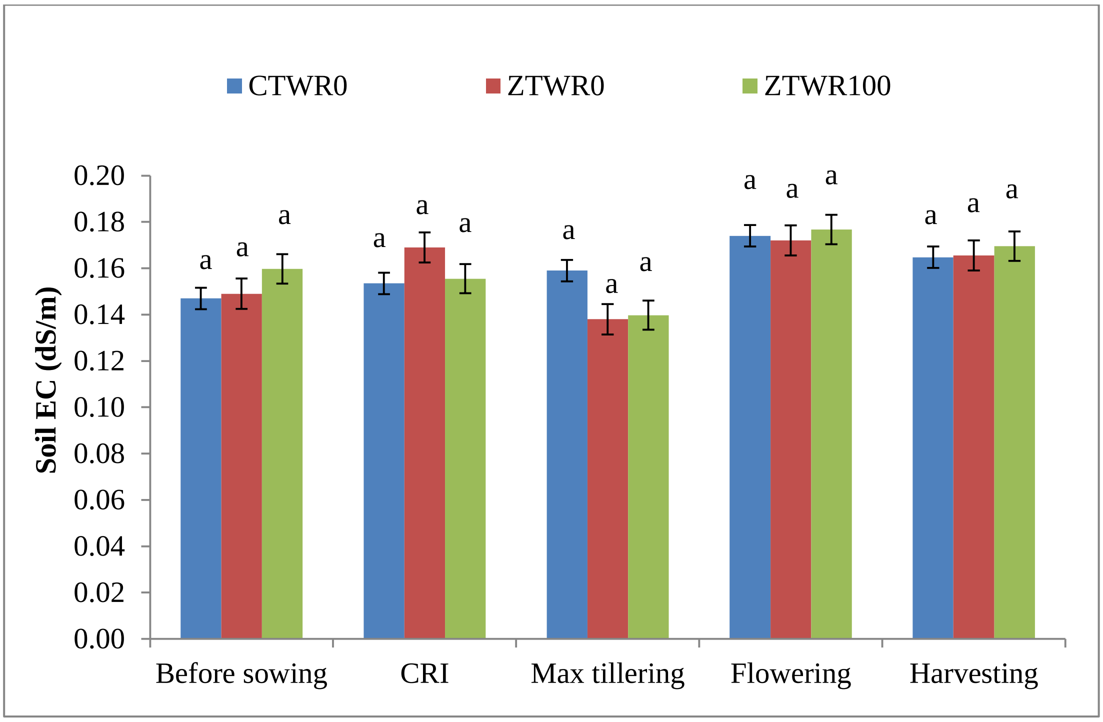


Fig. 4.34: Soil EC during different growth stages of wheat in sub-surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at p<0.05). Columns with same latter are not significantly different (p<0.05).

rice straw removal or burning as well as tillage had no significant effect on EC. Similarly, Roldan *et al* (2003) observed no any significant effect of tillage and residue addition on soil EC. Villamil and Nafziger (2015) reported that soil pH and EC was not affected by tillage practices (No-tillage and chisel plough) and corn residue management practices (complete residue removal, partial residue removal and residue retention) after 5 year of continuous corn (*Zea mays* L.) cropping. Monsefi *et al* (2014) reported that soil pH was not affected by different tillage and wheat residue management practices in a soybean-wheat cropping system.

4.2.2 Oxidizable soil organic carbon

Oxidizable soil organic carbon (SOC) content in soil was significantly affected by wheat straw and green manure practices in rice at sowing, CRI and maximum tillering stage in the surface soil layer (Fig 4.35) and at maximum tillering, flowering and harvesting stage in the sub-surface soil layer (Fig 4.36). Similarly, tillage and rice straw management practices in subsequent wheat, irrespective of different wheat straw and green manure practices in rice significantly affected SOC content in soil at all the growth stages of wheat in the surface soil layer and at maximum tillering, flowering and harvesting stage in the sub-surface soil layer. Interaction effects were not significant in both surface and sub-surface soil layer. In most of the cases, SOC was higher under PTR_{W0}+GM and PTR_{W25}+GM as compared with PTR_{W0} and $PTR_{W25.}$ Similarly, ZTW_{R100} exhibited higher SOC content than $ZTW_{R0,}$ which was further reduced under CTW_{R0}. SOC plays important role in maintaining soil fertility and agronomic productivity due to its immense impact on physical, biological and chemical properties of soil. Conservation tillage leads to increase of organic carbon in surface soil layer than sub-surface soil layers (Salinas-Gracia *et al* 2001). This increase of SOC is possibly due to poor residue-soil contact, less decomposition of structural plant constituents because of delay in colonisation by microbes (Henriksen and Breland 2002). Tillage breakdown the crop residues into smaller particles, incorporate them into greater soil depth and exposes a larger surface area for microbial attack (Summerell and Burgess 1989). Heidari *et al* (2016) observed increase in SOC content under no tillage with addition of organic manure. Similar results reported by Martinez *et al* (2013) and Syswerda *et al* (2011) who observed SOC content in soil was significantly higher under zero tillage than conventional tillage. This might be due to slow decomposition of crop residue in no tilled soil, as it is protected inside stable soil aggregate. Mitchell *et al* (2017) reported substantial increase of organic carbon under no tillage along with cover cropping at 0-15 cm soil layer. Yadvinder singh *et al* (2004) recorded significant increase of SOC after rice residue incorporation than its removal or burning in a long term rice-wheat system. Meena *et al* (2015) observed that incorporation of legume crop (chick pea: *Cicer arietinum* L.) into a maize based cropping system was effective in increasing organic carbon content in soil. In the present investigation, maximum SOC content in soil was observed at harvesting stage followed by flowering stage and least value at sowing of wheat crop in both the soil layers due to accumulation of organic matter over time.

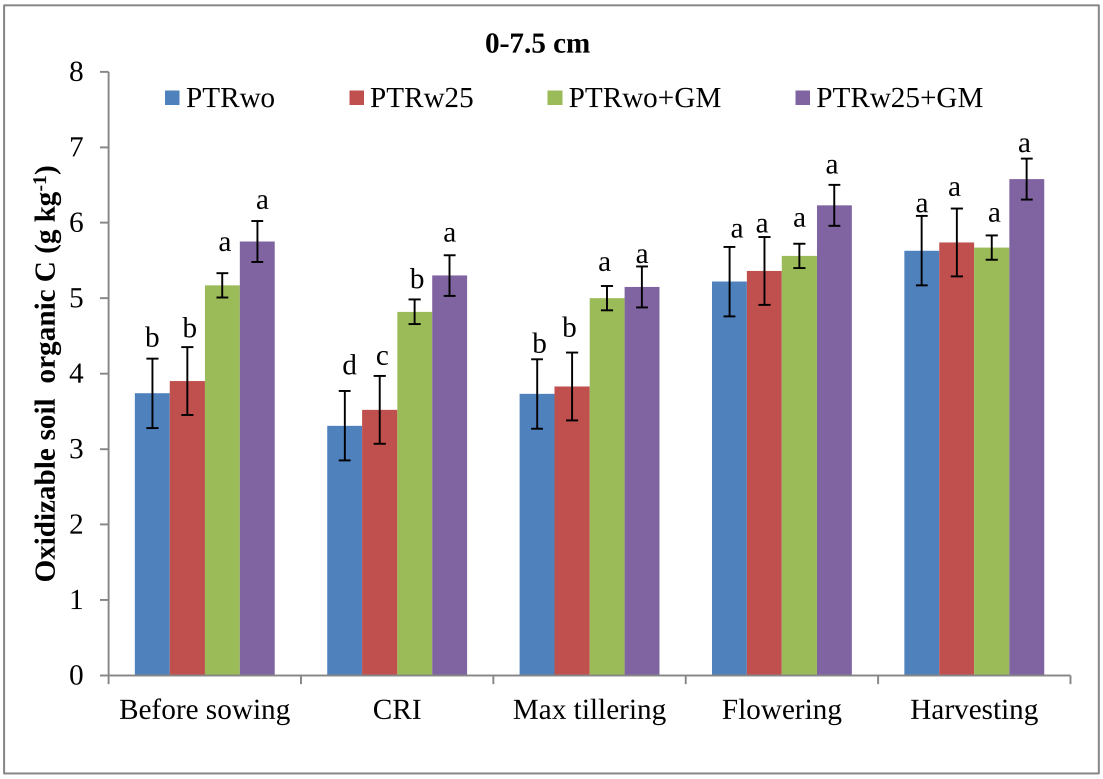
4.2.3 Available nitrogen (N) content

Wheat straw and green manure practices in rice significantly affected available N content in soil at CRI and flowering stage of wheat growth in the surface soil layer (Fig 4.37) and at sowing in the sub-surface soil layer (Fig 4.38). The effect of tillage and rice straw management practices in subsequent wheat, irrespective of different wheat straw and green manure practices in rice on available N content in soil was significant at CRI stage in the surface soil layer and at sowing in the sub-surface soil layer. Interaction effects were not significant in both surface and sub-surface soil layer at any of the growth stages of wheat. Among different wheat straw and green manure practices in rice, available N content was significantly higher under PTR_{W25}+GM than other treatments. Available N content under $PTR_{W0,}$ PTR_{W25} and PTR_{W0}+GM were statistically at par for all the treatments. Likewise, available N content was significantly higher under ZTW_{R100} than the other tillage and rice straw management practices in wheat. Maximum value of available N content in soil was higher at CRI stage in surface soil layer and at maximum tillering stage in the sub-surface soil layer. Conservation tillage practices such as zero tillage or reduced tillage with crop residue retention increases nitrogen availability (Habtegebrial *et al* 2007). Nagar *et al* (2016) observed significantly higher content of available nitrogen with application of pigeon pea stalk and phosphocompost and FYM as compared with sole application of mineral fertiliser. Similar findings were reported by Das *et al* (2014), they observed significant increase of soil available N in a rice crop after 4 years of no tillage as compared with conventional tillage practices. Nivelle *et al* (2016) observed positive impact of no tillage and cover cropping of leguminous plant species after 5 years experiment on soil nitrogen content in a wheat based cropping system as compared with CT and bare fallow in northern France.

4.2.4 Available phosphorus (P) content

Wheat straw and green manure practices in rice significantly affected available P content in soil at all the growth stages of wheat in the surface soil layer (Fig 4.39) except at sowing, and at sowing, CRI, maximum tillering and flowering stage in the sub-surface soil layer (Fig 4.40). However, the effect of tillage and rice straw management practices in subsequent wheat, irrespective of different wheat straw and green manure practices in rice on available P content in soil was significant at CRI and flowering stage of wheat in the surface soil layer and at CRI, maximum tillering and flowering stage in the sub-surface soil layer. The interaction between different wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was not significant in both the soil layer at all the growth stages of wheat. Among different wheat straw and green manure practices in rice,

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

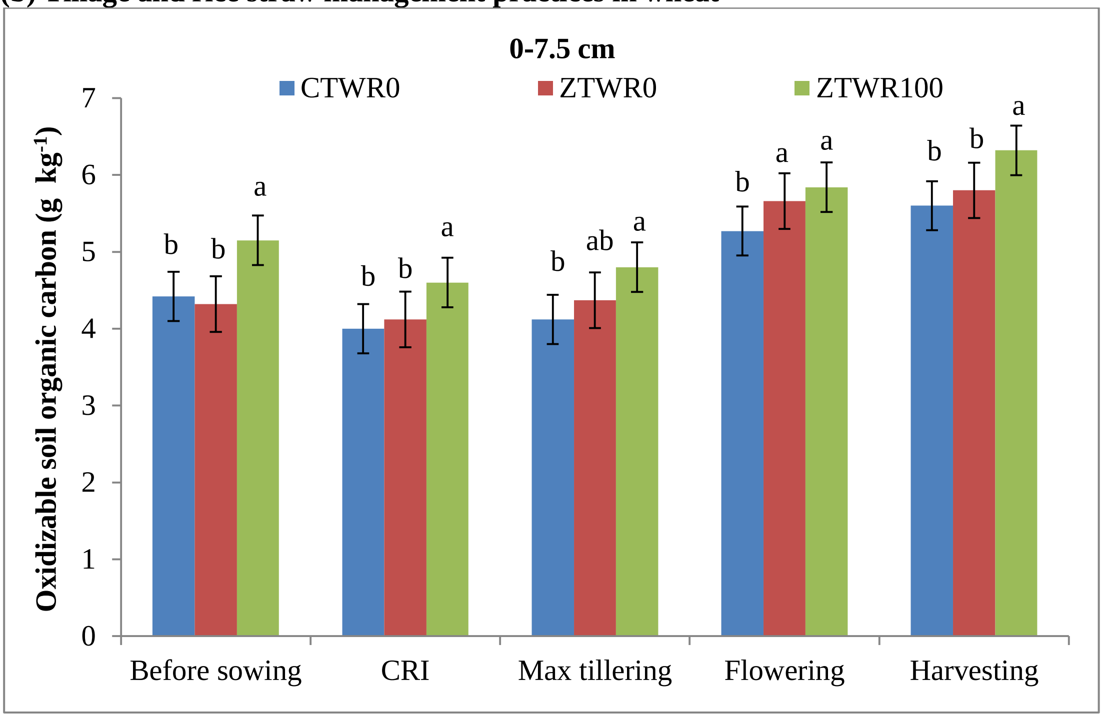
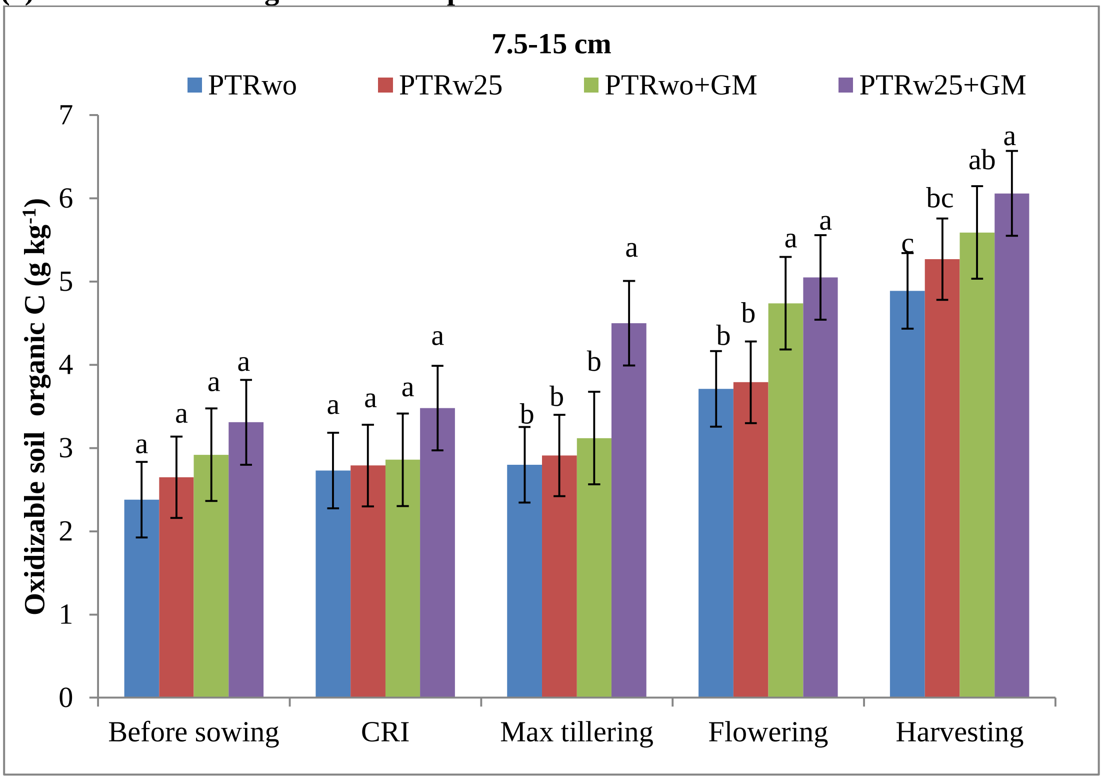


Fig. 4.35: Oxidizable soil organic carbon (g kg^{-1}) during different growth stages of wheat in surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at p<0.05). Columns with same latter are not significantly different (p<0.05).

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

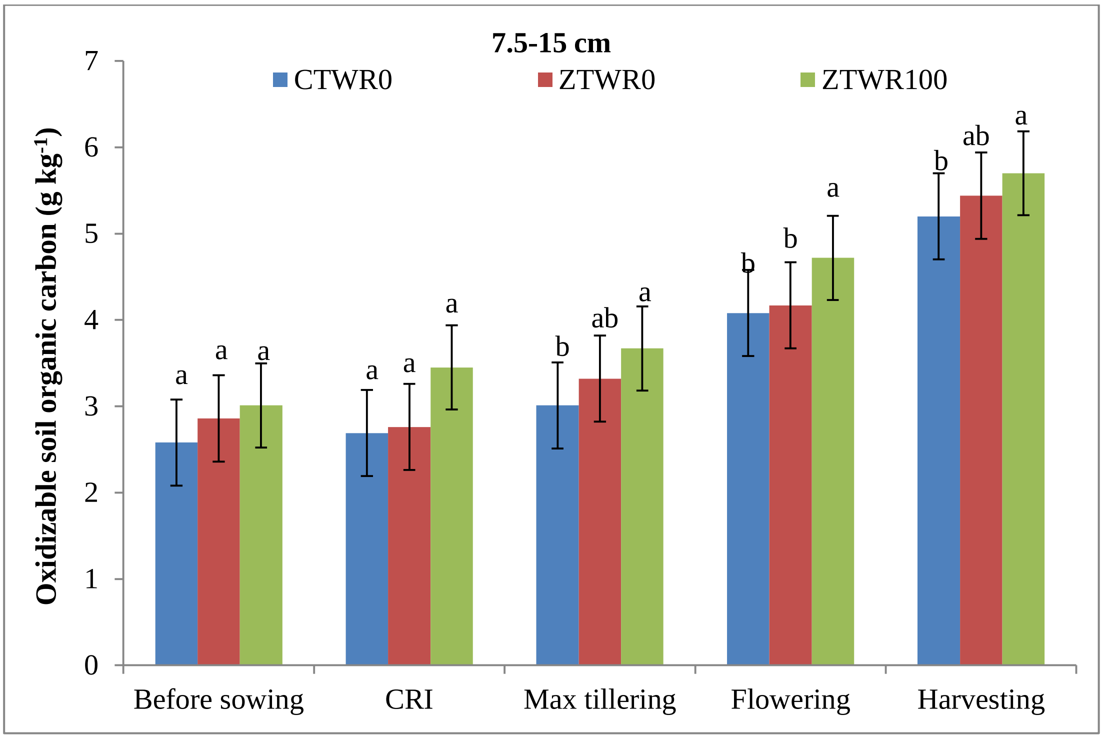
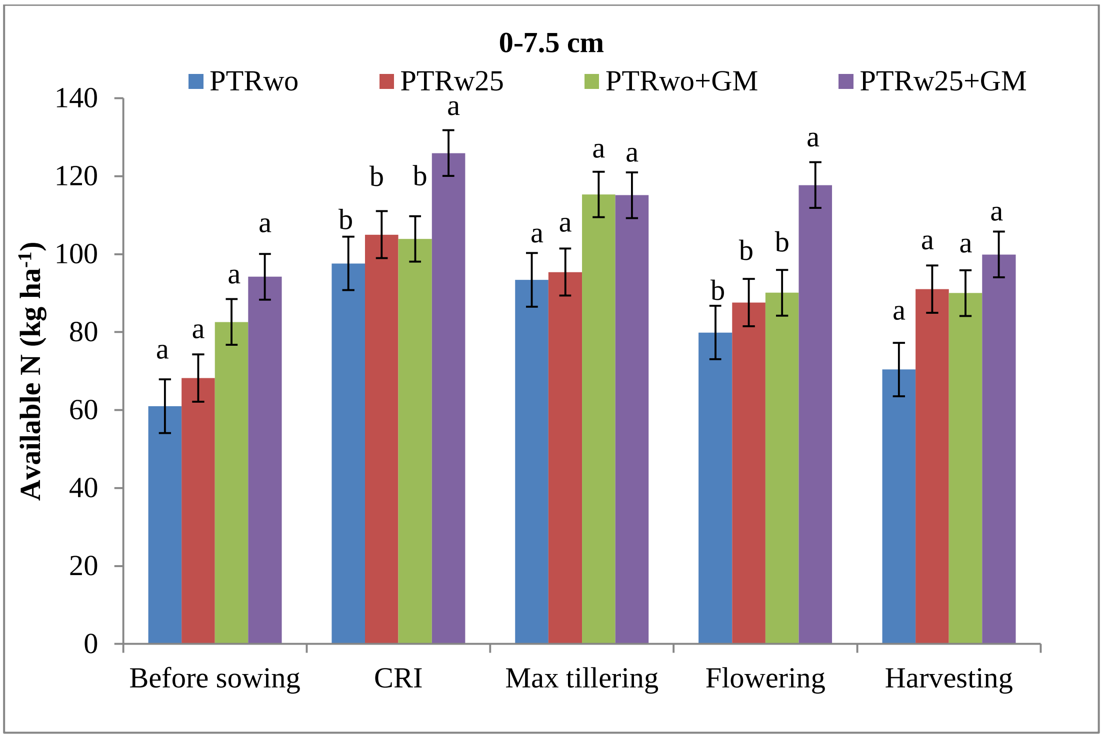


Fig. 4.36: Oxidizable soil organic carbon (g kg^{-1}) during different growth stages of wheat in sub-surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at p<0.05). Columns with same latter are not significantly different (p<0.05).

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

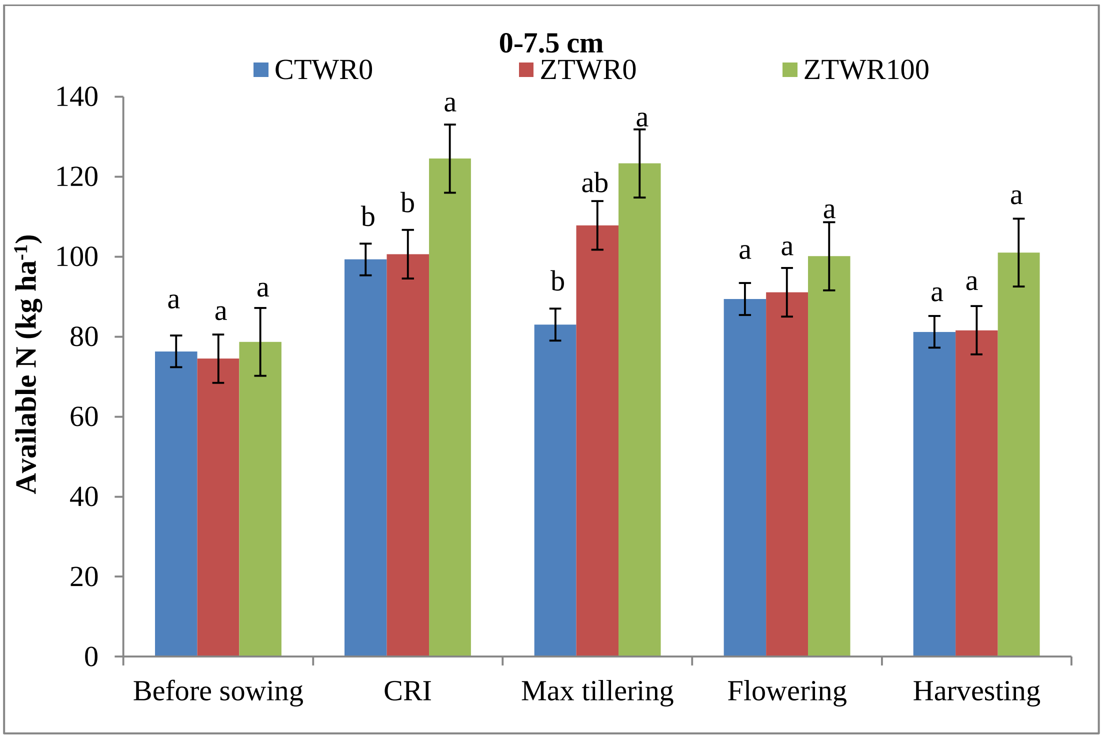
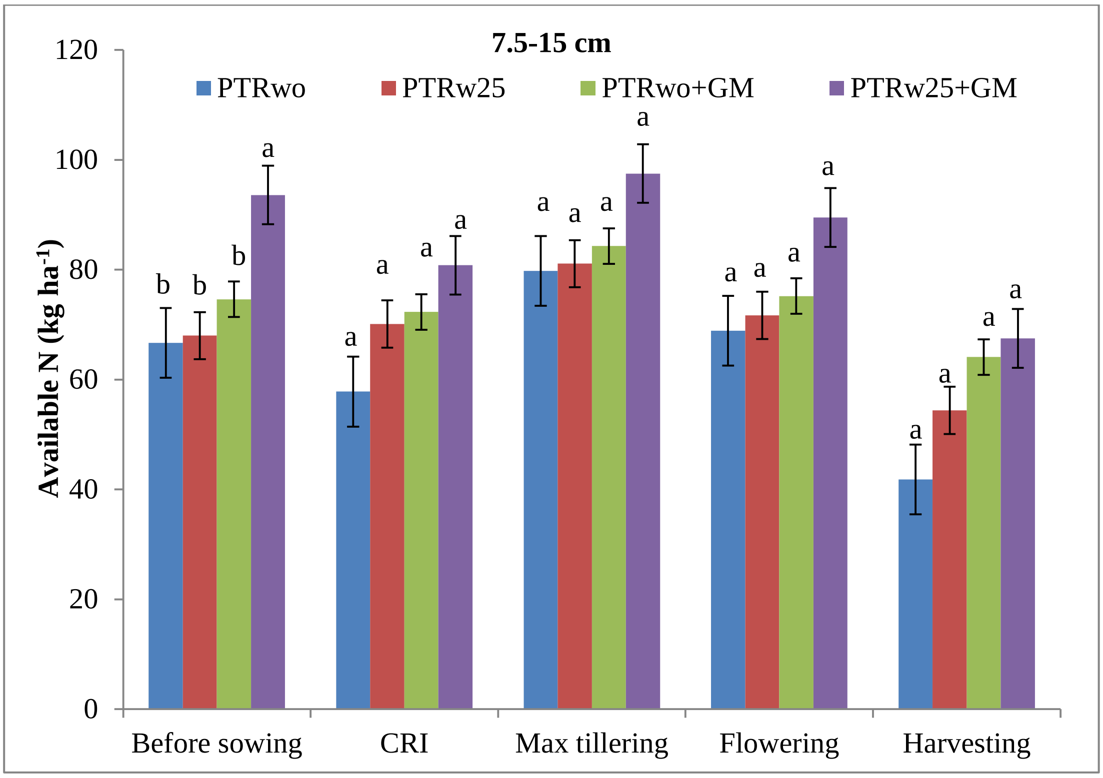


Fig. 4.37: Available nitrogen in soil (kg ha^{-1}) during different growth stages of wheat in surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at p<0.05). Columns with same latter are not significantly different (p<0.05).

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

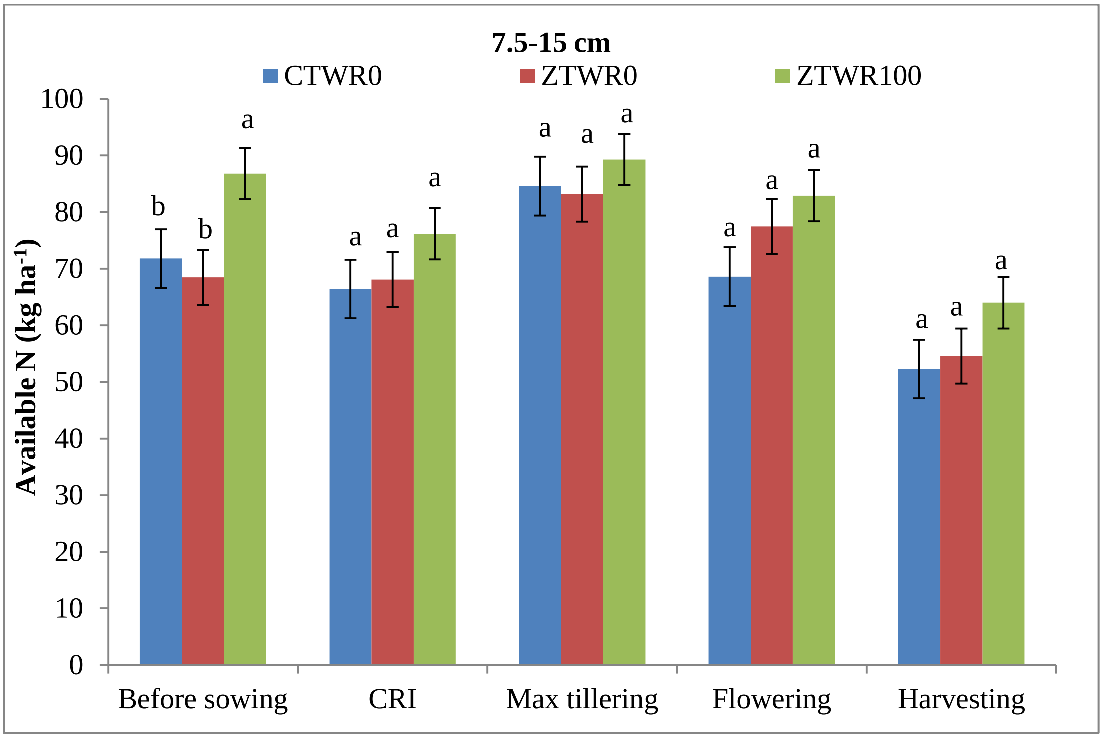
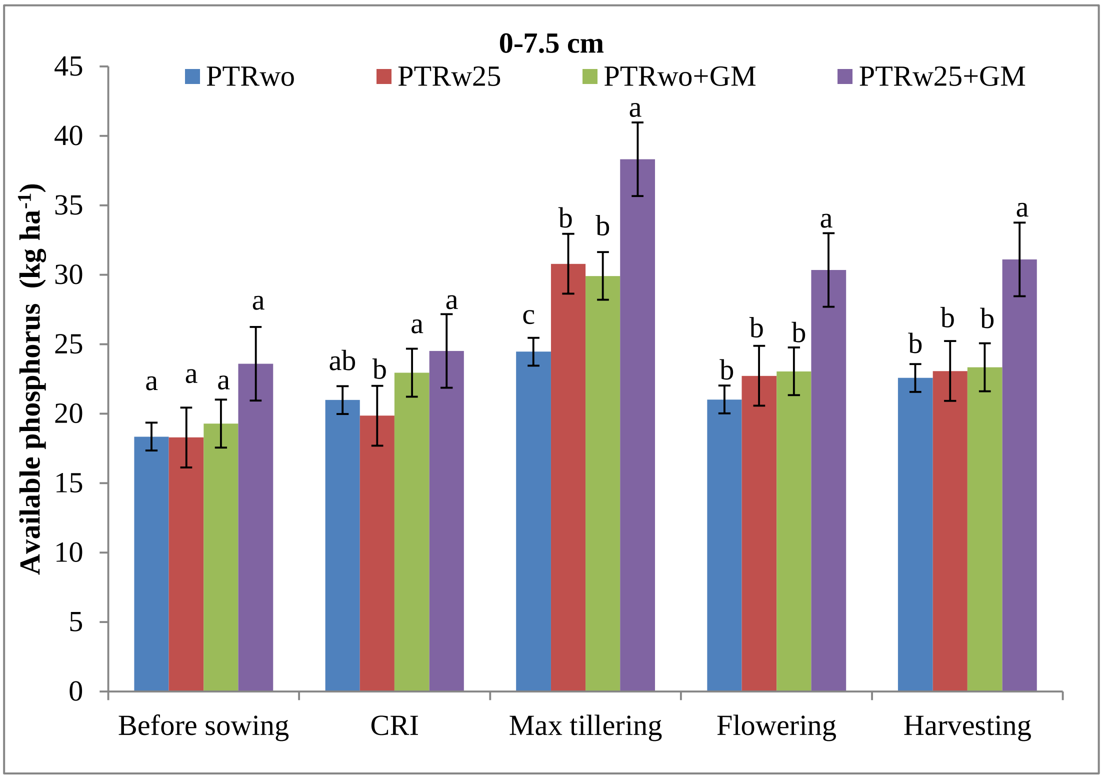


Fig. 4.38: Available nitrogen in soil (kg ha^{-1}) during different growth stages of wheat in sub-surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at p<0.05). Columns with same latter are not significantly different (p<0.05).

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

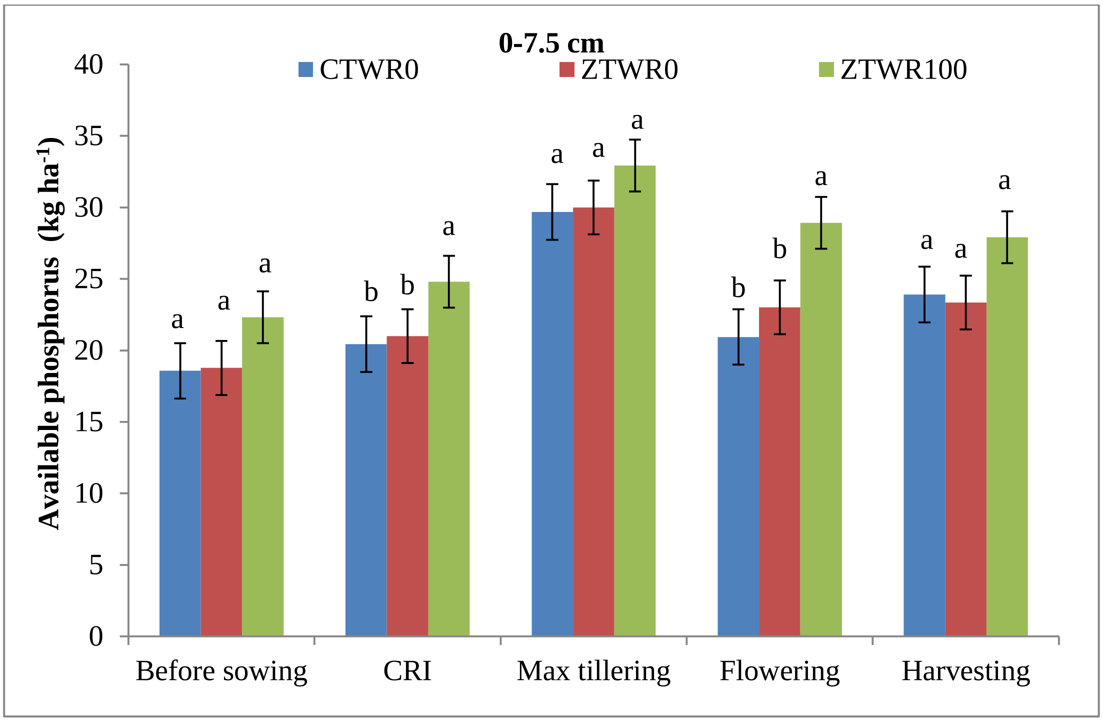
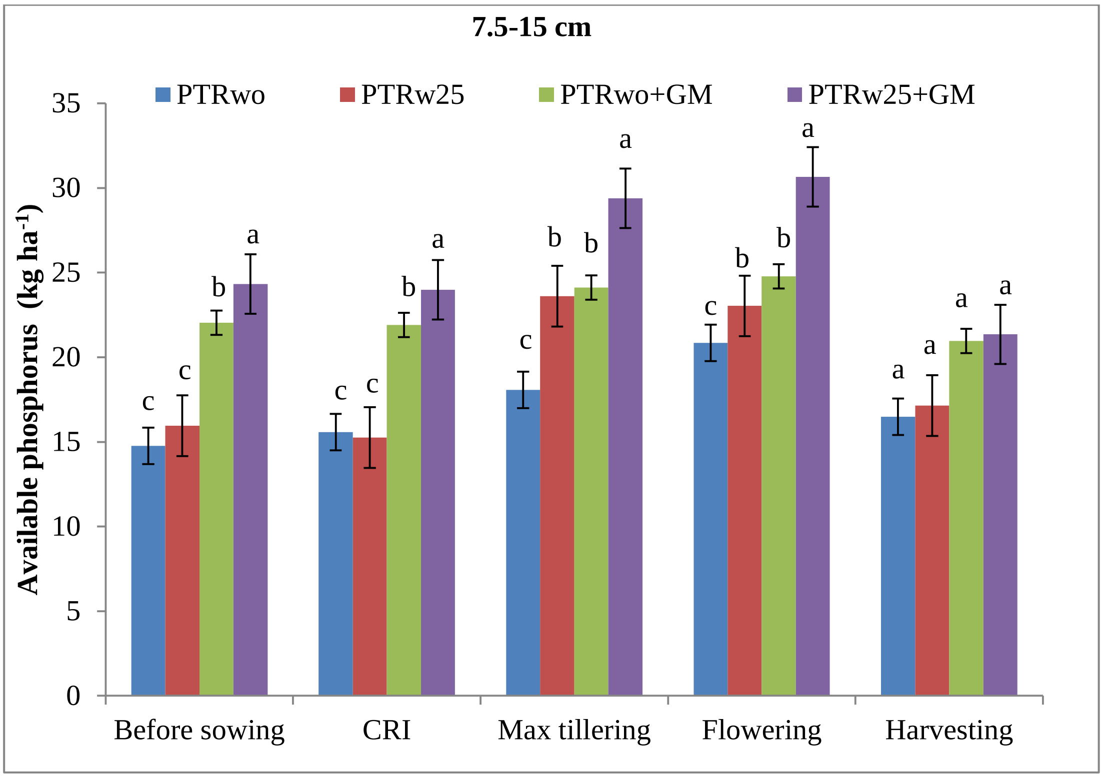


Fig. 4.39: Available phosphorus in soil (kg ha^{-1}) during different growth stages of wheat in surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at $p<0.05$). Columns with same latter are not significantly different ($p<0.05$).

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

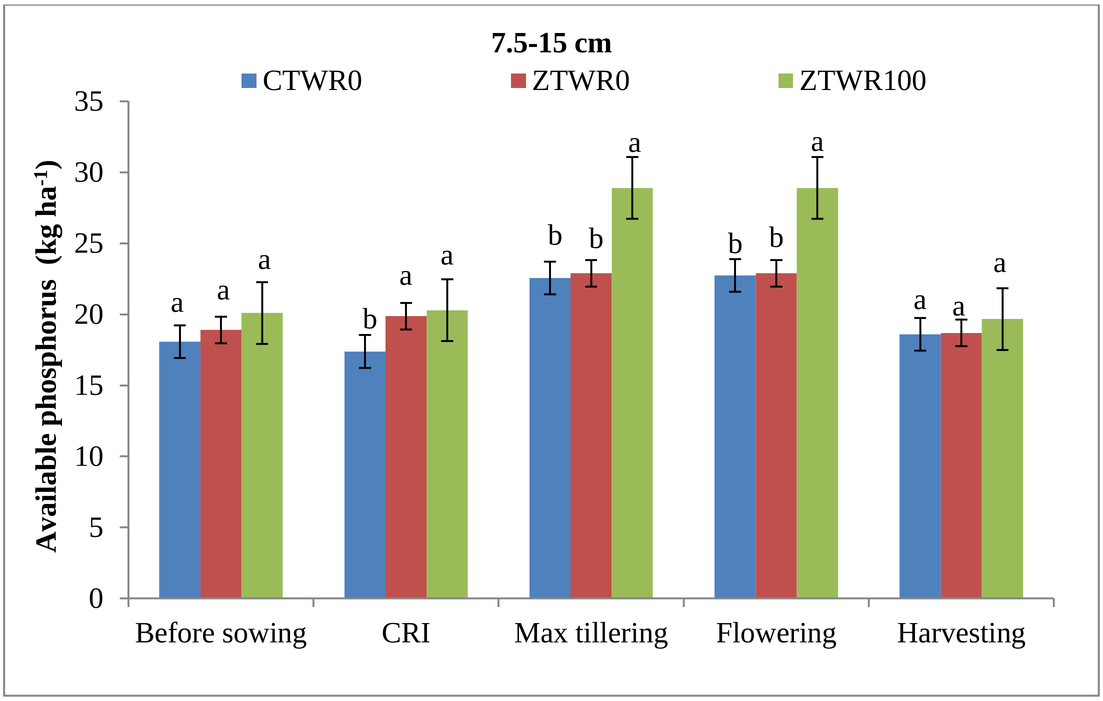
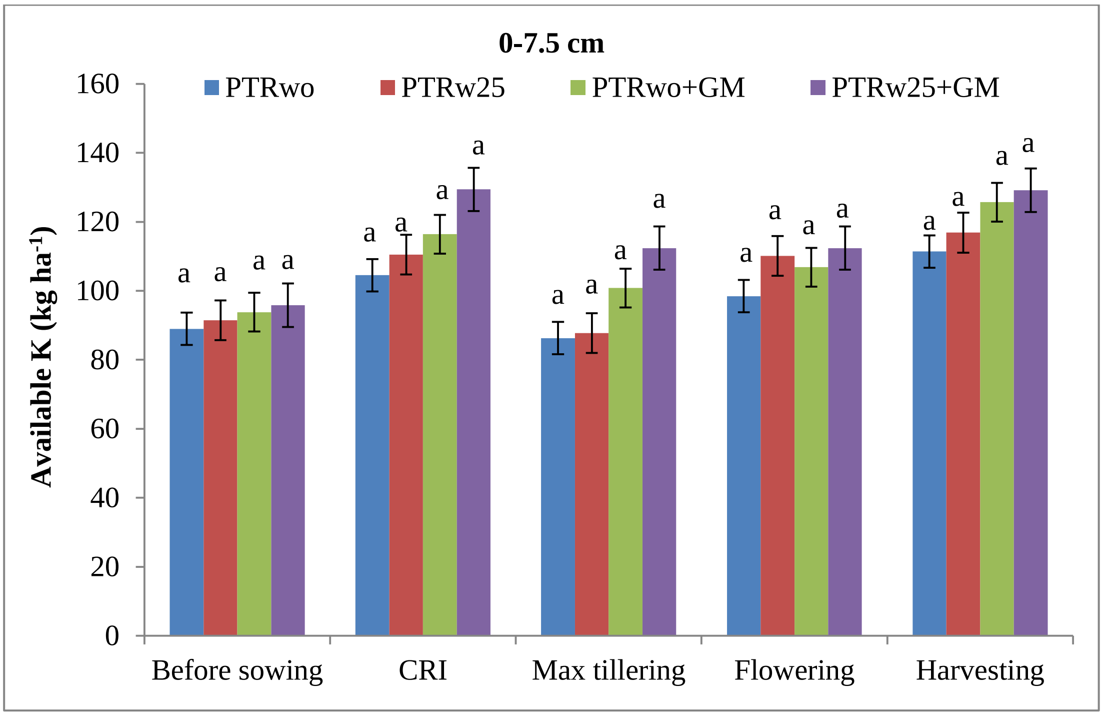


Fig. 4.40: Available phosphorus in soil (kg ha^{-1}) during different growth stages of wheat in sub-surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at p<0.05). Columns with same latter are not significantly different (p<0.05).

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

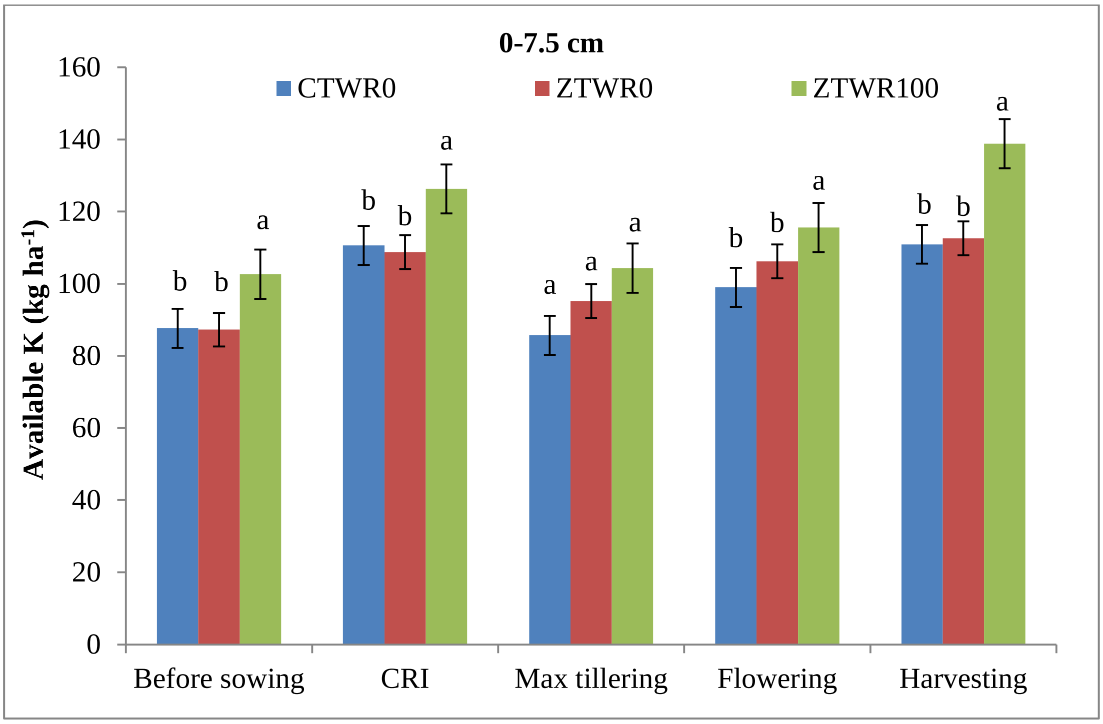
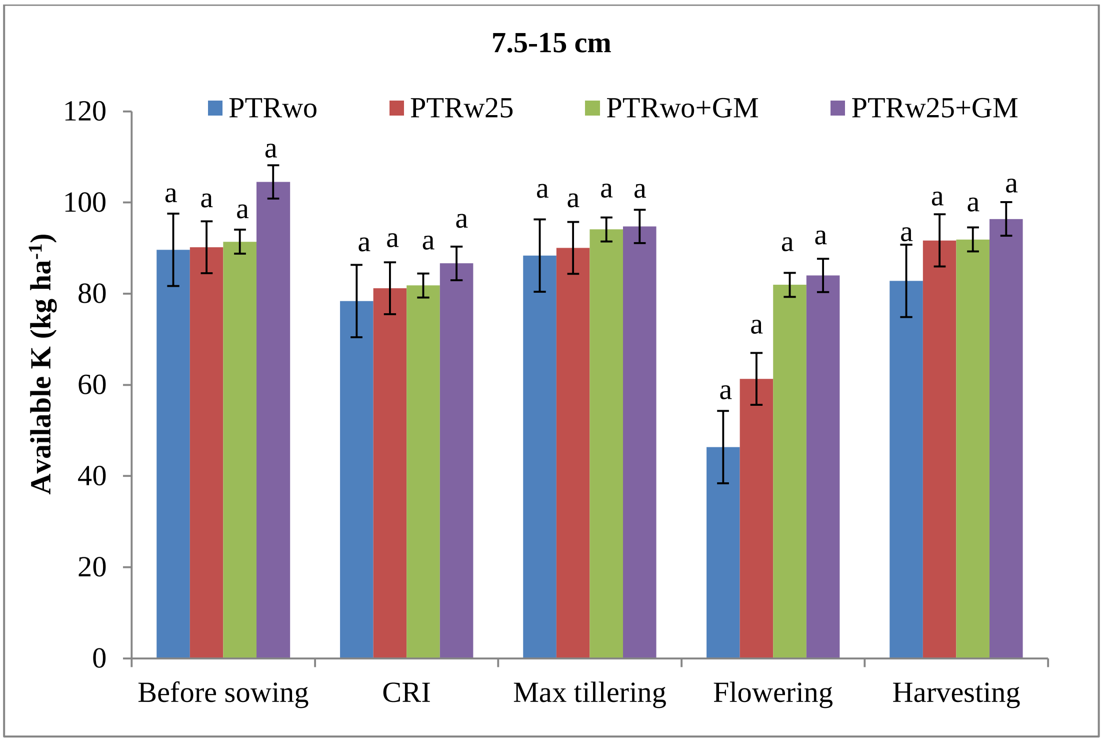


Fig. 4.41: Available potassium in soil (kg ha^{-1}) during different growth stages of wheat in surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at p<0.05). Columns with same latter are not significantly different (p<0.05).

(a) Wheat straw and green manure practices in rice



(b) Tillage and rice straw management practices in wheat

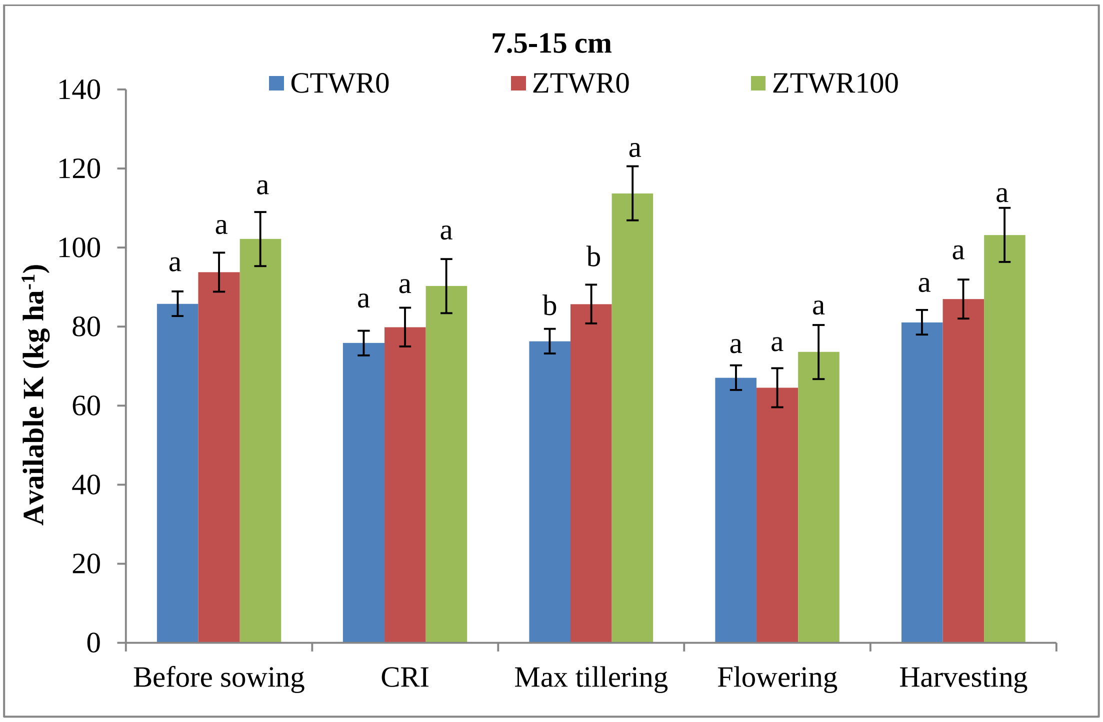


Fig. 4.42: Available potassium in soil (kg ha^{-1}) during different growth stages of wheat in sub-surface soil layer as influenced by (a) Wheat straw and green manure practices in rice (b) Tillage and rice straw management practices in wheat. (Vertical bars are the standard errors of the means at p<0.05). Columns with same latter are not significantly different (p<0.05).

available P content was significantly higher under PTR_{W25}+GM than the other treatments. Likewise, available P content was higher under zero tillage than the conventional tillage. Roldan *et al* (2003) concluded that adoption of no tillage leads to substantial increase of available P as compared with conventional tillage practices in maize (*Zea mays* L.) based cropping system. However, they did not observe any significant increase of available P after incorporation of legume into soil. In the present study, maximum value of available P content in soil was observed at maximum tillering stage in surface layer and at flowering stage in the sub-surface soil layer. Tamilselvi *et al* (2015) observed continuous increase of available P with growth of maize up to vegetative stage, and then it decreased gradually up to maturity. Das *et al* (2014) also reported significant increase of available P in rice crop under minimum tilled soil than intensive tillage systems. Available P content decreased with depth possibly due to greater amount of crop residue addition at superficial soil layer than to sub-surface soil layer. Kushwah *et al* (2016) observed increased availability of P in surface soil layer with wheat residue retention as compared to its burning or removal in a soybean-wheat system in central India.

4.2.5 Available potassium (K) content

Wheat straw and green manure practices in rice, irrespective of tillage and rice straw management practices in subsequent wheat failed to cause any significant effect on available K content in soil at any of the growth stages of wheat (Fig 4.41 and 4.42). However, available K content in soil was significantly affected by tillage and rice straw management practices in wheat at all the growth stages of wheat in the surface soil layer except at MT stage. The interaction between wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was not significant at all the growth stages of wheat in both the soil layer. ZTW_{R100} exhibited higher available K content than ZTW_{R0} and CTW_{R0}. Maximum available K content was observed at harvesting stage in surface soil layer and at maximum tillering stage in sub-surface soil layer. Available K decreased with depth. Retention of rice residue used to have positive effect on available K content in soil because 80-85% of K uptake by rice and wheat plant is retained in its straw (Yadvinder-Singh and Sidhu 2014). Das *et al* (2014) reported that minimising soil disturbance with no tillage practices had improved the status of available K in soil. Villamil and Nafziger (2015) reported that exchangeable K was significantly higher in 0-15 cm soil layer under no tillage and corn (*Zea mays* L.) residue retention than chisel plough and residue removal after 5 year of continuous corn cropping. Wei *et al* (2015) observed 10.3-27.3% increase of available K content in 0-40 cm soil layer under wheat straw incorporation (9.0 t ha^{-1}) into the soil as compared to wheat straw removal after 4 year of wheat-fallow cropping system. Iqbal *et al* (2005) reported that soil K content was not affected by tillage practices but soil mulching with wheat straw significantly increased K content in soil under wheat-maize system after 2 year field experimentation.

4.3 Effect of wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat on wheat yield and nutrient uptake

4.3.1 Yield and yield attributes of wheat

Wheat straw and green manure practices in rice, irrespective of tillage and rice straw management practices in wheat significantly affected grain yield of wheat (Table 4.1). Similarly, grain yield of wheat was significantly affected by tillage and rice straw management practices in wheat, irrespective wheat straw and green manure practices in rice. The interaction between wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was not significant. Grain yield under PTR_{W0}+GM and PTR_{W25}+GM was 13.8% and 15.8% higher than PTR_{W0} and PTR_{W25}. Among different tillage and rice straw management practices in wheat, wheat yield in ZTW_{R100} was increased by 19.9% and 8.7% as compared with ZTW_{R0} and CTW_{R0}, 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 greater availability of water to the wheat crop (Singh *et al* 2011). Usman *et al* (2014) 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. Zamir *et al* (2013) observed maximum yield of maize under zero tillage with wheat straw mulch than conventional tillage with straw dust mulch. Salahin *et al* (2017) reported significant increase of 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% lower under raised bed system as compared with flat and conventional tillage system. Yadvinder-singh *et al* (2004) 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 with mulching with *Sesbania rostrata* than without mulching in a maize-wheat cropping system. Lower lignin content (8.7%), higher decomposition and mobilization of nutrients of *sesbania* had positive effect on maize yield. Talukder *et al* (2008) recorded increase in grain yield of each crop in a rice-wheat-maize system in 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_{R00} (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 year 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. This difference between tillage permutations may be due to added conducive water balance under NT as an outcome of lesser evaporation rates in a semi-humid climate, which in turn leads to superior yield under NT (Bono *et al* 2008). 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. In a long term study, Parihar *et al* (2016) reported that maize yield under zero tillage is significantly higher as compared with conventional tillage. They also observed that incorporation of legumes into maize based cropping system significantly increased maize yield. Tillage and rice straw management practices in wheat significantly affected straw yield of wheat (Table 4.1). However, different wheat straw and green manure practices in rice, irrespective of tillage and rice straw management practices in wheat failed to produce any significant effect on straw yield of wheat. The interaction between wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat was not significant. ZTW_{R100} produced 4.7% higher straw yield than CTW_{R0}. Straw yield under ZTW_{R0} and CTW_{R0} were statistically at par. Salahin *et al* (2017) observed that straw yield of wheat was significantly higher under deep tillage and conventional tillage systems as compared to minimum tillage in the first year of adoption of minimum tillage practices. They also observed that in third cropping cycle, rice straw yield was significantly higher (5.85 t/ha) 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 a 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.

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 or

Table 4.1: Wheat yield as influenced by wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat after 5 years of rice-wheat cropping system

Treatments	**Grain yield ($t\ ha^{-1}$)**	**Straw yield ($t\ ha^{-1}$)**	**Harvest index**	**1000 Grain Weight (g)**
PTR_{wo}/CTW_{Ro}	4.75	6.67	0.417	32.4
PTR_{wo}/ZTW_{Ro}	4.10	6.62	0.381	28.1
PTR_{wo}/ZTW_{100}	5.28	6.79	0.436	33.0
PTR_{w25}/CTW_{Ro}	5.25	6.73	0.437	32.1
PTR_{w25}/ZTW_{Ro}	4.78	6.71	0.416	28.6
PTR_{w25}/ZTW_{R100}	5.43	6.98	0.434	32.7
PTR_{wo}+GM/CTW_{Ro}	5.41	6.78	0.442	31.7
PTR_{wo}+GM/ZTW_{R0}	4.81	6.74	0.416	29.6
PTR_{wo}+GM/ZTW_{R100}	5.86	7.26	0.446	34.2
PTR_{w25}+GM/CTW_{R0}	5.82	6.88	0.458	34.3
PTR_{w25}+GM/ZTW_{R0}	5.56	6.79	0.448	30.2
PTR_{w25}+GM/ZTW_{R100}	6.52	7.29	0.472	35.1
Wheat straw and green manure practices in rice				
PTR_{wo}	4.71b	6.69	0.412	31.2
PTR_{w25}	5.15b	6.80	0.429	31.1
PTR_{wo}+GM	5.36ab	6.92	0.435	31.2
PTR_{w25}+GM	5.96a	6.98	0.459	33.2
LSD (0.05)	0.80	NS	NS	NS
Tillage and rice straw management practices in wheat				
CTW_{R0}	5.31ab	6.76b	0.44	32.6
ZTW_{R0}	4.81b	6.71b	0.42	29.1
ZTW_{R100}	5.77a	7.08a	0.45	33.8
LSD (0.05)	0.54	0.22	NS	NS
LSD Interaction (0.05)	NS	NS	NS	NS

Table 4.2: Yield attributes of wheat as influenced by wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat after 5 years of rice-wheat cropping system

Treatments	Effective Tiller	Non effective tiller	Plant height (cm)	Spike length (cm)	No of grain/spike
PTR_{wo}/CTW_{Ro}	75.3	7.7	87.7	12.5	68.0
PTR_{wo}/ZTW_{Ro}	59.2	6.5	86.9	12.6	58.8
PTR_{wo}/ZTW_{100}	75.3	8.3	86.4	12.9	67.2
PTR_{w25}/CTW_{Ro}	79.2	8.2	86.7	12.7	69.7
PTR_{w25}/ZTW_{Ro}	68.0	8.0	83.9	12.2	62.7
PTR_{w25}/ZTW_{R100}	69.8	7.5	87.5	12.3	71.0
PTR_{wo}+GM/CTW_{Ro}	72.5	7.8	87.2	12.7	68.8
PTR_{wo}+GM/ZTW_{R0}	69.5	7.8	83.1	12.3	66.0
PTR_{wo}+GM/ZTW_{R100}	84.2	8.0	86.7	12.7	70.3
PTR_{w25}+GM/CTW_{R0}	72.8	6.7	81.5	12.6	69.0
PTR_{w25}+GM/ZTW_{R0}	64.3	7.3	84.3	12.4	68.2
PTR_{w25}+GM/ZTW_{R100}	75.7	7.5	87.0	12.7	73.5
Wheat straw and green manure practices in rice					
PTR_{wo}	69.9	7.5	87.0	12.7	64.7
PTR_{w25}	72.3	7.9	86.0	12.4	67.8
PTR_{wo}+GM	75.4	7.9	85.7	12.6	68.4
PTR_{w25}+GM	70.9	7.2	84.3	12.6	70.2
LSD (0.05)	NS	NS	NS	NS	NS
Tillage and rice straw management practices in wheat					
CTW_{R0}	75.0a	7.6	85.8	12.6	68.9a
ZTW_{R0}	65.3b	7.4	84.5	12.4	63.9b
ZTW_{R100}	76.3a	7.8	86.9	12.7	70.5a
LSD (0.05)	8.2	NS	NS	NS	4.9
LSD interaction (0.05)	NS	NS	NS	NS	NS

their interaction did not significantly affected the harvest index (Table 4.1). Among the wheat straw and green manure practices in rice, harvest index value was higher in PTR_{W25}+GM treatment. It signifies better productivity of the system. Similarly, highest value of harvest index was recorded under ZTW_{R100} followed by $CTW_{R0,}$ and least value was observed under $ZTW_{R0.}$ Thousand grain weights is a function of production factors that give indication of 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 as well as their interaction failed to cause any significant effect on thousand grain weight of wheat (Table 4.1). Nevertheless, highest value of thousand grain weight was observed under PTR_{W25}+GM (33.2 g). Similarly, among different tillage and rice straw management practices in wheat, highest value of thousand grain weight was observed under ZTW_{R100}. Jin *et al* (2009) observed higher thousand grain weight of wheat under ZT with maize residue as compared with 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 residue retention than other tillage methods with removal or burning of rice residue. Ruisi *et al* (2016) reported significant increase of 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 year 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.

Tillage and rice straw management in wheat, irrespective of wheat straw and green manure practices in rice significantly affected the numbers of effective tillers of wheat (Table 4.2). However, the effect of wheat straw and green manure practices in rice, on number of effective tillers of wheat was not significant. The interaction between tillage and rice straw management practices in wheat and different wheat straw and green manure practices in rice was not significant. Number of effective tillers of subsequent wheat under ZTW_{R100} and CTW_{R0} was significantly higher than $ZTW_{R0.}$ Tillage and rice straw management practices in wheat and different wheat straw and green manure practices in rice as well as their interaction failed to cause any significant effect on the numbers of non effective tillers of wheat (Table 4.2).

Spike length and plant height of wheat was not significantly affected by wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat (Table 4.2). Tillage and rice straw management practices in wheat, irrespective of different wheat straw and green manure practices in rice significantly affected grain $spike^{-1}$ of wheat

(Table 4.2). The effect of wheat straw and green manure practices in rice on grain spike^{-1} of wheat was not significant. Number of grain spike^{-1} of wheat under ZTW_{R100} was statistically similar with CTW_{R0}. The interaction between tillage and rice straw management practices in wheat and wheat straw and green manure practices in rice was not significant. Ruisi *et al* (2016) observed that number of spikes per square meter and the number of kernels per spike of wheat crop was not significantly affected by tillage practices. Usman *et al* (2014) observed significant response of tillage and nitrogen fertilization on number of grain per spike of wheat, grain per spike of wheat was significantly higher under ZT with retention or incorporation of rice straw rather than removal or burning. Similarly, Jin *et al* (2009) reported higher number of grain per spike under ZT with maize residue retention than ZT without residue and conventional tilled wheat. Rahman *et al* (2005) reported that number of grain per spike was higher in wheat sown with rice straw mulching as compared with no mulching. Seddaiu *et al* (2016) observed that the number of kernels per spike of wheat showed slightly higher value under no tillage than minimum tillage and conventional tillage after 20 year tillage experiment.

4.3.2 Total N, P and K concentration and uptake in grain and straw of wheat

Total Nitrogen uptake

Wheat straw and green manure practices in rice significantly affected nitrogen concentration in wheat straw, but failed to cause significant effect on nitrogen concentration in wheat grain (Table 4.3). The effect of tillage and rice straw management practices in subsequent wheat irrespective of different wheat straw and green manure practices in rice on nitrogen concentration in wheat grain and straw was not significant. Nitrogen concentration in wheat straw under PTR_{W0}+GM and PTR_{W25}+GM was 21.1% and 15.7% higher than PTR_{W0} and $PTR_{W25.}$ Nitrogen uptake (kg ha^{-1}) by grain and straw as well as total nitrogen uptake by the wheat crop was significantly affected by wheat straw and green manure practices in rice (Table 4.3). Tillage and rice straw management practices in wheat significantly affected nitrogen uptake by grain and total nitrogen uptake by wheat. Nitrogen uptake by grain increased 20.3% and 15.3% under PTR_{W0}+GM and PTR_{W25}+GM than PTR_{W0} and $PTR_{W25.}$ Similarly, nitrogen uptake by straw significantly increased (25.9% and 18.3%) under PTR_{W0}+GM and PTR_{W25}+GM than PTR_{W0} and $PTR_{W25.}$ Total nitrogen uptake by wheat crop under PTR_{W0}+GM and PTR_{W25}+GM was 21.98% and 16.1% higher than PTR_{W0} and $PTR_{W25.}$ Among different tillage and rice straw management practices in wheat, ZTW_{R100} increased 20.8% and 10.4% total nitrogen uptake by wheat crop as compared with ZTW_{R0} and $CTW_{R0.}$ The effect of different wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat as well as their interaction on nitrogen harvest index

Table 4.3: Nitrogen concentration (%) in grain and straw and nitrogen uptake (Kg ha^{-1}) in wheat as influenced by wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat after 5 years of rice-wheat cropping system

Treatments	N (%) in grain	N (%) in straw	N uptake by grain (Kg ha^{-1})	N uptake by straw (Kg ha^{-1})	Total N uptake (Kg ha^{-1})	NHI
PTR_{wo}/CTW_{Ro}	1.25	0.38	59.5	25.4	84.9	0.70
PTR_{wo}/ZTW_{Ro}	1.33	0.35	54.8	23.3	78.1	0.70
PTR_{wo}/ZTW_{100}	1.33	0.40	69.6	27.1	96.7	0.72
PTR_{w25}/CTW_{Ro}	1.40	0.43	73.5	28.7	102.3	0.72
PTR_{w25}/ZTW_{Ro}	1.36	0.34	64.9	22.5	87.4	0.74
PTR_{w25}/ZTW_{R100}	1.40	0.43	76.1	30.0	106.1	0.71
PTR_{wo}+GM/CTW_{Ro}	1.36	0.45	73.8	30.7	104.5	0.70
PTR_{wo}+GM/ZTW_{R0}	1.38	0.46	66.5	30.9	97.4	0.68
PTR_{wo}+GM/ZTW_{R100}	1.39	0.47	80.9	33.9	114.8	0.70
PTR_{w25}+GM/CTW_{R0}	1.38	0.45	80.2	30.7	111.0	0.72
PTR_{w25}+GM/ZTW_{R0}	1.33	0.46	74.0	31.4	105.4	0.70
PTR_{w25}+GM/ZTW_{R100}	1.42	0.47	93.1	34.0	127.2	0.73
Wheat straw and green manure practices in rice						
PTR_{wo}	1.30	0.38b	61.3b	25.3c	86.5b	0.71
PTR_{w25}	1.38	0.40b	71.5ab	27.1b	98.6b	0.72
PTR_{wo}+GM	1.37	0.46a	73.7ab	31.8a	105.6ab	0.70
PTR_{w25}+GM	1.39	0.46a	82.5a	32.1a	114.5a	0.72
LSD (0.05)	NS	0.03	12.9	1.5	13.2	NS
Tillage and rice straw management practices in wheat						
CTW_{R0}	1.34	0.43	71.8ab	28.9	100.7b	0.71
ZTW_{R0}	1.35	0.40	65.0b	27.0	92.1b	0.71
ZTW_{R100}	1.38	0.44	79.9a	31.3	111.2a	0.72
LSD (0.05)	NS	NS	9.1	NS	10.4	NS
LSD interaction (0.05)	NS	NS	NS	NS	NS	NS

(NHI) was not significant (Table 4.3). Iqbal *et al* (2011) reported that N, P and K concentration in wheat shoot was higher under minimum tillage, conventional tillage and deep tillage than zero tillage under wheat-maize cropping system. Malhi and Lamke (2007) reported that grain N uptake of wheat was significantly higher under zero tilled wheat with rice straw retained as surface mulch than zero tillage without mulch. Ebrahiman *et al* (2016) observed that nitrogen concentration in wheat grain and straw under chisel plough was significantly higher than mouldboard plough + disk plough in a rice-wheat cropping system. Martinez *et al* (2017) recorded significantly higher N uptake by wheat crop under no tillage than conventional tillage after 4 year experiment in a semi-humid climate of Argentina. Bakht *et al* (2009) reported that N uptake in wheat grain and straw was 1.31 and 1.64 times higher with incorporation of maize or mung bean residue than without residue incorporation. They also reported that N uptake in wheat grain and straw under incorporation of mungbean residue was 2.08 and 2.49 times higher as compared with incorporation of maize residue.

Total Phosphorus Uptake

Phosphorus concentration in wheat grain and straw was not significantly affected by wheat straw and green manure practices in rice and tillage and rice straw management practices in subsequent wheat as well as their interaction (Table 4.4). However, tillage and rice straw management practice in subsequent wheat, irrespective of different wheat straw and green manure practices in rice significantly affected P uptake by grain and total P uptake by the wheat crop (Table 4.4). Phosphorus uptake by grain under ZTW_{R100} was 28.6% and 19.6% higher than ZTW_{R0} and $CTW_{R0.}$ Similarly, total P uptake by wheat crop was significantly higher (28.2% and 19.6%) than ZTW_{R0} and $CTW_{R0.}$ Wheat straw and green manure practices in rice failed to cause any significant effect on P uptake by grain and straw as well as total P uptake by the wheat crop. Nevertheless, total P uptake by the wheat crop under PTR_{W0}+GM and PTR_{W25}+GM was 16.4% and 8.7% higher than PTR_{W0} and $PTR_{W25.}$ Wheat straw and green manure practices in rice and tillage and rice straw management practices in subsequent wheat as well as their interaction failed to cause any significant effect on phosphorus harvest index (PHI) (Table 4.4). Stanislawska-glubaik and koezeniowska (2012) observed that P concentration in grain and straw of winter wheat crop was not significantly affected by zero tillage

Table 4.4: Phosphorus concentration (%) in grain and straw and P uptake (Kg ha^{-1}) in wheat as influenced by wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat after 5 years of rice-wheat cropping system

Treatments	**P (%) in grain**	**P (%) in straw**	**P uptake by grain (Kg ha^{-1})**	**P uptake by straw (Kg ha^{-1})**	**Total P uptake (Kg ha^{-1})**	**PHI**
PTR_{wo}/CTW_{Ro}	0.29	0.031	13.8	2.04	15.8	0.87
PTR_{wo}/ZTW_{Ro}	0.26	0.031	10.5	2.07	12.6	0.84
PTR_{wo}/ZTW_{100}	0.30	0.035	16.3	2.40	18.7	0.86
PTR_{w25}/CTW_{Ro}	0.29	0.029	14.8	1.97	16.8	0.86
PTR_{w25}/ZTW_{Ro}	0.33	0.021	15.6	1.41	17.0	0.91
PTR_{w25}/ZTW_{R100}	0.31	0.031	16.6	2.19	18.8	0.88
PTR_{wo}+GM/CTW_{Ro}	0.29	0.031	15.3	2.13	17.5	0.87
PTR_{wo}+GM/ZTW_{R0}	0.31	0.031	14.8	2.11	16.9	0.87
PTR_{wo}+GM/ZTW_{R100}	0.30	0.036	17.8	2.59	20.4	0.87
PTR_{w25}+GM/CTW_{R0}	0.27	0.031	15.4	2.14	17.5	0.88
PTR_{w25}+GM/ZTW_{R0}	0.27	0.033	14.3	2.26	16.5	0.86
PTR_{w25}+GM/ZTW_{R100}	0.31	0.038	20.3	2.77	23.1	0.88
Wheat straw and green manure practices in rice						
PTR_{wo}	0.28	0.032	13.5	2.17	15.7	0.86
PTR_{w25}	0.31	0.027	15.7	1.86	17.5	0.89
PTR_{wo}+GM	0.30	0.033	16.0	2.28	18.3	0.97
PTR_{w25}+GM	0.28	0.034	16.7	2.39	19.0	0.87
LSD (0.05)	NS	NS	NS	NS	NS	NS
Tillage and rice straw management practices in wheat						
CTW_{R0}	0.28	0.030	14.8ab	2.07	16.9b	0.87
ZTW_{R0}	0.29	0.029	13.8b	1.96	15.8b	0.87
ZTW_{R100}	0.30	0.035	17.7a	2.49	20.2a	0.87
LSD (0.05)	NS	NS	3.2	NS	3.1	NS
LSD interaction (0.05)	NS	NS	NS	NS	NS	NS

Table 4.5: Potassium concentration (%) in grain and straw and K uptake (Kg ha^{-1}) in wheat as influenced by wheat straw and green manure practices in rice and tillage and rice straw management practices in wheat after 5 years of rice-wheat cropping system

Treatments	K (%) in grain	K (%) in straw	K uptake by grain (Kg ha^{-1})	K uptake by straw (Kg ha^{-1})	Total K uptake (Kg ha^{-1})	KHI
PTR_{wo}/CTW_{Ro}	0.33	0.93	16.2	62.3	78.6	0.21
PTR_{wo}/ZTW_{Ro}	0.32	1.06	13.1	70.3	83.5	0.16
PTR_{wo}/ZTW_{100}	0.33	1.25	17.5	84.3	101.9	0.17
PTR_{w25}/CTW_{Ro}	0.36	0.96	19.1	64.4	83.6	0.22
PTR_{w25}/ZTW_{Ro}	0.32	0.92	15.2	61.9	77.1	0.20
PTR_{w25}/ZTW_{R100}	0.36	1.36	19.9	94.6	114.5	0.17
PTR_{wo}+GM/CTW_{Ro}	0.35	0.98	18.8	66.9	85.8	0.23
PTR_{wo}+GM/ZTW_{R0}	0.39	1.03	18.7	69.3	88.1	0.22
PTR_{wo}+GM/ZTW_{R100}	0.36	1.29	20.9	93.9	114.8	0.18
PTR_{w25}+GM/CTW_{R0}	0.35	1.14	20.4	78.1	98.5	0.21
PTR_{w25}+GM/ZTW_{R0}	0.36	0.99	19.8	67.0	86.9	0.23
PTR_{w25}+GM/ZTW_{R100}	0.34	1.42	21.8	103.4	125.2	0.17
Wheat straw and green manure practices in rice						
PTR_{wo}	0.33	1.08	15.6	72.3	88.0	0.18
PTR_{w25}	0.35	1.08	18.1	73.6	91.8	0.20
PTR_{wo}+GM	0.36	1.10	19.5	76.7	96.3	0.21
PTR_{w25}+GM	0.35	1.18	20.6	82.8	103.5	0.21
LSD (0.05)	NS	NS	NS	NS	NS	NS
Tillage and rice straw management practices in wheat						
CTW_{R0}	0.35	1.00b	18.6	68.0b	86.7b	0.22
ZTW_{R0}	0.35	1.00b	16.7	67.2b	83.9b	0.20
ZTW_{R100}	0.35	1.32a	20.0	94.0a	114.1a	0.17
LSD (0.05)	NS	0.20	NS	13.2	12.7	NS
LSD interaction (0.05)	NS	NS	NS	NS	NS	NS

and conventional tillage systems. Kachroo *et al* (2006) observed significant increase of total P uptake with incorporation of rice and wheat straw rather than its removal. Pradhan *et al* (2011) observed that tillage systems with crop residue incorporation significantly increased P uptake by cotton or maize than tillage treatments without residue incorporation.

Total Potassium uptake

Wheat straw and green manure practices in rice, irrespective of tillage and rice straw management practices in subsequent wheat failed to cause any significant effect on concentration of K in wheat grain and straw (Table 4.5). However, tillage and rice straw management practices in wheat had significant effect on concentration of K in wheat straw. K concentration in wheat straw under ZTW_{R100} was significantly higher (32%) than CTW_{R0}. The interaction between wheat straw and green manure practices and tillage and rice straw management practices in subsequent wheat was not significant. Similarly, K uptake by wheat straw and grain as well as total K uptake by the wheat crop was not significantly affected by wheat straw and green manure practices in rice (Table 4.5). However, the effect of tillage and rice straw management practices was significant on K uptake by straw and total K uptake by the wheat crop. K uptake by wheat straw and total K uptake by wheat crop was significantly higher under ZTW_{R100} compared with ZTW_{R0} and $CTW_{R0.}$ Total K uptake by the wheat crop under ZTW_{R100} was 32.1% higher than $CTW_{R0.}$ Wheat straw and green manure practices in rice and tillage and rice straw management practices in subsequent wheat as well as their interaction was not significant on KHI (Table 4.5). Stanislawska-glubaik and koezeniowska (2012) observed that K concentration in grain and straw of winter wheat crop was not significantly affected by zero tillage and conventional tillage systems. Sharma and Bali (1998) reported significant increase of K uptake by wheat crop with incorporation of rice stubble with 30kg N ha^{-1} to decompose rice stubbles. This may be due to rapid decomposition of rice stubbles because of N application at the time of field preparation. Kachroo *et al* (2006) observed significant increase of total K uptake with incorporation of rice and wheat straw rather than its removal, as 75-80% of K is retained in cereal crop residues making them valuable nutrient sources. Iqbal *et al* (2005) observed higher K concentration in the order minimum tillage>conventional tillage >deep tillage.

4.4 Correlation among soil enzyme activities, chemical properties, nutrient uptake and grain yield in surface and subsurface soil layer

Correlation among soil enzyme activities, chemical properties, nutrients uptake and grain yield in surface and subsurface soil layer during different growth stages of wheat are presented in Tables 4.8-4.17.

Before sowing of wheat, DHA was significantly correlated with all the enzymatic activities except urease in the surface soil layer (Table 4.8) and ALP and phytase in the sub-surface soil layer (Table 4.9). DHA was highly correlated with MBC in both surface (0.793**) and sub-surface (0.846**) soil layer. Similarly, FDA was significantly correlated with MBC and SOC in both the soil layers. ALP activity in the surface soil layer was highly correlated with ACP (0.915**), total polysaccharide carbon (0.910**), total glomalin content (0.885**), SOC (0.948**) and available nitrogen (0.948**). ACP activity was highly correlated with total polysaccharide carbon (.863**), total glomalin content (0.905**), MBC (0.890**) and SOC (0.870**) in the surface soil layer. Phytase activity was highly correlated with total carbohydrate carbon (0.912**) and MBC (0.855**) in the surface soil layer. β-glucosidase activity was highly correlated with total polysaccharide carbon (0.873**) in the sub-surface soil layer. Cellulase activity was highly correlated with MBC in both surface (0.900**) and sub-surface (0.874**) soil layer. Polyphenol oxidase and peroxidase activity were negatively correlated with all other enzyme activities, chemical properties, nutrient uptake and wheat yield. But they were positively correlated with each other. Total polysaccharide carbon was highly correlated with total carbohydrate carbon (0.922**) and total glomalin content (0.891**) in the surface soil layer, and MBC (0.851**) in the sub-surface soil layer. Total carbohydrate carbon was highly correlated with total glomalin content (0.875**) and MBC (0.866**) in the surface soil layer. Total glomalin content was highly correlated to MBC (0.878**) and SOC (0.920**) in the surface soil layer. MBC was highly correlated to SOC (0.864**) and available phosphorus (0.875**) in the surface soil layer and soil respiration (0.883**), SOC (0.867**) and total nitrogen uptake (0.859**) in the sub-surface soil layer. Soil respiration was highly correlated to available phosphorus (0.883**) in the sub-surface soil layer. Grain yield was significantly correlated with DHA (0.789**) alkaline phosphatase (0.713**), basal soil respiration (0.877**), SOC (0.861**), available N (0.790**) and available P (0.744**) in the surface soil layer and with DHA (0.732**), acid phosphatase (0.890**), MBC (0.842**), basal soil respiration (0.764**), available N (0.818**) and available P (0.744**) in the sub-surface soil layer.

At CRI stage, DHA was highly correlated with alkaline phosphatase (0.891**), β-glu (0.974**), MBC (0.914**), basal soil respiration (0.864**) and SOC (0.912**) in the surface soil layer (Table 4.10). FDA was highly correlated with β-glu (0.894**), total N uptake (0.905**) and total P uptake (0.850**) in the sub-surface soil layer (Table 4.11). Acid phosphatase was highly correlated with alkaline phosphatase (0.933**), β-glu (0.912**), total polysaccharide carbon (0.889**) and MBC (0.869**) in the surface soil layer. β-glu was highly correlated with SOC (0.914**) in the surface soil layer. Xylanase in the surface soil layer was highly correlated with easily extractable glomalin (0.940**) and MBC (0.875**).

Polyphenol oxidase and peroxidase activity were negatively correlated with all other enzyme activities, chemical properties, nutrient uptake and wheat yield. But they were positively correlated with each other. Significant correlation was observed between total polysaccharide carbon and total carbohydrate carbon in both surface (0.897**) and sub-surface (0.868**) soil layer. MBC was highly correlated with soil respiration (0.868**) and total N uptake (0.918**) in the surface soil layer and available K (0.880**) in the sub-surface soil layer. Grain yield of wheat was significantly correlated with DHA (0.763**), acid phosphosphatase (0.791**), xylanase (0.833**), MBC (0.875**), basal soil respiration (0.893**), SOC (0.764**), available N (0.818**), available P (0.748**) and available K (0.847**) in the surface soil layer and with DHA (0.887**), FDA (0.825**) and β-glu (0.840**) in the sub-surface soil layer.

At maximum tillering stage, DHA was highly correlated with acid phosphatase (0.897**), β-glu (0.865**), Cellulase (0.815**), total carbohydrate carbon (0.790**), SOC (0.794**) and total N uptake (0.797**) in the surface soil layer (Table 4.12). Similarly in the sub-surface soil layer (Table 4.13), DHA was highly correlated with alkaline phosphatase (0.856**), acid phosphatase (0.869**), β-glu (0.851**), Cellulase (0.842**), total polysaccharide carbon (0.829**), MBC (0.797**), SOC (0.844**), available P (0.888**) and total N uptake (0.852**). Alkaline phosphatase activity in the surface soil layer was highly correlated with acid phosphatase (.864**), β-glu (0.874**), MBC (0.870**), basal soil respiration (0.934**), SOC (0.819**) and available P (0.862**). Alkaline phosphatase activity was highly correlated with available P (0.913**) in the sub-surface soil layer. Acid phosphatase activity in the surface soil layer was highly correlated with MBC (0.907**) and SOC (0.892**). β-glu activity was highly correlated with total carbohydrate C (0.905**), MBC (0.914**) and SOC (0.897**) in the surface soil layer and MBC (0.908**) in the sub-surface soil layer. Cellulase activity was highly correlated with SOC (0.893**) in the sub-surface soil layer. Polyphenol oxidase and peroxidase activity were negatively correlated with all the soil variables studied. Total carbohydrate carbon was highly correlated with SOC (0.966**) in the surface soil layer and with MBC in both surface (0.866**) and sub-surface (0.853**) soil layer. MBC and basal soil respiration were significantly correlated (0.886**) in the surface soil layer. SOC was significantly correlated with available K (0.873**) in the surface soil layer and available N (0.813**) and available k (0.817**) in the sub-surface soil layer. Grain yield of wheat was highly correlated with DHA (0.771**), cellulase (0.812**), total carbohydrate carbon (0.788**) and available P (0.807**) in the surface soil layer and

DHA (0.808**), alkaline phosphatase (0.812**) and available P (0.860**) in the sub-surface soil layer.

At flowering stage, DHA was highly correlated with alkaline phosphatase (0.866**), phytase (0.883**), β-glu (0.834**), MBC (0.859**) and SOC (0.948**) in the surface soil layer (Table 4.14) and with β-glu (0.955**) and SOC (0.928**) in the sub-surface soil layer (Table 4.15). Alkaline phosphatase activity in the surface soil layer was highly correlated with β-glu (0.874**), total polysaccharide carbon (0.940**) and easily extractable glomalin (0.885**). Acid phosphatase activity was highly correlated with total glomalin content (0.958**), SOC (0.863**) and available P (0.904**) in the surface soil layer. Phytase activity was highly correlated with cellulase (0.928**) and SOC (0.879**) in the surface soil layer. β-glu acitivity was highly correlated with SOC in both surface (0.862**) and subsurface (0.928**) soil layer. SOC and basal soil respiration was significantly correlated (0.880**) with each other in the surface soil layer. Polyphenol oxidase and peroxidase activity were negatively correlated with all other enzyme activities, chemical properties, nutrient uptake and wheat yield. Grain yield of wheat was highly correlated with FDA (0.907**) in the surface soil layer and with β-glu (0.783**) and available P (0.884**) in the subsurface soil layer.

At harvesting stage, DHA in the surface soil layer (Table 4.16) was highly correlated with, cellulase (0.908**), SOC (0.834**), total P uptake (0.872**) and total K uptake (0.847**). FDA was highly correlated with MBC (0.943**) and basal soil respiration (0.943**) in the surface soil layer and with total carbohydrate carbon (0.866**) in the sub-surface soil layer (Table 4.17). Alkaline phosphatase activity was highly correlated with acid phosphatase (0.945**), xylanase (0.920**) and total carbohydrate carbon (0.930**) in the surface soil layer. Asparginase activity in the surface soil layer was highly correlated with cellulase (0.921**). β-glu activity was highly correlated with MBC (0.902**) and basal soil respiration (0.902**) in the surface soil layer. Xylanase in the surface soil layer was highly correlated with cellulase (0.875**). Polyphenol oxidase and peroxidase activity were negatively correlated with all other enzyme activities, chemical properties, nutrient uptake and wheat yield. MBC was significantly correlated with SOC (0.791**), available P (0.815**) and total N uptake (0.866**) in the surface soil layer and with SOC (0.813**) and total N uptake (0.881**) in the sub-surface soil layer. SOC in the surface soil layer was highly correlated with available P (0.904**). Grain yield of wheat was highly correlated with FDA (0.821**), xylanase (0.808**), cellulase (0.843**), MBC (0.815**), soil respiration (0.815**) and available P in soil (0.868**) in the surface soil layer.

The results of the present study are conformity with the findings of Alvaro-Fuentes *et al* (2013), who observed strong correlation of MBC and DHA with SOC in a long-term (12 years) tillage experiment comprising of no tillage, minimum tillage and conventional tillage permutations cropped with barley (*Hordeum vulgare* L.) in Spain. Mohammadi (2011) reported strong correlation of acid phosphatase and urease with microbial biomass carbon in wheat crop after 2 years of tillage experiment comprising of minimum tillage and conventional tillage practices. Deng and Tabatabai (1997) observed significant correlation between acid and alkaline phosphatase activity, and both the enzymes were strongly correlated with soil organic carbon, signifying that soil organic carbon plays an imperative role in maintaining and protecting soil enzymes in their active forms. Hazarika *et al* (2011) observed significant positive correlation of hot water extractable carbohydrate with microbial biomass carbon, acid phosphatase and β-glu activity in a long-term tillage experiment on wheat crop. Meena *et al* (2013) reported significant positive correlation between DHA and SOC at flowering and harvesting stages of wheat. They observed that polyphenol oxidase and peroxidase were negatively correlated with SOC and other soil variables. Similar results were reported by Sinsabaugh *et al* (2008), who observed that polyphenol oxidase activity is inversely related to the amount of soil organic matter. Li et *al* (2006) observed that soil organic matter decreases with increase in polyphenol oxidase activity in soil. Chu *et al* (2016) observed that polyphenol oxidase and peroxidase were not significantly correlated with SOC in wheat crop. Balota *et al* (2004) observed that soil enzymes (cellulase, acid phosphatase and alkaline phosphatase) were significantly correlated with microbial biomass and soil organic carbon under long-term tillage and crop rotation systems in a subtropical ecosystem. Piotrowska and Wilczewski (2012) reported significant correlation of alkaline phosphatase, acid phosphatase and urease activity with soil organic carbon and total nitrogen in a wheat crop after incorporation of green manure (*Raphanus sativus* L. and *Pisum sativum* L.) after 3 years. Alvear *et al* (2005) observed that MBC was closely associated with ACP and β-glu activity after 3 year experiment with no tillage and stubble retention in wheat-lupin-wheat cropping sequence. Green *et al* (2007) observed that β-glu, ACP and FDA exhibited significant correlation with total soil nitrogen in a maize crop under no till, disk harrow and disk plough tillage practices.

Principal component analysis

Analysis of principal components (PC) of the assessed topsoil (0-7.5 cm) variables showed that first and second component explain 56.01 % of total variance. The variability added by two PCs was 56.01% of which PC1 contributes 43.92% and PC2 another 12.09%

(Fig 4.43; Supplementary Table 4.6). All the assessed variables except pH, PERO, URE and PH OX showed positive correlation with PC1 (Fig. 1A). Among the variables, DHA, ACP, β-glu, CHO, MBC, RES, N, P, GY, SY, NU, PU and KU had significant contribution (>40%) to PC1, while, FDA, URE, PH OXI, PERO, EEG and K contributed to PC2. The parameters (DHA, ACP, β-glu, CHO, MBC, RES) contributed a total of 65.7% variability to PC1, while the other significant variables like FDA, URE, PH OX, PERO, EEG and K added 51.54% cumulative contribution to the PC2 variability.

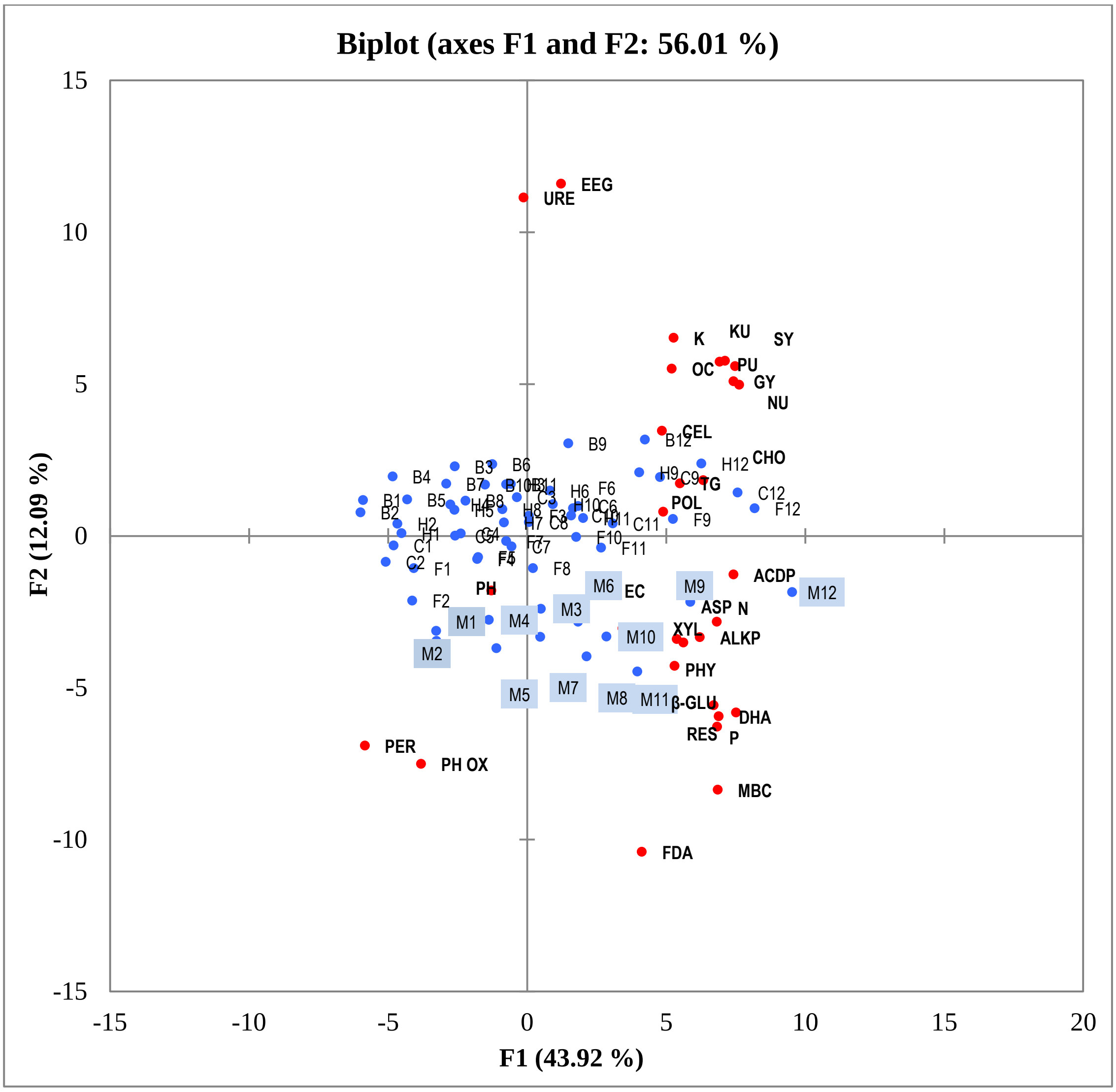
The biplot (Fig 4.43) shows the position of variables and long-term tillage, green manure and residue management practices enforced to soil at different growth stages of wheat in the orthogonal space defined by two PCs. The first two PC has clearly separated maximum tillering stage of wheat from rest of the growth stages of wheat. Most of the treatments in maximum tillering stage are positioned to the right end of the biplot which shows positive score for PC1 and negative score for PC2. The assayed variables (MBC, DHA, P, RES, β-glu, PHY, ALKP, N, ASP, ACDP, XYL and EC) are closely ordinated with the data points representing the treatments in maximum tillering stage in orthogonal space, which depicts that these variables were highly influenced at maximum tillering stage as compared with the other growth stages studied. To some extent PCA separated PTR_{W0}+GM and PTR_{W25}+GM from PTR_{W0} and PTR_{W25} and ZTW_{R100} from ZTW_{R0} and CTW_{R0} respectively.

The PCA of assessed variables for sub-surface (7.5-15 cm) soils of long-term management enforced soils had similar response as that of the surface soil layer (0-7.5 cm). The first two PCs of PCA explained 57.98% of total variability of which PC1 contributed 43.37%, while the PC2 added another 14.61% of variability (Fig. 1C). As similar to top soil, most of the assessed variables except pH showed positive correlation with PC1 and among them, DHA, ACP, β-glu, CHO, MBC, RES, N, P , GY, SY, NU, PU and KU had significant contribution (>40%). The biochemical variables including DHA, ACP, β-glu, CHO, MBC and RES cumulatively contributed 39.55% of the PC1 variablity.

The biplot (Fig 4.44) of variables and treatments clearly discriminated maximum tillering stage of wheat from rest of the wheat growth stages, as 8 of the 12 data points representing the treatments in maximum tillering stage are positioned to the right end of the biplot which has positive score for both the PCs. Among the variables DHA, ACP, ALKP, β-glu, RES, PHY, MBC N and P are closely ordinated with the maximum tillering stage treatments, suggesting that these variables were highly influenced by maximum tillering stage than the rest of the growth stages studied.

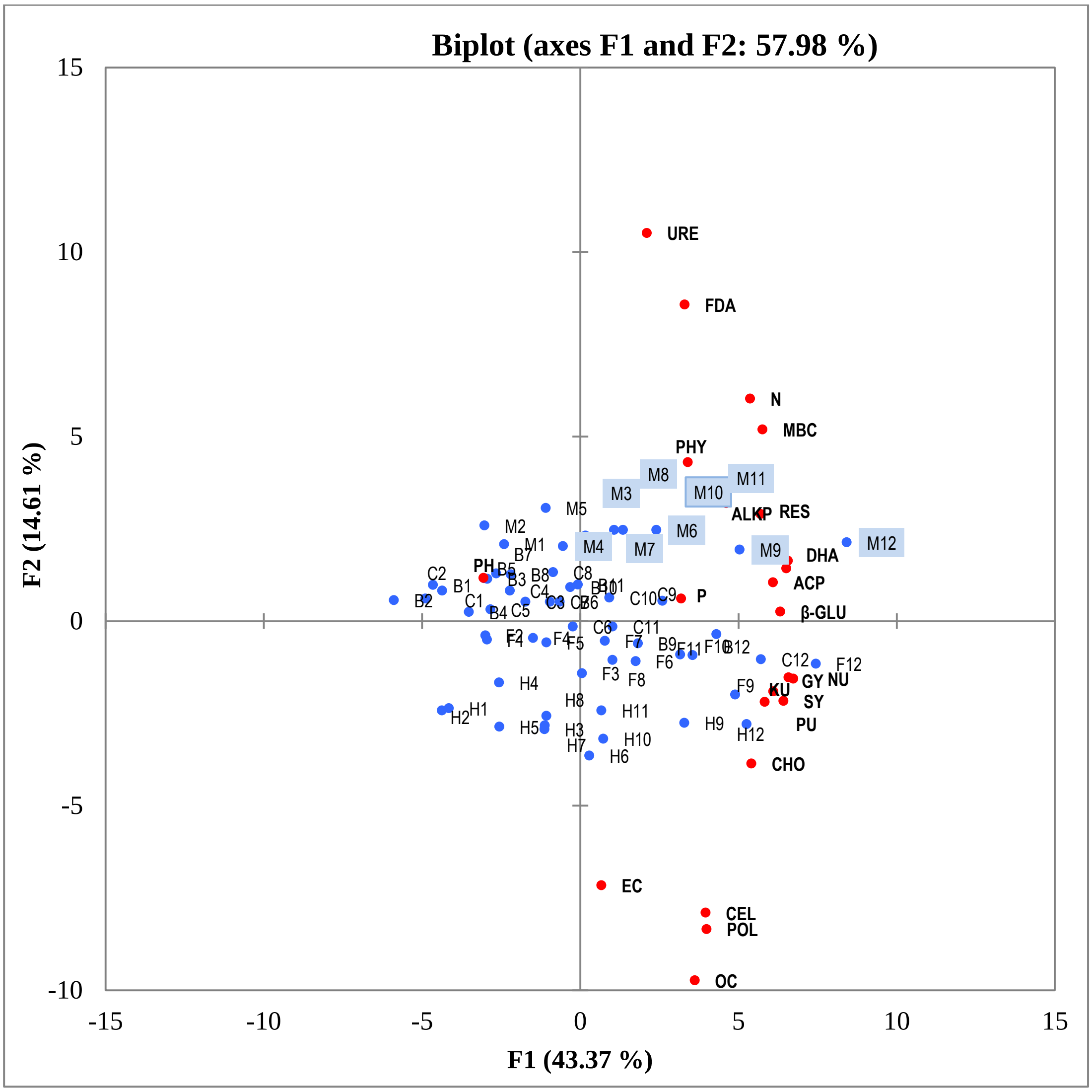
Bini *et al* (2014) observed that PCA clearly separated no tillage from conventional tillage in the factorial space defined by two PCs. They observed that available P, total N and acid phosphatase activity were positioned in similar position in the orthogonal space suggesting that these parameters were highly influenced by no tillage as compared with conventional tillage practices. Similar results were reported by Mathew *et al* (2012); they observed that in PCA, the data points for no tillage at surface soil layer are distinctly separated from data points for conventional tillage. The influential variables for the principal component were soil organic carbon, total nitrogen, alkaline phosphatase, phosphodiesterase and soil moisture. Tamilselvi *et al* (2015) performed PCA to separate different microbial parameters as influenced by organic and inorganic nutrient management at different growth stages of maize. They reported that PCA clearly separated vegetative growth stage of maize (30 days after sowing) from reproductive growth stages. Assayed variables are higher in vegetative stage of wheat growth as compared with reproductive stage. They further reported that assayed variables clearly discriminated organically managed variables from inorganically managed soil and most of assayed variables *viz*. MBC, dehydrogenase, urease, arysulfatase, acid and alkaline phosphatase ordinated with organically managed soil, which inferred that addition of diversified carbon sources through organic manure enhanced microbial biomass and enzymatic activities in soil.

Fig. 4.43: Principal component analysis of assayed variables at surface soil layer



B-Before sowing; C-Crown root initiation stage; M-Maximum tillering; F-Flowering; H-Harvesting; 1-PTR$_{w0}$/CTW$_{R0}$; 2-PTR$_{w0}$/ZTW$_{R0}$; 3-PTR$_{wo}$/ZTW$_{R100}$; 4-PTR$_{w25}$/CTW$_{R0}$; 5-PTR$_{w25}$/ZTW$_{R0}$; 6-PTR$_{w25}$/ZTW$_{R100}$; 7-PTR$_{w0}$+GM/CTW$_{R0}$; 8-PTR$_{w0}$+GM/ZTW$_{R0}$; 9-PTR$_{w0}$+GM/ZTW$_{R100}$; 10-PTR$_{w25}$+GM/CTW$_{R0}$; 11-PTR$_{w25}$+GM/ZTW$_{R0}$; 12-PTR$_{w25}$+GM/ZTW$_{R100}$; DHA-Dehydrogenase activity; FDA-fluorescein diacetate activity; ALKP-Alkaline phosphatase activity; ACDP-Acid phosphatase activity; PHY-Phytase; URE-Urease; ASP-Asparaginase; β-glu- β-glucosidase; XYL-Xylanase; CEL-Cellulase; PH OX-Polyphenol oxidase; PERO-Peroxidase activity; POL-Total polysaccharide carbon; CHO-Total carbohydrate carbon; MBC-Microbial biomass carbon; EEG-Easily extractable glomalin content; TG-Total glomalin content; RES-Soil respiration; OC-Oxidisable carbon; N-Available Nitrogen content; P-Available phosphorus content; K-Available potassium content; GY-Grain yield; SY-Straw yield.

Fig. 4.44: Principal component analysis of assayed variables at sub-surface soil layer



B-Before sowing; C-Crown root initiation stage; M-Maximum tillering; F-Flowering; H-Harvesting; 1-PTR_{w0}/CTW_{R0}; 2-PTR_{w0}/ZTW_{R0}; 3-PTR_{wo}/ZTW_{R100}; 4-PTR_{w25}/CTW_{R0}; 5-PTR_{w25}/ZTW_{R0}; 6-PTR_{w25}/ZTW_{R100}; 7-PTR_{w0}+GM/CTW_{R0}; 8-PTR_{w0}+GM/ZTW_{R0}; 9-PTR_{w0}+GM/ZTW_{R100}; 10-PTR_{w25}+GM/CTW_{R0}; 11-PTR_{w25}+GM/ZTW_{R0}; 12-PTR_{w25}+GM/ZTW_{R100}; DHA-Dehydrogenase activity; FDA-fluorescein diacetate activity; ALKP-Alkaline phosphatase activity; ACDP-Acid phosphatase activity; PHY-Phytase; URE-Urease; ASP-Asparaginase; β-glu- β-glucosidase; CEL-Cellulase; POL-Total polysaccharide carbon; CHO-Total carbohydrate carbon; MBC-Microbial biomass carbon; RES-Soil respiration; OC-Oxidisable carbon; N-Available Nitrogen content; P-Available phosphorus content; K-Available potassium content; GY-Grain yield; SY-Straw yield.

Table 4.6: Loading values and percent contribution of assayed soil variables (Biochemical properties) at surface soil layer on the axis identified by the principal component analysis

Soil variables	PC1		PC2	
	Loading values	Contribution of variables (%)	Loading values	Contribution of variables (%)
DHA	**0.781**	4.784	-0.353	3.552
FDA	0.468	1.719	-0.617	10.874
ALKP	0.704	3.889	-0.198	1.123
ACDP	**0.840**	5.544	-0.076	0.164
PHY	0.601	2.839	-0.254	1.845
URE	-0.013	0.001	0.661	12.452
ASP	0.637	3.188	-0.209	1.244
β-glu	**0.761**	4.544	-0.331	3.131
XYL	0.610	2.922	-0.202	1.160
CEL	0.549	2.370	0.205	1.197
PH OX	-0.430	1.451	-0.446	5.666
PERO	-0.659	3.405	-0.410	4.798
POL	0.554	2.414	0.047	0.062
CHO	0.717	4.040	0.108	0.334
MBC	**0.777**	4.741	-0.496	7.026
EEG	0.139	0.152	0.688	13.491
TG	0.623	3.050	0.102	0.300
RES	**0.851**	5.682	-0.345	3.404
OC	0.589	2.726	0.326	3.040
PH	-0.144	0.163	-0.107	0.329
EC	0.390	1.194	-0.181	0.936
N	0.773	4.693	-0.168	0.808
P	0.774	4.709	-0.373	3.974
K	0.598	2.806	0.387	4.261
GY	0.840	5.545	0.302	2.598
SY	0.847	5.639	0.331	3.126
NU	0.864	5.855	0.295	2.478
PU	0.806	5.107	0.342	3.331
KU	0.784	4.829	0.340	3.297
Eigen value		12.736		3.506
Variability (%)		43.919		12.089
Cumulative (%)		43.919		56.007

Values in bold explained >40% contribution to the significant component. DHA-Dehydrogenase activity; FDA-fluorescein diacetate activity; ALKP-Alkaline phosphatase activity; ACDP-Acid phosphatase activity; PHY-Phytase; URE-Urease; ASP-Asparaginase; β-glu- β-glucosidase; XYL-Xylanase; CEL-Cellulase; PH OX-Polyphenol oxidase; PERO-Peroxidase activity; POL-Total polysaccharide carbon; CHO-Total carbohydrate carbon; MBC-Microbial biomass carbon; EEG-Easily extractable glomalin content; TG-Total glomalin content; RES-Soil respiration; OC-Oxidisable carbon; N-Available Nitrogen content; P-Available phosphorus content; K-Available potassium content; GY-Grain yield; SY-Straw yield.

Table 4.7: Loading values and percent contribution of assayed soil variables (Biochemical properties) at sub-surface soil layer on the axis identified by the principal component analysis

Soil variables	PC1		PC2	
	Loading values	Contribution of variables (%)	Loading values	Contribution of variables (%)
DHA	**0.846**	7.175	0.122	0.440
FDA	0.426	1.819	0.640	12.173
ALKP	0.595	3.548	0.238	1.681
ACDP	**0.785**	6.186	0.078	0.179
PHY	0.439	1.928	0.321	3.068
URE	0.272	0.742	0.785	18.319
β-glu	**0.814**	6.645	0.019	0.011
CEL	0.512	2.626	-0.590	10.373
POL	0.515	2.657	-0.623	11.565
CHO	0.697	4.874	-0.288	2.474
MBC	**0.742**	5.526	0.387	4.460
RES	**0.735**	5.414	0.216	1.393
OC	0.467	2.188	-0.727	15.738
PH	-0.392	1.544	0.087	0.224
EC	0.087	0.076	-0.535	8.511
N	0.692	4.803	0.450	6.012
P	0.839	7.062	0.106	0.336
P	0.412	1.699	0.045	0.060
GY	0.848	7.213	-0.114	0.390
SY	0.828	6.870	-0.162	0.782
NU	0.867	7.543	-0.117	0.406
PU	0.786	6.200	-0.143	0.607
KU	0.751	5.661	-0.164	0.797
Eigenvalue		9.974		3.361
Variability (%)		43.365		14.613
Cumulative %		43.365		57.978

Values in bold explained >40% contribution to the significant component. DHA-Dehydrogenase activity; FDA-fluorescein diacetate activity; ALKP-Alkaline phosphatase activity; ACDP-Acid phosphatase activity; PHY-Phytase; URE-Urease; β-glu- β-glucosidase; CEL-Cellulase; POL-Total polysaccharide carbon; CHO-Total carbohydrate carbon; MBC-Microbial biomass carbon; RES-Soil respiration; OC-Oxidisable carbon; N-Available Nitrogen content; P-Available phosphorus content; K-Available potassium content; GY-Grain yield; SY-Straw yield.

Table 4.8: Correlations among soil enzyme activities, chemical properties, nutrients uptake and grain yield in the surface soil layer before sowing of wheat

	DHA	FDA	ALP	ACP	PHY	URE	ASP	BGLUC	XYL	CEL	PHOX	PERO	POLY	CHO	EEG	TG	MBC	RES	SOC	AVN	AVP	AVK	TNU	TPU	TKU	GY	SY
DHA	1	.731**	.637*	.641*	.791**	0.377	.781**	.724**	.613*	.853**	-.759**	-.823**	.613*	.752**	.642*	.815**	.793**	.781**	.716**	0.544	.713**	.798**	.773**	.860**	.882**	.789**	.857**
FDA		1	.822**	.867**	.659*	0.306	.807**	.877**	0.308	.824**	-0.563	-.647*	.790**	.828**	0.472	.907**	.836**	.722**	.837**	.721**	.637*	.617*	.778**	.688*	.780**	.710**	.828**
ALP			1	.915**	.698*	0.547	.633*	.790**	0.134	.721**	-0.347	-0.507	.910**	.827**	0.431	.885**	.839**	.699*	.948**	.948**	.677*	0.451	.810**	.633*	0.521	.771**	.658*
ACP				1	.681*	0.521	.618*	.822**	0.287	.829**	-0.427	-0.514	.863**	.809**	0.449	.905**	.890**	.606*	.870**	.834**	.631*	0.438	.688*	0.541	0.57	.592*	.644*
PHY					1	.601*	.836**	.589*	0.483	.744**	-.659*	-.775**	.795**	.912**	.763**	.813**	.855**	0.516	.770**	0.515	.730**	0.36	.581*	.721**	.637*	.609*	.725**
URE						1	0.423	0.262	-0.018	0.45	-0.136	-0.278	0.516	0.448	0.312	0.563	.586*	0.299	.665*	0.47	.607*	-0.067	0.479	0.436	0.351	0.459	0.523
ASP							1	.752**	0.483	.786**	-.747**	-.721**	.686*	.828**	.659*	.774**	.808**	.734**	.753**	0.496	.750**	0.42	.698*	.765**	.815**	.713**	.883**
BGLU								1	0.371	.799**	-0.575	-0.501	.783**	.739**	0.477	.840**	.755**	.812**	.770**	.744**	0.547	.581*	.718**	0.561	.663*	.692*	.724**
XYL									1	.660*	-.819**	-.647*	0.211	0.421	.612*	0.297	0.464	0.459	0.15	0.073	0.371	0.362	0.261	0.412	0.491	0.21	0.412
CEL										1	-.717**	-.688*	.656*	.735**	.662*	.847**	.900**	.781**	.789**	.677*	.792**	0.547	.782**	.736**	.843**	.701*	.825**
PHOX											1	.867**	-0.45	-.646*	-.764**	-0.519	-.692*	-.651*	-0.366	-0.226	-.620*	-0.525	-0.426	-0.498	-.701*	-0.409	-.628*
PERO												1	-.609*	-.788**	-.758**	-.680*	-.729**	-0.575	-0.521	-0.333	-.620*	-.639*	-0.55	-.663*	-.713**	-0.535	-.721**
POLY													1	.922**	.584*	.891**	.797**	0.554	.843**	.764**	0.533	0.361	.619*	0.521	0.428	.602*	.624*
CHO														1	.641*	.875**	.866**	.583*	.808**	.629*	.622*	0.474	.625*	.685*	.597*	.618*	.726**
EEG															1	.603*	.667*	0.455	0.471	0.344	.640*	0.267	0.395	0.394	0.528	0.398	0.522
TG																1	.878**	.670*	.920**	.770**	.679*	.579*	.791**	.729**	.740**	.755**	.839**
MBC																	1	.706*	.864**	.734**	.875**	0.473	.727**	.675*	.755**	.671*	.759**
RES																		1	.728**	.738**	.741**	.635*	.889**	.728**	.769**	.877**	.789**
SOC																			1	.894**	.783**	0.436	.885**	.772**	.680*	.861**	.805**
AVN																				1	.669*	0.412	.837**	0.56	0.466	.790**	0.561
AVP																					1	0.368	.768**	.686*	.779**	.744**	.726**
AVK																						1	.613*	.644*	.705*	.627*	.594*
TNU																							1	.866**	.790**	.973**	.865**
TPU																								1	.833**	.885**	.891**
TKU																									1	.766**	.916**
GY																										1	.845**
SY																											1

DHA-Dehydrogenase, FDA-Fluorescein diacetate, ALP-Alkaline phosphatase, ACP-Acid phosphatase, PHY-Phytase, URE-Urease, ASP-L-asparaginase, BGLU-Beta glucosidase, XYL-Xylanase, CEL-Cellulase, PHOX-Polyphenol oxidase, PERO-Peroxidase, POLY-Total polysaccharide carbon, CHO-Total carbohydrate carbon, EEG-Easily extractable glomalin, TG-Total glomalin, MBC-Microbial biomass carbon, RES-Basal soil respiration, SOC-Soil organic carbon, AVN-Available N, AVP-Available P, AVK-Available K, TNU-Total N uptake, TPU-Total P uptake, TKU-Total K uptake, GY-Grain yield, SY-Straw yield. (** Significant at 0.01 level, * Significant at 0.05 level).

Table 4.9: Correlations among soil enzyme activities, chemical properties, nutrients uptake and grain yield in the sub-surface soil layer before sowing of wheat

	DHA	FDA	ALP	ACP	PHY	URE	BGLU	CEL	POLY	CHO	MBC	RES	SOC	AVN	AVP	AVK	TNU	TPU	TKU	GY	SY
DHA	1	.732**	0.482	.769**	-0.047	.682*	.715**	.830**	.812**	.790**	.846**	.670*	.713**	.812**	0.552	.589*	.694*	.813**	.803**	.732**	.863**
FDA		1	0.453	.709**	0.055	0.441	0.551	.681*	.628*	0.545	.721**	.687*	.795**	.582*	.721**	0.513	.623*	.633*	0.544	.628*	.669*
ALP			1	0.38	-0.216	0.301	0.373	.639*	0.391	0.268	.672*	0.552	0.409	.615*	.665*	0.415	0.389	0.222	0.315	0.341	0.292
ACP				1	0.149	0.394	0.467	.686*	.731**	.703*	.869**	.774**	.860**	.748**	.708*	0.25	.850**	.840**	.663*	.890**	.776**
PHY					1	0.118	-0.324	0.065	-0.094	-0.067	-0.015	0.14	0.218	-0.203	0.008	-0.122	-0.166	-0.14	-0.448	-0.07	-0.286
URE						1	.591*	.689*	0.524	.581*	0.549	0.545	0.472	.678*	0.348	.854**	0.469	0.547	0.448	0.485	0.479
BGLU							1	.647*	.873**	.745**	.668*	0.508	0.571	0.566	0.42	0.566	.602*	0.51	.660*	0.56	.746**
CEL								1	.831**	.778**	.874**	.738**	.818**	.763**	.670*	.707*	.595*	0.559	.614*	0.574	.661*
POLY									1	.898**	.851**	.668*	.803**	.656*	.586*	0.494	.723**	.621*	.742**	.701*	.840**
CHO										1	.832**	.757**	.799**	.650*	.623*	0.483	.775**	.734**	.750**	.725**	.893**
MBC											1	.883**	.867**	.841**	.863**	0.502	.859**	.739**	.708*	.842**	.818**
RES												1	.826**	.636*	.883**	0.404	.837**	.690*	0.565	.764**	.695*
SOC													1	.630*	.777**	0.41	.723**	.660*	0.502	.702*	.713**
AVN														1	.667*	.686*	.780**	.784**	.723**	.818**	.730**
AVP															1	0.42	.799**	0.558	0.477	.744**	.616*
AVK																1	0.381	0.385	0.452	0.381	0.423
TNU																	1	.866**	.790**	.973**	.865**
TPU																		1	.833**	.885**	.891**
TKU																			1	.766**	.916**
GY																				1	.845**
SY																					1

DHA-Dehydrogenase, FDA-Fluorescein diacetate, ALP-Alkaline phosphatase, ACP-Acid phosphatase, PHY-Phytase, URE-Urease, BGLU-Beta glucosidase, CEL-Cellulase, POLY-Total polysaccharide carbon, CHO-Total carbohydrate carbon, MBC-Microbial biomass carbon, RES-Basal soil respiration, SOC-Soil organic carbon, AVN-Available N, AVP-Available P, AVK-Available K, TNU-Total N uptake, TPU-Total P uptake, TKU-Total K uptake, GY-Grain yield, SY-Straw yield (** Significant at 0.01 level, * Significant at 0.05 level).

Table 4.10: Correlations among soil enzyme activities, chemical properties, nutrients uptake and grain yield in the surface soil layer at CRI stage of wheat

	DHA	FDA	ALP	ACP	PHY	URE	ASP	BGLU	XYL	CEL	PHOX	PERO	POLY	CHO	EEG	TG	MBC	RES	SOC	AVN	AVP	AVK	TNU	TPU	TKU	GY	SY
DHA	1	.703*	.891**	.933**	0.537	.706*	.629*	.974**	.710**	.841**	-.713**	-.742**	.795**	.723**	.755**	.819**	.914**	.864**	.912**	.765**	.795**	.816**	.801**	.620*	.594*	.763**	.676*
FDA		1	.583*	.642*	.630*	.645*	0.324	.701*	.643*	0.384	-0.233	-0.302	0.452	0.424	.593*	.650*	.790**	0.563	0.536	.614*	.696*	.596*	.745**	.577*	0.537	.715**	.695*
ALP			1	.933**	0.408	.604*	.606*	.842**	.785**	.851**	-.749**	-.811**	.856**	.737**	.867**	.793**	.855**	.752**	.793**	.667*	.684*	.675*	.769**	.614*	.615*	.693*	.696*
ACP				1	0.402	.779**	0.54	.912**	.719**	.791**	-.699*	-.787**	.889**	.796**	.758**	.768**	.869**	.861**	.856**	.740**	.716**	.780**	.804**	.662*	0.561	.791**	.689*
PHY					1	0.352	.671*	0.492	.701*	.595*	-0.553	-0.354	0.488	0.463	.643*	0.522	.618*	0.463	0.414	0.515	.731**	0.484	.673*	0.568	.766**	.613*	.629*
URE						1	0.351	.707*	0.382	0.383	-0.365	-0.408	.622*	0.491	0.39	0.481	.611*	.656*	.580*	.615*	0.538	0.517	0.548	0.361	0.361	.609*	0.437
ASP							1	0.539	.750**	.782**	-.851**	-.719**	.643*	.636*	.662*	.753**	.662*	0.559	.577*	.772**	.763**	.602*	.587*	0.565	.855**	0.559	.721**
BGLU								1	.646*	.771**	-.669*	-.724**	.780**	.756**	.697*	.771**	.874**	.793**	.914**	.666*	.795**	.749**	.742**	0.564	0.514	.696*	.636*
XYL									1	.765**	-.717**	-.695*	.799**	.788**	.940**	.848**	.875**	.696*	.676*	.721**	.782**	.667*	.908**	.828**	.886**	.833**	.928**
CEL										1	-.931**	-.855**	.818**	.726**	.802**	.719**	.782**	.753**	.758**	.677*	.731**	.738**	.714**	.657*	.696*	.645*	.644*
PHOX											1	.886**	-.835**	-.746**	-.698*	-.622*	-.691*	-.641*	-.647*	-.637*	-.726**	-.593*	-.582*	-.618*	-.730**	-0.527	-.637*
PERO												1	-.857**	-.837**	-.678*	-.717**	-.721**	-.637*	-.731**	-.691*	-.793**	-.721**	-.616*	-.701*	-.703*	-.593*	-.728**
POLY													1	.897**	.815**	.685*	.824**	.813**	.797**	.654*	.744**	.656*	.811**	.763**	.724**	.781**	.752**
CHO														1	.774**	.789**	.742**	.677*	.833**	.608*	.782**	.675*	.767**	.703*	.688*	.738**	.784**
EEG															1	.820**	.837**	.683*	.742**	.578*	.699*	.591*	.884**	.692*	.771**	.769**	.795**
TG																1	.845**	.690*	.838**	.809**	.808**	.790**	.814**	.647*	.744**	.773**	.851**
MBC																	1	.868**	.833**	.820**	.848**	.796**	.918**	.823**	.775**	.875**	.873**
RES																		1	.840**	.801**	.645*	.835**	.865**	.762**	.603*	.893**	.659*
SOC																			1	.670*	.742**	.781**	.794**	.595*	0.552	.764**	.653*
AVN																				1	.789**	.889**	.753**	.769**	.775**	.818**	.815**
AVP																					1	.778**	.768**	.772**	.860**	.748**	.879**
AVK																						1	.793**	.790**	.647*	.847**	.735**
TNU																							1	.866**	.790**	.973**	.865**
TPU																								1	.833**	.885**	.891**
TKU																									1	.766**	.916**
GY																										1	.845**
SY																											1

DHA-Dehydrogenase, FDA-Fluorescein diacetate, ALP-Alkaline phosphatase, ACP-Acid phosphatase, PHY-Phytase, URE-Urease, ASP-L-asparaginase, BGLU-Beta glucosidase, XYL-Xylanase, CEL-Cellulase, PHOX-Polyphenol oxidase, PERO-Peroxidase, POLY-Total polysaccharide carbon, CHO-Total carbohydrate carbon, EEG-Easily extractable glomalin, TG-Total glomalin, MBC-Microbial biomass carbon, RES-Basal soil respiration, SOC-Soil organic carbon, AVN-Available N, AVP-Available P, AVK-Available K, TNU-Total N uptake, TPU-Total P uptake, TKU-Total K uptake, GY-Grain yield, SY-Straw yield. (** Significant at 0.01 level, * Significant at 0.05 level).

Table 4.11: Correlations among soil enzyme activities, chemical properties, nutrients uptake and grain yield in the sub-surface soil layer at CRI stage of wheat

	DHA	FDA	ALP	ACP	PHY	URE	BGLU	CEL	POLY	CHO	MBC	RES	SOC	AVN	AVP	AVK	TNU	TPU	TKU	GY	SY
DHA	1	.682*	.806**	.759**	.708*	.653*	.784**	.871**	.800**	.833**	.823**	.697*	.816**	.699*	.722**	.850**	.905**	.850**	.832**	.887**	.867**
FDA		1	.743**	.727**	.608*	.658*	.894**	0.568	.739**	.655*	0.544	0.522	.591*	0.43	.807**	0.432	.815**	.678*	0.556	.825**	.660*
ALP			1	.659*	.718**	.627*	.810**	0.551	.740**	.731**	.743**	0.506	.656*	.588*	.760**	.679*	.823**	.780**	.748**	.733**	.870**
ACP				1	.688*	.665*	.832**	.632*	.803**	.808**	.595*	.685*	.653*	0.42	.756**	0.566	.707*	0.49	0.424	.716**	.578*
PHY					1	0.346	.690*	.628*	0.435	.608*	.577*	0.295	0.52	.607*	.637*	0.419	.617*	0.497	0.496	0.575	.666*
URE						1	.644*	.644*	.863**	.744**	.691*	0.551	0.508	0.429	.818**	0.529	.627*	.614*	0.35	.608*	0.44
BGLU							1	.616*	.852**	.746**	.632*	.719**	.671*	.665*	.792**	0.552	.878**	.647*	.602*	.840**	.756**
CEL								1	.680*	.821**	.715**	0.458	.628*	.695*	.736**	.665*	.682*	.649*	.640*	.679*	.596*
POLY									1	.868**	.651*	.733**	.738**	.610*	.790**	.655*	.797**	.704*	0.546	.780**	.668*
CHO										1	.578*	0.508	.630*	.628*	.839**	.586*	.701*	.615*	0.533	.660*	.600*
MBC											1	.608*	.634*	0.534	.671*	.880**	.732**	.710**	.768**	.681*	.755**
RES												1	0.552	0.467	0.452	.644*	.796**	0.529	0.504	.775**	0.564
SOC													1	0.474	0.512	.804**	.712**	.807**	.750**	.783**	.850**
AVN														1	0.47	0.434	.679*	.578*	0.524	.596*	.642*
AVP															1	0.506	.661*	0.527	0.475	.603*	0.525
AVK																1	.716**	.757**	.885**	.707*	.822**
TNU																	1	.866**	.790**	.973**	.865**
TPU																		1	.833**	.885**	.891**
TKU																			1	.766**	.916**
GY																				1	.845**
SY																					1

DHA-Dehydrogenase, FDA-Fluorescein diacetate, ALP-Alkaline phosphatase, ACP-Acid phosphatase, PHY-Phytase, URE-Urease, BGLU-Beta glucosidase, CEL-Cellulase, POLY-Total polysaccharide carbon, CHO-Total carbohydrate carbon, MBC-Microbial biomass carbon, RES-Basal soil respiration, SOC-Soil organic carbon, AVN-Available N, AVP-Available P, AVK-Available K, TNU-Total N uptake, TPU-Total P uptake, TKU-Total K uptake, GY-Grain yield, SY-Straw yield (** Significant at 0.01 level, * Significant at 0.05 level).

Table 4.12: Correlations among soil enzyme activities, chemical properties, nutrients uptake and grain yield in the surface soil layer at maximum tillering stage of wheat

	DHA	FDA	ALP	ACP	PHY	URE	ASP	BGLU	XYL	CEL	PHOX	PERO	POLY	CHO	EEG	TG	MBC	RES	SOC	AVN	AVP	AVK	TNU	TPU	TKU	GY	SY
DHA	1	0.386	.794**	.897**	.675*	0.525	.820**	.865**	0.507	.815**	-.705*	-.744**	0.529	.790**	.727**	.655*	.779**	.699*	.794**	.685*	.747**	.670*	.797**	.673*	.611*	.771**	.629*
FDA		1	.607*	0.444	0.284	0.543	0.415	0.443	0.173	0.446	-0.44	-0.279	0.18	0.477	0.483	0.303	.600*	.664*	0.372	0.192	0.38	0.095	0.448	0.321	0.327	0.476	0.435
ALP			1	.864**	0.46	.672*	.708**	.874**	0.477	.659*	-.726**	-0.448	0.521	.855**	.721**	.655*	.870**	.934**	.819**	.649*	.862**	.669*	.782**	.628*	0.553	.722**	.667*
ACP				1	.581*	.722**	.795**	.912**	0.449	.796**	-.794**	-.608*	.759**	.908**	.801**	.670*	.907**	.835**	.892**	.735**	.785**	.746**	.778**	.652*	.616*	.755**	.706*
PHY					1	0.198	.833**	0.438	0.468	.874**	-.732**	-.867**	0.569	0.485	0.466	.636*	0.405	0.266	0.484	.587*	0.48	.617*	.583*	.792**	.819**	.632*	.718**
URE						1	0.484	.657*	0.378	0.544	-0.461	-0.237	0.515	.753**	.722**	0.511	.837**	.834**	.698*	0.386	.635*	0.403	.763**	0.516	0.549	.749**	.662*
ASP							1	.739**	0.336	.873**	-.854**	-.666*	.673*	.754**	.703*	.896**	.663*	.579*	.807**	.649*	.716**	.851**	.708*	.765**	.769**	.710**	.801**
BGLU								1	0.38	.717**	-.693*	-0.533	.659*	.905**	.659*	.743**	.914**	.816**	.897**	.714**	.738**	.712**	.757**	.615*	0.513	.677*	.660*
XYL									1	0.454	-0.09	-.588*	0.276	0.463	0.384	0.307	0.397	0.355	0.34	0.107	.593*	0.324	.709**	.781**	0.437	.767**	0.491
CEL										1	-.809**	-.883**	.741**	.759**	.679*	.717**	.695*	.577*	.719**	.765**	.628*	.658*	.811**	.836**	.897**	.812**	.892**
PHOX											1	0.566	-.707*	-.662*	-.652*	-.707*	-.696*	-.640*	-.702*	-.825**	-.617*	-.713**	-0.529	-0.532	-.715**	-0.501	-.683*
PERO												1	-0.563	-0.517	-0.482	-0.459	-0.46	-0.3	-0.433	-.591*	-0.464	-0.421	-.668*	-.773**	-.716**	-.706*	-.668*
POLY													1	.746**	.607*	.618*	.604*	0.486	.708*	.664*	0.549	.735**	0.539	.633*	.606*	0.548	.755**
CHO														1	.706*	.718**	.866**	.844**	.966**	.696*	.743**	.791**	.849**	.722**	.650*	.788**	.827**
EEG															1	0.52	.658*	.781**	.658*	0.432	.875**	0.553	.730**	0.548	0.52	.785**	.643*
TG																1	.660*	0.518	.796**	0.542	.654*	.847**	.658*	.750**	.686*	.617*	.765**
MBC																	1	.886**	.836**	.656*	.675*	0.568	.762**	.584*	0.569	.705*	.658*
RES																		1	.790**	.580*	.799**	0.524	.766**	0.484	0.492	.708**	.627*
SOC																			1	.717**	.707*	.873**	.778**	.660*	.636*	.698*	.775**
AVN																				1	0.452	.645*	0.57	0.487	.716**	0.449	.663*
AVP																					1	.689*	.798**	.693*	0.529	.807**	.665*
AVK																						1	.607*	.687*	.620*	0.56	.725**
TNU																							1	.866**	.790**	.973**	.865**
TPU																								1	.833**	.885**	.891**
TKU																									1	.766**	.916**
GY																										1	.845**
SY																											1

DHA-Dehydrogenase, FDA-Fluorescein diacetate, ALP-Alkaline phosphatase, ACP-Acid phosphatase, PHY-Phytase, URE-Urease, ASP-L-asparaginase, BGLU-Beta glucosidase, XYL-Xylanase, CEL-Cellulase, PHOX-Polyphenol oxidase, PERO-Peroxidase, POLY-Total polysaccharide carbon, CHO-Total carbohydrate carbon, EEG-Easily extractable glomalin, TG-Total glomalin, MBC-Microbial biomass carbon, RES-Basal soil respiration, SOC-Soil organic carbon, AVN-Available N, AVP-Available P, AVK-Available K, TNU-Total N uptake, TPU-Total P uptake, TKU-Total K uptake, GY-Grain yield, SY-Straw yield. (** Significant at 0.01 level, * Significant at 0.05 level).

Table 4.13: Correlations among soil enzyme activities, chemical properties, nutrients uptake and grain yield in the sub-surface soil layer at maximum tillering stage of wheat

	DHA	FDA	ALP	ACP	PHY	URE	BGLU	CEL	POLY	CHO	MBC	RES	SOC	AVN	AVP	AVK	TNU	TPU	TKU	GY	SY
DHA	1	.786**	.856**	.869**	0.361	0.487	.851**	.842**	.829**	.646*	.797**	.747**	.844**	.700*	.888**	0.49	.852**	.761**	.738**	.808**	.780**
FDA		1	.756**	.875**	0.348	0.003	.884**	.787**	0.511	.838**	.834**	0.437	.729**	.614*	.741**	0.359	.652*	0.454	0.384	.579*	0.537
ALP			1	.813**	0.311	0.312	.811**	.675*	0.544	.681*	.786**	.632*	.621*	.589*	.913**	0.359	.888**	.713**	.586*	.812**	.751**
ACP				1	0.488	0.377	.891**	.789**	.657*	.851**	.846**	.663*	.789**	.699*	.860**	0.451	.780**	0.56	0.566	.764**	.708*
PHY					1	0.531	0.262	0.414	0.222	0.398	0.465	0.321	0.428	0.065	0.315	0.273	0.266	-0.035	0.224	0.24	0.129
URE						1	0.168	0.387	0.505	0.077	0.33	.606*	0.433	0.275	0.429	0.201	0.424	0.393	0.485	0.515	0.359
BGLU							1	.689*	.679*	.829**	.908**	0.489	.755**	.715**	.790**	0.282	.760**	0.57	0.484	.697*	.653*
CEL								1	.710**	.600*	.706*	.675*	.893**	.658*	.787**	0.539	.788**	.638*	.664*	.769**	.646*
POLY									1	0.319	0.519	.634*	.830**	.765**	.680*	.601*	.702*	.757**	.800**	.705*	.790**
CHO										1	.853**	0.318	0.499	0.374	.583*	0.232	.631*	0.324	0.358	0.572	0.476
MBC											1	0.474	.706*	0.573	.735**	0.089	.735**	0.469	0.37	.690*	0.474
RES												1	.755**	.726**	.849**	0.267	.708**	.621*	0.538	.757**	0.568
SOC													1	.813**	.817**	0.413	.708**	0.551	0.555	.697*	.578*
AVN														1	.803**	0.239	.684*	.688*	0.441	.744**	.629*
AVP															1	0.369	.878**	.723**	.583*	.860**	.741**
AVK																1	0.464	0.499	.809**	0.41	.753**
TNU																	1	.866**	.790**	.973**	.865**
TPU																		1	.833**	.885**	.891**
TKU																			1	.766**	.916**
GY																				1	.845**
SY																					1

DHA-Dehydrogenase, FDA-Fluorescein diacetate, ALP-Alkaline phosphatase, ACP-Acid phosphatase, PHY-Phytase, URE-Urease, BGLU-Beta glucosidase, CEL-Cellulase, POLY-Total polysaccharide carbon, CHO-Total carbohydrate carbon, MBC-Microbial biomass carbon, RES-Basal soil respiration, SOC-Soil organic carbon, AVN-Available N, AVP-Available P, AVK-Available K, TNU-Total N uptake, TPU-Total P uptake, TKU-Total K uptake, GY-Grain yield, SY-Straw yield (** Significant at 0.01 level, * Significant at 0.05 level).

Table 4.14: Correlations among soil enzyme activities, chemical properties, nutrients uptake and grain yield in the surface soil layer at flowering stage of wheat

	DHA	FDA	ALP	ACP	PHY	URE	ASP	BGLU	XYL	CEL	PHOX	PERO	POLY	CHO	EEG	TG	MBC	RES	SOC	AVN	AVP	AVK	TNU	TPU	TKU	GY	SY
DHA	1	.810**	.866**	.850**	.883**	.634*	.593*	.834**	0.535	.842**	-.721**	-.609*	.795**	.740**	.842**	.811**	.859**	.803**	.948**	.841**	.805**	.579*	.782**	.694*	.625*	.762**	.720**
FDA		1	.819**	.876**	.698*	.726**	0.446	.702*	0.564	.742**	-.779**	-.745**	.796**	.674*	.798**	.792**	.612*	.786**	.850**	.848**	.881**	.636*	.859**	.731**	.624*	.907**	.737**
ALP			1	.756**	.584*	.610*	0.55	.874**	0.46	.632*	-.698*	-.670*	.940**	.689*	.885**	.740**	.751**	.763**	.843**	.825**	.665*	0.454	.835**	.612*	0.486	.780**	.623*
ACP				1	.785**	0.431	0.467	.813**	.797**	.869**	-.782**	-.674*	.790**	.859**	.738**	.958**	.826**	.778**	.863**	.730**	.904**	.725**	.832**	.740**	.771**	.820**	.898**
PHY					1	0.553	0.527	.632*	0.547	.928**	-.746**	-0.553	0.52	.700*	.649*	.743**	.733**	.783**	.879**	.713**	.846**	.620*	.612*	.674*	.711**	.622*	.696*
URE						1	0.33	0.351	0.087	0.441	-0.375	-0.444	0.509	0.162	.594*	0.38	0.292	0.481	.621*	.624*	.605*	0.246	0.528	0.42	0.18	.592*	0.25
ASP							1	0.44	0.312	0.55	-0.372	-.581*	0.436	0.556	.775**	0.505	0.528	.669*	0.498	0.415	0.381	0.233	.738**	.830**	.619*	.682*	.650*
BGLU								1	.662*	.752**	-.707*	-.662*	.853**	.776**	.744**	.842**	.802**	.782**	.862**	.662*	.620*	0.422	.724**	0.544	0.558	.650*	.649*
XYL									1	.701*	-.647*	-0.454	0.553	.674*	0.518	.767**	0.509	.626*	.611*	0.28	.589*	.700*	0.513	0.554	0.557	0.467	.702*
CEL										1	-.813**	-.764**	.595*	.858**	.710**	.855**	.776**	.848**	.853**	.659*	.841**	.667*	.732**	.772**	.859**	.716**	.827**
PHOX											1	.703*	-.671*	-.799**	-.681*	-.695*	-.586*	-.856**	-.823**	-.788**	-.788**	-.757**	-.653*	-.631*	-.700*	-.650*	-.686*
PERO												1	-.591*	-.775**	-.762**	-.671*	-0.558	-.771**	-.614*	-.615*	-.613*	-0.464	-.850**	-.804**	-.814**	-.844**	-.737**
POLY													1	.721**	.833**	.802**	.738**	.747**	.794**	.716**	.672*	0.498	.767**	.590*	0.453	.724**	.668*
CHO														1	.734**	.867**	.858**	.793**	.715**	.649*	.741**	.682*	.798**	.783**	.907**	.743**	.927**
EEG															1	.705*	.679*	.848**	.775**	.719**	.625*	0.573	.879**	.870**	.623*	.860**	.754**
TG																1	.856**	.781**	.830**	.619*	.851**	0.557	.810**	.711**	.762**	.767**	.882**
MBC																	1	.622*	.754**	.689*	.731**	0.506	.754**	.609*	.735**	.669*	.804**
RES																		1	.880**	.697*	.719**	0.536	.755**	.816**	.700*	.757**	.742**
SOC																			1	.833**	.838**	0.551	.724**	.635*	.587*	.720**	.667*
AVN																				1	.796**	0.565	.755**	0.574	0.576	.778**	.602*
AVP																					1	.686*	.745**	.652*	.732**	.763**	.786**
AVK																						1	0.519	.606*	.618*	0.541	.709**
TNU																							1	.866**	.790**	.973**	.865**
TPU																								1	.833**	.885**	.891**
TKU																									1	.766**	.916**
GY																										1	.845**
SY																											1

DHA-Dehydrogenase, FDA-Fluorescein diacetate, ALP-Alkaline phosphatase, ACP-Acid phosphatase, PHY-Phytase, URE-Urease, ASP-L-asparaginase, BGLU-Beta glucosidase, XYL-Xylanase, CEL-Cellulase, PHOX-Polyphenol oxidase, PERO-Peroxidase, POLY-Total polysaccharide carbon, CHO-Total carbohydrate carbon, EEG-Easily extractable glomalin, TG-Total glomalin, MBC-Microbial biomass carbon, RES-Basal soil respiration, SOC-Soil organic carbon, AVN-Available N, AVP-Available P, AVK-Available K, TNU-Total N uptake, TPU-Total P uptake, TKU-Total K uptake, GY-Grain yield, SY-Straw yield. (** Significant at 0.01 level, * Significant at 0.05 level).

Table 4.15: Correlations among soil enzyme activities, chemical properties, nutrients uptake and grain yield in the sub-surface soil layer flowering stage of wheat

	DHA	FDA	ALP	ACP	PHY	URE	BGLU	CEL	POLY	CHO	MBC	RES	SOC	AVN	AVP	AVK	TNU	TPU	TKU	GY	SY
DHA	1	0.463	.685*	.800**	.616*	0.318	.955**	.716**	.700*	.809**	0.367	0.556	.928**	.754**	.805**	.773**	.776**	.645*	.664*	.726**	.797**
FDA		1	0.353	0.439	0.56	0.211	0.412	0.457	.699*	0.365	0.306	0.071	0.542	0.525	0.228	0.445	0.518	0.322	0.454	0.438	0.355
ALP			1	.649*	.711**	0.091	.588*	0.423	0.551	0.523	-0.033	0.52	.638*	0.472	0.549	.662*	.578*	0.471	0.41	0.518	0.549
ACP				1	0.352	0.168	.732**	0.544	0.511	0.567	-0.045	0.385	.596*	.607*	0.561	0.52	0.531	0.348	0.491	0.466	.663*
PHY					1	0.231	0.551	0.288	.791**	.766**	0.181	0.457	.771**	0.425	0.505	.799**	0.572	0.308	0.408	0.504	0.338
URE						1	0.512	0.242	0.574	0.561	0.267	0.548	0.406	0.505	.587*	0.36	0.567	0.396	0.249	.686*	0.332
BGLU							1	.643*	.719**	.840**	0.459	.700*	.928**	.788**	.824**	.749**	.814**	.655*	.641*	.783**	.796**
CEL								1	0.516	0.392	.592*	0.364	.643*	.844**	.691*	0.489	.636*	.698*	.598*	.604*	.654*
POLY									1	.840**	0.347	.608*	.815**	.790**	.661*	.609*	.651*	0.432	0.538	.639*	0.496
CHO										1	0.247	.662*	.867**	.633*	.765**	.757**	.652*	0.375	0.5	.645*	0.534
MBC											1	0.439	0.531	.606*	0.402	0.346	0.511	0.537	0.407	0.443	0.38
RES												1	.658*	.706*	.692*	0.511	.588*	0.459	0.433	0.569	0.537
SOC													1	.769**	.807**	.831**	.837**	.676*	.719**	.781**	.755**
AVN														1	.782**	0.486	.708*	.663*	.671*	.685*	.714**
AVP															1	.678*	.859**	.802**	.769**	.884**	.845**
AVK																1	.793**	0.494	0.474	.713**	0.543
TNU																	1	.866**	.790**	.973**	.865**
TPU																		1	.833**	.885**	.891**
TKU																			1	.766**	.916**
GY																				1	.845**
SY																					1

DHA-Dehydrogenase, FDA-Fluorescein diacetate, ALP-Alkaline phosphatase, ACP-Acid phosphatase, PHY-Phytase, URE-Urease, BGLU-Beta glucosidase, CEL-Cellulase, POLY-Total polysaccharide carbon, CHO-Total carbohydrate carbon, MBC-Microbial biomass carbon, RES-Basal soil respiration, SOC-Soil organic carbon, AVN-Available N, AVP-Available P, AVK-Available K, TNU-Total N uptake, TPU-Total P uptake, TKU-Total K uptake, GY-Grain yield, SY-Straw yield (** Significant at 0.01 level, * Significant at 0.05 level).

Table 4.16: Correlations among soil enzyme activities, chemical properties, nutrients uptake and grain yield in the surface soil layer at harvesting stage of wheat

	DHA	FDA	ALP	ACP	PHY	URE	ASP	BGLU	XYL	CEL	PHOX	PERO	POLY	CHO	EEG	TG	MBC	RES	SOC	AVN	AVP	AVK	TNU	TPU	TKU	GY	SY
DHA	1	.709**	.611*	.593*	0.493	.578*	.855**	.742**	.657*	.908**	-.701*	-.811**	0.328	0.545	.635*	.771**	.699*	.699*	.834**	.587*	.775**	.828**	.726**	.872**	.847**	.725**	.810**
FDA		1	.799**	.763**	0.295	0.47	.850**	.841**	.768**	.834**	-.699*	-.855**	.720**	.870**	.642*	.672*	.943**	.943**	.721**	.610*	.767**	.613*	.872**	.683*	.615*	.821**	.702*
ALP			1	.945**	0.308	0.428	.800**	.714**	.920**	.850**	-.597*	-.877**	.625*	.930**	.803**	.808**	.841**	.841**	.692*	.645*	.680*	.696*	.788**	.605*	.628*	.737**	.764**
ACP				1	0.416	0.471	.799**	.598*	.854**	.785**	-0.507	-.844**	.582*	.898**	.698*	.736**	.781**	.781**	.721**	.627*	.701*	.701*	.721**	0.573	.628*	.713**	.749**
PHY					1	0.396	0.503	0.246	0.53	0.46	-0.228	-0.336	-0.206	0.174	0.164	0.229	0.349	0.349	0.472	.613*	0.489	0.409	0.472	0.55	.648*	0.546	0.542
URE						1	0.406	0.564	0.45	0.488	-0.49	-0.483	0.225	0.359	0.478	0.47	.624*	.624*	.779**	0.383	.734**	0.381	0.494	0.365	.646*	0.497	0.498
ASP							1	.722**	.802**	.921**	-.683*	-.863**	0.449	.741**	.683*	.752**	.806**	.806**	.673*	.644*	.694*	.762**	.815**	.821**	.807**	.760**	.859**
BGLU								1	.759**	.809**	-.709**	-.798**	.580*	.680*	.713**	.595*	.902**	.902**	.763**	.584*	.643*	.606*	.735**	.592*	.644*	.673*	.683*
XYL									1	.875**	-.610*	-.812**	0.399	.820**	.665*	.674*	.820**	.820**	.688*	.863**	.657*	.714**	.842**	.711**	.718**	.808**	.857**
CEL										1	-.747**	-.909**	0.452	.779**	.723**	.847**	.822**	.822**	.799**	.718**	.763**	.886**	.879**	.886**	.851**	.843**	.909**
PHOX											1	.829**	-0.55	-0.48	-.720**	-.758**	-.639*	-.639*	-0.554	-0.538	-0.477	-0.519	-0.558	-0.495	-0.564	-0.447	-0.534
PERO												1	-.723**	-.808**	-.855**	-.892**	-.825**	-.825**	-.793**	-.622*	-.714**	-.747**	-.720**	-.656*	-.653*	-.678*	-.710**
POLY													1	.718**	.693*	.606*	.658*	.658*	0.481	0.166	0.471	0.238	0.379	0.138	0.051	0.33	0.148
CHO														1	.642*	.705*	.851**	.851**	.679*	.591*	.731**	.649*	.822**	.609*	0.502	.802**	.693*
EEG															1	.870**	.736**	.736**	.635*	0.338	0.574	0.471	0.504	0.381	0.504	0.414	0.479
TG																1	.670*	.670*	.707*	0.434	.711**	.703*	.652*	.639*	.634*	.600*	.630*
MBC																	1	1.000**	.791**	.593*	.815**	0.574	.866**	.630*	.674*	.815**	.716**
RES																		1	.791**	.593*	.815**	0.574	.866**	.630*	.674*	.815**	.716**
SOC																			1	0.566	.904**	.756**	.714**	.685*	.739**	.771**	.709**
AVN																				1	0.549	.594*	.713**	.698*	.580*	.729**	.756**
AVP																					1	.629*	.820**	.744**	.699*	.868**	.675*
AVK																						1	.727**	.852**	.823**	.751**	.891**
TNU																							1	.866**	.790**	.973**	.865**
TPU																								1	.833**	.885**	.891**
TKU																									1	.766**	.916**
GY																										1	.845**
SY																											1

DHA-Dehydrogenase, FDA-Fluorescein diacetate, ALP-Alkaline phosphatase, ACP-Acid phosphatase, PHY-Phytase, URE-Urease, ASP-L-asparaginase, BGLU-Beta glucosidase, XYL-Xylanase, CEL-Cellulase, PHOX-Polyphenol oxidase, PERO-Peroxidase, POLY-Total polysaccharide carbon, CHO-Total carbohydrate carbon, EEG-Easily extractable glomalin, TG-Total glomalin, MBC-Microbial biomass carbon, RES-Basal soil respiration, SOC-Soil organic carbon, AVN-Available N, AVP-Available P, AVK-Available K, TNU-Total N uptake, TPU-Total P uptake, TKU-Total K uptake, GY-Grain yield, SY-Straw yield. (** Significant at 0.01 level, * Significant at 0.05 level).

Table 4.17: Correlations among soil enzyme activities, chemical properties, nutrients uptake and grain yield in the sub-surface soil layer at harvesting stage of wheat

	DHA	FDA	ALP	ACP	PHY	URE	BGLU	CEL	POLY	CHO	MBC	RES	SOC	AVN	AVP	AVK	TNU	TPU	TKU	GY	SY
DHA	1	0.49	.651*	0.382	0.406	.649*	.669*	.727**	0.153	0.516	.770**	.692*	.683*	0.483	0.381	.801**	.756**	.830**	.894**	.739**	.872**
FDA		1	.658*	0.271	-0.43	-0.005	0.379	0.534	0.367	.866**	0.493	0.465	.758**	0.192	0.256	0.477	0.52	0.369	0.425	0.495	0.276
ALP			1	.728**	-0.189	0.203	.872**	.637*	0.477	0.52	.863**	0.536	.836**	.749**	.785**	0.479	.821**	.596*	0.552	.769**	.660*
ACP				1	-0.073	0.104	.703*	.623*	.606*	0.163	.617*	0.167	0.514	.708**	.832**	0.304	0.492	0.298	0.437	0.469	0.551
PHY					1	.658*	0.077	0.117	-0.144	-0.282	0.139	0.281	-0.085	0.034	-0.058	0.398	0.145	0.36	0.388	0.175	0.409
URE						1	0.182	0.45	0.26	-0.041	0.346	0.304	0.41	0.405	-0.006	0.543	0.332	.620*	0.49	0.401	0.552
BGLU							1	0.502	0.262	0.335	.834**	.601*	.583*	.607*	.796**	0.447	.735**	0.52	0.527	.669*	.680*
CEL								1	.671*	0.351	.701*	.598*	.628*	.666*	0.359	.794**	.668*	.778**	.751**	.719**	.758**
POLY									1	-0.02	0.375	0.198	0.476	0.575	0.25	0.346	0.252	0.277	0.09	0.344	0.199
CHO										1	0.36	0.439	.589*	-0.005	0.283	0.433	0.503	0.344	0.549	0.428	0.306
MBC											1	.689*	.813**	.793**	.723**	.739**	.881**	.759**	.698*	.820**	.851**
RES												1	0.451	0.339	0.286	.793**	.783**	.801**	.625*	.795**	.662*
SOC													1	.656*	0.571	.629*	.736**	.600*	.586*	.691*	.620*
AVN														1	.687*	0.472	.709**	.667*	0.487	.696*	.731**
AVP															1	0.276	.678*	0.34	0.454	.581*	.602*
AVK																1	.694*	.835**	.794**	.682*	.784**
TNU																	1	.866**	.790**	.973**	.865**
TPU																		1	.833**	.885**	.891**
TKU																			1	.766**	.916**
GY																				1	.845**
SY																					1

DHA-Dehydrogenase, FDA-Fluorescein diacetate, ALP-Alkaline phosphatase, ACP-Acid phosphatase, PHY-Phytase, URE-Urease, BGLU-Beta glucosidase, CEL-Cellulase, POLY-Total polysaccharide carbon, CHO-Total carbohydrate carbon, MBC-Microbial biomass carbon, RES-Basal soil respiration, SOC-Soil organic carbon, AVN-Available N, AVP-Available P, AVK-Available K, TNU-Total N uptake, TPU-Total P uptake, TKU-Total K uptake, GY-Grain yield, SY-Straw yield (** Significant at 0.01 level, * Significant at 0.05 level).

CHAPTER V

SUMMARY

Soil management practices often leaves footprints on soil physical, chemical and biological properties, which strictly determine the soil quality in long term. Undoubtedly, study on the influence of management practices on soil health in intensive and nutrient exhausting rice-wheat system (RWS) is of great importance. A number of soil health issues have cropped-up in the region in the last four decades, threatening the sustainability of this important RWS. To attain sustainability in conventional RWS, various resource conservation technologies such as zero tillage, direct seeded rice, crop residue management and green manuring are proposed as alternative measures, which may increase productivity and profitability of the system. Present investigation on "Soil biochemical changes under tillage, green manure and straw management and their effect on wheat" was carried out in a long-term field experiment at the experimental area of Department of Soil Science, Punjab Agricultural University, Ludhiana, with the following objectives:

1. To study the periodic changes of biochemical activities in soil during growing season of wheat and their relationship with yield and nutrient uptake of wheat.
2. To correlate soil biochemical activities with yield and nutrient uptake of wheat as influenced by tillage, green manure and straw management.

The experiment was established in 2011 in a split plot design with three replications. The treatments in the main plots comprised of wheat straw and green manure 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 + sesbania 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}).

Soil samples were collected at 0-7.5 cm and 7.5-15 cm soil depths at different growth stages of wheat; before sowing (BS), crown root initiation (CRI), maximum tillering (MT), flowering (Fl) and harvest (H) stages. The soil samples were analyzed for different biochemical properties (dehydrogenase, fluorescein diacetate, alkaline and acid phosphatase, phytase, urease, L-asparaginase, β-glucosidase, xylanase, cellulase, polyphenol oxidase, peroxidase, total polysaccharide carbon, total carbohydrate carbon, total and easily extractable glomalin, microbial biomass carbon and soil respiration) and chemical properties (pH, EC, OC, available N, available P and available K). Grain and straw samples of wheat were collected at harvest and analysed for total N, P and K contents.

Wheat straw and green manure practices in rice and tillage and rice straw management practices in subsequent wheat had significant effect on all the biochemical parameters in both the soil layers. All biochemical properties studied increased with wheat straw retention and green manuring (i.e. PTR_{W0} + GM and PTR_{W25} + GM) and zero tillage with residue retention (i.e. ZTW_{R100}) except polyphenol oxidase and peroxidase, which has shown the reverse trend. All biochemical parameters decreased with depth. All the biochemical properties varied with wheat growth stages. Dehydrogenase activity reached highest (2.9 and 3.1 fold) at MT stage as compared with BS of wheat crop in the surface and sub-surface soil layer, respectively. FDA activity reached highest at MT stage, which was 3.5 and 5.1 fold higher as compared with BS of wheat crop in surface and sub-surface soil layer. Alkaline phosphatase activity was recorded highest at CRI in the surface soil layer, which was 50% higher as compared with BS of wheat crop. In the sub-surface soil layer, maximum activity of alkaline phosphatase was recorded at Fl stage, which was 21% higher as compared with BS of wheat crop. Acid phosphtase activity was recorded at MT, which was 23% and 93% higher as compared with BS in surface and sub-surface soil layer, respectively. Phytase activity reached highest (27% and 84%) at MT as compared with BS in the surface and sub-surface soil layer, respectively. In the surface soil layer highest urease activity was recorded at CRI stage, which was 5.4% higher than before sowing of wheat crop. L-asparaginase activity in the surface soil layer was recorded highest at MT stage, which was 41% higher as compared with BS of wheat crop. β-glucosidase activity reached maximum at MT, which was 2.9 and 2.1 fold higher as compared with BS in surface and sub-surface soil layers, respectively. In the surface soil layer, xylanase was recorded highest activity at MT stage (1.7 times higher than BS of wheat crop). Cellulase activity gradually increases with time and reached highest at H stage, which was 3.4 and 3.2 times higher than BS in the surface and sub-surface soil layers, respectively. Maximum activity of polyphenol oxidase was recorded at Fl stage in the surface soil layer, which was 53% higher than BS of wheat crop. Similarly, highest peroxidase activity was recorded at Fl stage in the surface soil layer. Highest total polysaccharide carbon was recorded at Fl stage, which was 2.1 times higher as compared with BS of wheat in surface and sub-surface soil layers, respectively. In the surface soil layer, highest value of total carbohydrate carbon was recorded at CRI, which was 24% higher as compared to BS of wheat. In the sub-surface soil layer, total carbohydrate carbon was maximum at Fl stage, which was 44% higher than BS of wheat. Easily extractable glomalin content in soil was highest at Fl stage. Similarly, total glomalin content in soil was maximum at Fl stage which was 39% higher as compared with BS of wheat. Microbial biomass carbon content was recorded highest at MT stage in both the soil layers, which was 2.6 and 1.6 times higher as compared with BS of wheat in surface and sub-surface soil layers, respectively.

Similarly, soil respiration was highest at MT in the surface soil layer, which was 2.1 fold higher as compared with BS of wheat. In the sub-surface soil layer, maximum value of soil respiration was recorded at Fl stage, which was 41% higher as compared with BS of wheat.

Oxidisable organic carbon (OC), available N, available P and available K contents in soil were significantly affected by wheat straw and green manure practices in rice as well as tillage and rice straw management practices in subsequent wheat. All these parameters responded positively to straw retention, green manuring and zero tillage with retention of rice straw. Soil OC and available N, P and K contents were higher in PTR_{W25} + GM treatments as compared with the other treatments. Similarly, ZTW_{R100} produced higher value of OC and available N, P and K contents as compared with CTW_{R0}. Soil pH and EC were not affected by wheat straw and GM in rice as well as tillage and rice straw management practices in subsequent wheat. Soil OC content gradually increased with time and reached maximum at H stage of wheat crop in both the soil layers. It increased by 27% as compared with BS in the surface soil layer and by 1.9-fold in the sub-surface soil layer. Available N content in soil was highest at CRI stage in the surface soil layer, which was 41% higher as compared with BS of wheat. In the sub-surface soil layer, maximum available N content was recorded at MT stage, which was 13.2% higher as compared with BS of wheat crop. Available P in soil was highest at MT in the surface soil layer, which was 55% higher as compared with BS of wheat crop. In the sub-surface soil layer, maximum value of available N content was recorded at Fl stage, which was 29% higher as compared with BS of wheat crop. Maximum value of available K content in soil was recorded at H and MT in the surface and sub-surface soil layers, respectively.

Significant positive correlation was observed among soil enzyme activities and soil OC. Dehydrogenase, fluorescein diacetate and β-glucosidase activity were highly correlated with microbial biomass carbon and oxidisable organic carbon. However, polyphenol oxidase and peroxidase activity were negatively correlated with all other soil enzymes as well as OC. Maximum correlation between DHA and MBC was observed at CRI stage (0.914**) and between FDA and MBC was recorded at harvest (0.943**). Maximum correlation between β-glucosidase and MBC was observed at MT stage (0.914**). Maximum correlation between DHA and SOC was observed at Fl (0.948**) and between FDA and OC was observed at Fl stage (0.850**). Maximum correlation between β-glucosidase and SOC was observed at Fl stage (0.928**). Wheat straw and grain yield were significantly correlated with microbial biomass carbon and OC. Maximum correlation between grain yield and microbial biomass carbon was recorded at CRI stage (0.875**) and between grain yield and SOC was recorded at BS of wheat crop (0.861**).

Retention of wheat residue (25%) and GM in the previous rice crop significantly improved grain and straw yields of the subsequent wheat crop. Wheat grain yield under PTR_{W0}+GM and PTR_{W25}+GM was 13.8% and 15.8% higher as compared to PTR_{W0} and PTR_{W25}. Among different tillage and rice straw management practices in wheat, maximum wheat grain yield was recorded in ZTW_{R100}, which was increased by 19.9% and 8.7% as compared with ZTW_{R0} and CTW_{R0}, respectively. Harvest index of wheat was higher under PTR_{W25}+GM/ZTW_{R100} treatment (0.47). Nitrogen content in wheat straw and grain as well as uptake was higher in treatment with straw retention and GM (PTR_{W0} + GM and PTR_{W25} + GM). Similarly, higher N concentration and uptake was recorded in Turbo Happy Seeder plots (i.e. ZTW_{R100}). Total P and K uptake was higher in ZTW_{R100} as compared with ZTW_{R0} and CTW_{R0} treatments.

Conclusions

The results from the present study showed that residue retention, green manuring and zero tillage caused marked positive changes in soil biochemical and chemical properties at different growth stages of wheat in RWS. The majority of the enzyme activities were higher at vigorous vegetative growth stage as compared with the reproductive growth stage. Irrespective of wheat straw and green manure practices in rice, increase in mean wheat grain yield under ZTW_{R100} was 19.9% and 8.7% higher as compared with ZTW_{R0} and CTW_{R0}, respectively. Correlation analysis showed that dehydrogenase, fluorescein diacetate, β-glucosidase activity had higher relationship with microbial biomass carbon and oxidizable organic carbon at most of the growth stages in both soil layers. Furthermore, our study identified a set of soil quality indicators (Dehydrogenase, acid phosphatase, β-glucosidase, microbial biomass carbon and soil respiration) that provided guideline to distinguish the most sustainable CA-based practices (e,g. ZT and residues retention) at tillering or flowering stage of wheat in RWS. These screened indicators may be used by the researchers for real-time monitoring of soil quality as well as ecological processes in future studies under various CA-based cropping systems. This outcome from this study may further be extrapolated to the soils of similar or related agro-ecological regions to improve overall soil quality for the long term sustainability of the cropping system.

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