LONG TERM EFFECT OF RICE STRAW INCORPORATION ON SOIL PHYSICAL PROPERTIES AND CROP PRODUCTIVITY IN RICE-WHEAT SYSTEM

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: Soil and Water Engineering)

By

Ramteke Pratik Rukmanand
(L-2017-A-153-M)

Department of Soil Science
College of Agriculture
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CERTIFICATE I

This is to certify that the thesis entitled **“Long term effect of rice straw incorporation on soil physical properties and crop productivity in rice wheat system”** submitted for the degree of **Master of Science** in the subject of **Soil Science** (Minor subject: **Soil and Water Engineering**) of the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Mr. Ramteke Pratik Rukmanand (L-2017-A-153-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.

(Dr. Bharat Bhushan Vashisht)
Major Advisor
Soil Physicist
Department of Soil Science
Punjab Agricultural University
Ludhiana

CERTIFICATE – II

This is to certify that the thesis entitled, **“Long term effect of rice straw incorporation on soil physical properties and crop productivity in rice wheat system”** submitted by **Mr. Ramteke Pratik Rukmanand** (Admn. No. **L-2017-A-153-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: **Soil and Water Engineering**) has been approved by the Student’s Advisory Committee along with External Examiner after an oral examination on the same.

(Dr. Bharat Bhushan Vashisht) **Major Advisor**	**(Dr. Sanjeev Kumar Sandal)** **External Examiner** **Principal Scientist (Soil Physics)** **Department of Soil Science** **CSK Himachal Pradesh Agricultural University, Palampur - 176062 (HP)**

(Dr. O.P. Choudhary)
Head of the Department

(Dr. Gurinder Kaur Sangha)
Dean Postgraduate Studies

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Ramteke Pratik Rukmanand

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Name of the Student and Admission No. : Ramteke Pratik Rukmanand (L-2017-A-153-M)

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Name and Designation of Major Advisor : Dr. B.B. Vashisht
Soil Physicist

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ABSTRACT

The sustainability of rice-wheat cropping system in recent some years, has come into question because of multiple reasons and most recently the burning of huge amount of crop residue. From the perspective of managing surplus rice straw and an alternative to residue burning, the present study evaluated the long term (2008-2018) effect of different rates of rice straw incorporation (0, 5, 7.5 and 10 t ha^{-1}) and nitrogen levels (0, 90, 120 and 150 Kg ha^{-1}) on soil physico-chemical properties and crop productivity. Soil samples were analysed for different physico-chemical properties of soil and biochemical properties within soil aggregates. The study resulted that, incorporation of rice straw @ 7.5 and 10 t ha^{-1} along with 150 Kg N ha^{-1} significantly improved the soil physical properties by increasing bulk density, aggregation status, infiltration rate, soil moisture retention, and decreasing total porosity, penetration resistance and saturated hydraulic conductivity as well as increased the fertility status of soil. The biochemical properties within soil aggregates were significantly higher in macro-aggregates fraction under 10 t ha^{-1} rice straw incorporation rate. In simulation study with DSSAT CERES-wheat, yield, water and nitrogen balance components of wheat with changed soil properties were evaluated. Simulation study revealed that, there would be an increase in precipitation, evapotranspiration, evaporation, nitrogen leaching and decrease in uptake of nitrogen in future compared to past and present time scenarios. However, wheat grain yield would yield decline in future, which could be sustained with incorporation of rice residue over a longer period of time.

Keywords: Rice-wheat, rice straw incorporation, soil physico-chemical properties, simulation study, DSSAT.

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

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ਸਾਰ-ਅੰਸ਼

ਕਣਕ-ਝੋਨਾ ਫ਼ਸਲੀ ਚੱਕਰ ਦੀ ਹੰਢਣਸਾਰਤਾ ਉੱਪਰ ਕੁਝ ਕੁ ਸਾਲਾਂ ਉੱਪਰ ਸਵਾਲੀਆ ਨਿਸ਼ਾਨ ਲੱਗੇ ਹਨ, ਜਿਸਦੇ ਕਈ ਕਾਰਣ ਹਨ ਅਤੇ ਇਹਨਾਂ ਵਿੱਚ ਇੱਕ ਵੱਡਾ ਕਾਰਨ ਫ਼ਸਲੀ ਰਹਿੰਦ-ਖੂੰਦ ਨੂੰ ਜਲਾਉਣਾ ਹੈ। ਵਾਧੂ ਪਰਾਲੀ ਦੇ ਨਿਪਟਾਰੇ ਅਤੇ ਅੱਗ ਲਗਾਉਣ ਦੇ ਬਦਲ ਤੇ ਲਿਹਾਜ ਨਾਲ ਮੌਜੂਦਾ ਅਧਿਐਨ ਲੰਮੇ ਸਮੇਂ (2008-2018) ਤੱਕ ਵੱਖ-ਵੱਖ ਮਾਤਰਾ (0,5,7.5 ਅਤੇ 10 t ha^{-1}) ਵਿੱਚ ਝੋਨੇ ਦੀ ਪਰਾਲੀ ਨੂੰ ਖੇਤਾਂ ਵਿੱਚ ਮਿਲਾਉਣ ਅਤੇ ਨਾਈਟ੍ਰੋਜਨ (0, 90, 120 ਅਤੇ 150 kg/ha) ਦਾ ਫ਼ਸਲਾ ਦੀ ਭੌਤਿਕੀ-ਰਸਾਇਣਿਕ ਵਿਸ਼ੇਸ਼ਤਾਵਾਂ ਅਤੇ ਫ਼ਸਲੀ ਉਤਪਾਦਕਤਾ ਉੱਪਰ ਅਸਰ ਦੇਖਣ ਲਈ ਕੀਤਾ ਗਿਆ। ਮਿੱਟੀ ਦੇ ਨਮੂਨੇ ਵੱਖ-ਵੱਖ ਭੌਤਿਕੀ ਰਸਾਇਣਿਕ ਖਾਸੀਅਤਾਂ ਲਈ ਨਿਰੀਖਣ ਕੀਤੇ ਗਏ ਨਤੀਜੇ ਦਰਸਾਉਂਦੇ ਹਨ ਕਿ 150 ਕਿਲੋ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਦੇ ਨਾਲ ਝੋਨੇ ਦੀ ਪਰਾਲੀ 10 t/ha ਖੇਤਾਂ ਵਿੱਚ ਮਿਲਾਉਣ ਦੇ ਨਾਲ ਬਲਕ ਘਣਤਾ ਘੱਟਣ, ਪਾਣੀ ਸਮਾਉਣ ਦੀ ਦਰ, ਪਾਣੀ ਸੰਭਾਲਣ ਦੀ ਸਮਰੱਥਾ ਅਤੇ ਪੋਰੋਸਿਟੀ, ਸਖਤਪਨ ਅਤੇ ਸੈਚੂਰੇਟਡ ਹਾਇਡਰੋਲਿਕ ਚਾਲਕਤਾ ਘਟਾ ਕੇ ਮਿੱਟੀ ਦੇ ਗੁਣਾ ਵਿੱਚ ਅਰਥਪੂਰਨ ਸੁਧਾਰ ਹੋਇਆ ਅਤੇ ਮਿੱਟੀ ਦੇ ਉਪਜਾਊਪਨ ਵਿੱਚ ਸੁਧਾਰ ਹੋਇਆ। ਮਿੱਟੀ ਦੇ ਐਗਰੀਗੇਟ ਦੇ ਵਿਚਕਾਰ ਬਾਇਓਕੈਮੀਕਲ ਵਿਸ਼ੇਸ਼ਤਾਵਾਂ 10 t/ha ਝੋਨੇ ਦੀ ਪਰਾਲੀ ਰਲਾਉਣ ਨਾਲ ਅਰਥਪੂਰਨ ਵਧੇਰੇ ਸੀ। ਅਭਾਸੀ ਅਧਿਐਨ DSSAT CERES ਨਾਲ ਕਣਕ, ਝਾੜ, ਪਾਣੀ ਅਤੇ ਨਾਈਟ੍ਰੋਜਨ ਬੈਲੈਂਸ ਕੰਪੋਨੈਂਟ ਮਿੱਟੀ ਦੇ ਬਦਲਾਅ ਨਾਲ ਪਰਖੇ ਗਏ। ਅਭਾਸੀ ਅਧਿਐਨ ਦਰਸਾਉਂਦਾ ਹੈ ਕਿ ਮੌਜੂਦਾ ਅਤੇ ਪਹਿਲਾਂ ਦੇ ਸਮੇਂ ਨਾਲੋਂ ਆਉਣ ਵਾਲੇ ਸਮੇਂ ਵਿੱਚ ਮੀਂਹ, ਵਾਸ਼ਪੀਕਰਣ, ਨਾਈਟ੍ਰੋਜਨ ਰਿਸਾਅ ਅਤੇ ਨਾਈਟ੍ਰੋਜਨ ਗ੍ਰਹਣ ਵਿੱਚ ਕਮੀ ਆਵੇਗੀ। ਹਾਲਾਂਕਿ ਕਣਕ ਦੇ ਝਾੜ ਵਿਚ ਕਮੀ ਆਵੇਗੀ ਜਿਸਨੂੰ ਝੋਨੇ ਦੀ ਪਰਾਲੀ ਨੂੰ ਲੰਮੇ ਸਮੇਂ ਤੱਕ ਖੇਤਾਂ ਵਿੱਚ ਰਲਾਉਣ ਨਾਲ ਬਰਕਰਾਰ ਰੱਖਿਆ ਜਾ ਸਕਦਾ ਹੈ।

ਮੁੱਖ ਸ਼ਬਦ: ਕਣਕ-ਝੋਨਾ, ਝੋਨੇ ਦੀ ਪਰਾਲੀ, ਮਿੱਟੀ ਭੌਤਿਕੀ-ਰਸਾਇਣਿਕ ਵਿਸ਼ੇਸ਼ਤਾਵਾਂ, ਅਭਾਸੀ ਅਧਿਐਨ ।

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ਵਿੱਦਿਆਰਥੀ ਦੇ ਹਸਤਾਖਰ

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CHAPTER I

INTRODUCTION

Rice-wheat cropping system of Indo-Gangetic Plains (IGP) contribute to about one-third of the total cereals production and one-half of total calorie intake in India (FAO 2007). The area under rice-wheat cropping system is about 10 M ha in the Indo-Gangetic basin of India and out of that 2.6 M ha of area falls in Indian Punjab, which is popularly known as the “Grain bowl of India” (Jalota *et al* 2018). The productivity of rice and wheat ranges from 5.5-6.5 and 4.0-5.5 t ha^{-1}, respectively. In this region the sustainability of rice-wheat cropping system in recent some years, has come into question because of reduction in soil organic matter (SOM), multi-nutrient deficiencies (Ladha *et al* 2003), adoption of unsuitable soil and crop management strategies, burning of huge amount of crop residue and declining ground water table (Hira *et al* 2004) as a consequent of which maintenance and improvement of soil fertility and crop productivity are of great challenges for farmers (Bhandari *et al* 2002, Singh *et al* 2008). Annual crop residue production in India is estimated to about 350 x 10^{6} Kg (Lal and Kimble 2002). With increase in area under cultivation of rice and wheat, the residue production of these crops has also increased markedly. Cereal crops contribute to maximum residue production accounting for 51% of rice residue and 27% of wheat residue (Lal and Kimble 2002). About 84-141 Mt yr^{-1} of surplus crop residue is available in India where rice and wheat crops contribute to a large extent which is largely burnt in the field. In the Indian Punjab conditions, the management of wheat straw is not a serious concern but managing the rice straw is one of the great challenges for farmers. To do timely planting of wheat crop farmers in this region resort to in-situ burning of crop residue. It is estimated that in Punjab, about 7-8 million metric tonnes of rice straw is burnt every year (PRSC 2015) which leads to almost complete loss of soil nitrogen, 25% of phosphorus losses, 20% of potassium losses and sulfur loss to about 5-60% (Dobermann and Fairhurst 2002). Moreover it deprives soils of organic matter, deteriorates structural and hydraulic properties of soil, losses huge amount biomass, exhaust soil flora and fauna, contribute largely to environmental pollution creating health hazard problems and deprivation of the agricultural environment. Other than burning the residue management options available for farmers are removal of straw, surface retention and mulching and incorporation into the soil. Incorporation of crop residue into the soil helps to rebuild the biological activity and play a vital role in improvement and maintenance of soil physical condition for a long period of run. Moreover, it helps in building of SOM, improvement in soil aggregation and its stability, bulk density (BD), porosity and pore size, development of soil structure, moisture holding capacity, hydraulic characteristics, penetration resistance (Zhang *et al* 2014), brings out modification in soil thermal and moisture regimes and contributes to nutrient pools of soil. It also reduces unproductive soil and water losses, helps to reduces soil temperature extremes and modifies microbial habitat for the proliferation of soil biota (Blanco-Canqui and Lal 2009). For sustaining the productive potential of this cropping systems, it is essential that the management practice should aim at improving soil physical condition via improving soil structural and hydraulic properties, reduction in nutrient losses, providing favourable microbial habitat and controlling soil degradation by the ways that are effective and inexpensive (Lal *et al* 1980). One of the cost effective option for improving overall condition of soil is the build-up of SOM through incorporation of crop residue. On farm recycling of crop residue is the pre-eminent management practice for restoring the declined SOM content which is identified as the nucleus for improving soil physico-chemical and biological condition and sustaining agriculture production (Salahin *et al* 2017). Alternatively, simulation technique with a suitable crop models for estimating crop growth, water and nitrogen balance is a powerful tool in variety of soils and agro-ecological conditions (Vashisht *et al* 2019, 2013).

In this region, there is need to find a best alternative to residue burning. Many studies found that the crop residue is rich in organic material and soil nutrients, so its incorporation in soil is beneficial for crop production and soil conservation point of view (Duiker and Lal 1999, Saroa and Lal 2003). In order to sustain agriculture production, it is essential to assess the magnitudes of change in soil physical environment with incorporation of rice straw. Keeping this in view a study from a long term experiment on rice straw incorporation in rice-wheat system was planned with the following objectives.

I. To investigate the effect of rice straw incorporation on soil physical properties in rice-wheat system.

II. Simulation of changed soil physical properties with rice straw management on the crop productivity, water and nitrogen balance components.

CHAPTER II

REVIEW OF LITERATURE

The effect of rice straw incorporation and nitrogen fertilization on soil physico-chemical properties under rice wheat cropping system have been reviewed under following headings:

2.1 Effect on crop productivity
2.2 Effect on physical properties of soil
    2.2.1 Effect on bulk density and porosity
    2.2.2 Effect on aggregation and aggregate stability
    2.2.3 Effect on soil penetration resistance
    2.2.4 Effect on hydraulic properties of soil
2.3 Effect on chemical properties of soil
    2.3.1 Effect on soil organic carbon
    2.3.2 Effect on available N, P and K
2.4 Effect on enzyme activities and soil carbon pools

Many researchers around the world studied the effects of rice straw incorporation on soil physico-chemical as well as biological properties under wide range of soil and climatic conditions and reported positive effects on soil physical parameters viz. soil porosity, aggregation, bulk density, penetration resistance, hydraulic properties, soil chemical properties viz. available nutrient content and soil biochemical properties viz. enzyme activities, carbon fractions and the improvement in overall soil health that ultimately leads to attain higher grain yields in long run.

2.1 Effect on crop productivity

In the Eastern India, Sarkar and Kar (2011) reported that grain yield of rice and wheat significantly improved with application of rice straw and wheat straw either separately or in combination as compared to without crop residue treatment. This was mainly attributed to improvement in soil organic carbon (SOC) levels, reduce evaporative loss of water, improved water infiltration, which improved the soil physical condition and reduced the nutrient losses. Similarly, Yuana *et al* (2014) showed the significant increment in grain yield with rice straw incorporation and nitrogen fertilization. In another study, Wilhelm *et al* (1986) observed that grain yield of corn and soybean could reduced by about 0.10 Mg ha^{-1} with removal of each Mg ha^{-1} of residue. Shafi *et al* (2007) in Pakistan reported that incorporation of crop residue increased the grain yield of maize by 23.7% as compared to residue removal treatments. Similar results have been reported by Kouyate *et al* (2000) about 37% increase in grain yield of cereals with crop residue incorporation as compared to without incorporation. Power *et al* (1998) reported increased maize yield with increasing amount of crop residue. Highest yield

(4900 Kg ha^{-1}) were found under plot that received 150% of crop residues from previous crop as compared to control. While number of studies reported the higher grain yield with residue management, there are few studies who reported the decrease or variable effect of crop residue on crop productivity. Shaha *et al* (2003) reported that lentil grain yields in year 1995-96 were 0.82 and 1.17 t ha^{-1}, 0.28 and 0.35 t ha^{-1} in 1996-97, 1.63 and 1.24 t ha^{-1} in 1997-98 under residue removal and residue retained treatments. When averaged over all years, no any significant effect of residue retention and residue removal on grain yield of lentil were reported. In sandy clay loam soils of Philippines, Surekha *et al* (2003) did not find any significant effect of residue treatments on grain yield in the first and second cropping cycle, however in third and fourth cropping cycle, 100% straw treated plots showed significantly higher grain yield as compared to 50% straw incorporation and control. In last cropping cycle, burning of residue recorded highest grain yield of about 18.5% over control followed by 100% straw + green manure (16.8%) and 100% straw (15.4%). Similarly, Uhlen (1991) in a long term experiment, reported that some years showed higher grain yield while some not. However, overall effect was found to be non-significant. Such variable reports have also been presented by Borresen (1999) who reported that in the first year of experimentation, the different straw management treatments did not show any significant effect on grain yield. In second year, the grain yield was significantly improved with the incorporation of normal and double amounts of straw. However, at the fourth year of experimentation, straw managed treatments showed significant negative impact on grain yield. On an average, incorporation of normal and double amounts straw increased the mean grain yields by 0.29 Mg ha^{-1} as compared to other treatments. Paul *et al* (2013) in Kenya did not find any significant effect of crop residue management in combination with tillage practices on the grain yield of maize and soybean. In Punjab, India, Sidhu and Beri (1989) found that residue burning resulted in highest yield of rice and wheat as compared to incorporation or residue removal. Reduction in yield with residue incorporation was mainly due to immobilization of nitrogen and phosphorus. Residue incorporation together with application of N @ 60, 120 and 180 Kg ha^{-1} resulted in depression of wheat yield by 0.54, 0.27 and 0.08 t ha^{-1}, respectively. However the positive effects of residue incorporation were reported after 13 years when residue management practices where discontinued.

2.2 Effect on physical properties of soil

2.2.1 Effect on bulk density and porosity

In Punjab, India, Singh *et al* (2007) in a long term experiment reported decrease bulk density (BD) in rice straw managed treatment over control. Among different treatments, treatments consisting of wheat straw + urea + rice straw incorporation resulted in maximum reduction in BD (1.65 Mg m^{-3}) because of incorporation of residue of both crops. Similarly in another study at Philippines, Surekha *et al* (2003) reported that all the plots receiving rice straw treatment significantly decreased the soil BD. It was 1.25, 1.29, 1.26, 1.42 and 1.41g cm^{-3} under 100%, 50% straw incorporation, 100% straw + green manure, straw burning and control respectively. BD under control and straw burnt plot were statistically at par, but straw incorporation had resulted in lowering of soil BD over burning and control mainly because of increase in SOC storage. While studying the long term effect of crop residue incorporation on two different soil types, Hassan *et al* (2013) reported lower BD with crop residue incorporation in both the soil types. However the magnitude of decrease was highest in Shahpur soil (coarse silty in texture and low SOM) as compared to Awagat soil (fine loam texture). Similar results were also reported for total porosity of soil. This was mainly attributed to the property of crop residue in improving soil structure mainly in the soil with light texture and low SOM content. Blanco-Canqui and Lal (2007) studied the long term effect of different levels of wheat straw mulch (0, 8, and 16 Mg ha^{-1} yr^{-1}) on a silt loam soil of Central Ohio and reported that in 0-3 cm soil depth, 16 Mg ha^{-1} yr^{-1} treatment lowered the BD by 58% (0.84 Mg m^{-3}) and 8 Mg ha^{-1} yr^{-1} treatment by 19% (1.11 Mg m^{-3}) than BD under 0 Mg ha^{-1} yr^{-1} (1.32 Mg m^{-3}). However this trend was decrease at 3-10 cm soil layer, where the BD was lowered by 36% and 9% under 16 and 8 Mg ha^{-1} yr^{-1} as compared to control. They further reported that at 10-20 cm layer, the effect among different treatments on was non-significant. Similarly, total porosity was also affected by wheat straw mulch. Macro and meso-porosity was greater and micro-porosity were lower in mulched treatments in 0-3 cm soil depth. Total porosity under 0, 8, and 16 Mg ha^{-1} yr^{-1} of wheat straw mulch was 0.50 m^3 m^{-3}, 0.64 m^3 m^{-3} and 0.72 m^3 m^{-3}, respectively and it increased by about 28% and 44% under 8 and 16 Mg ha^{-1} yr^{-1} of wheat straw mulch over control treatment. However, Boguzas *et al* (2010) in Lithuania did not find any significant effect of chopped straw incorporation on soil BD in upper 3-13 cm and lower 15-25 cm depth soil layer. They reported the total BD of 1.25–1.49 Mg m^{-3} in upper soil layer without straw and 1.29–1.47 Mg m^{-3} in plot with straw incorporation. Similar results have also been reported by Borresen (1999) in a long term study with straw incorporation. While studying the effect of tillage and previous crop residue management on soil properties in Punjab, Ghuman and Sur (2001) found reduction in BD at 0.025 m soil depth for all three treatments, however lowest BD was recorded by Minimum tillage with residue (MTR) as compared to Minimum (MT) and conventional tillage (CT) solely. The similar trend was found up to 0.10 m soil depth, however BD under MTR and MT was statistically uniform in 0.15 cm soil depth but significantly less than CT.

In a three year study with different tillage practices and eight levels of crop residue management under wheat-mungbean-rice cropping system, Salahin *et al* (2017) in Bangladesh reported that BD under S_{wrm} (where residue of all three crops were incorporated) was found to be the lowest (1.38 g cm^{-3}) followed by S_{mr} (1.40 g cm^{-3}) and S_{mw} (1.40 g cm^{-3}) having incorporation of two crop residues. S_0 (Plot without incorporation of crop residue) showed the highest BD (1.44 g cm^{-3}). Similarly, S_{wrm} showed highest total porosity (43.2%) and lowest was in S_0. However, Singh and Malhi (2006) in Canada did not find any significant effect of crop residue on BD. However, when averaged across crop residue, BD was higher for No-tillage than tillage by about 15% in black Chernozen and 18% in gray Luvisol. Similar results have been reported by Dalal *et al* (2011) in vertisol soil type of Australia where the effect of residue management on BD was non-significant. While studying the effect of conservation tillage on productivity of wheat for 15 years (1992-2006) in Northern China, Li *et al* (2007) reported that for the first six years, BD was significantly less for CT (conventional till). It was statistically uniform for CT and NTSC (no-till and residue cover) in the next five years, afterwards NTSC resulted in lowering of soil BD. The total porosity increased with increasing mulch rate (Jordan *et al* 2010). However, lower mulching rates up to 5 Mg ha^{-1} yr^{-1} did not show any significant difference in total porosity. Up to 5 Mg ha^{-1} yr^{-1}, mean total porosity was 0.3% and it increased by about 173% under 10 and 15 Mg ha^{-1} yr^{-1} of mulch rate. Mandal *et al* (2004) reported that crop residue management significantly affected the total porosity of soil. Total soil porosity was 49.4, 48.8, 51.9 and 54.6% under control, straw burning and removal, straw incorporation and straw incorporation plus FYM treated plot respectively. Similar results have been reported by Mulumba and Lal (2008), Oliveira and Merwin (2001) and Roppongi *et al* (1993). Total porosity was lower for low mulch rate and it increased by about 95% with 8 Mg ha^{-1} of mulch rate. In a short term study in Western Nigeria, Lal (2000) reported decreased BD with increasing mulch rate in 0-5 cm soil layer i.e. 1.17 Mg m^{-3} under control to 0.97 Mg m^{-3} with 8 Mg ha^{-1} $Season^{-1}$ of mulch treatment. Similarly, Marahatta *et al* (2014) observed 58% lower BD under the high-mulch treatment, 19% lower under the low-mulch treatment as compared to the BD under the un-mulched treatment for the 0-3 cm depth.

2.2.2 Effect on aggregation and aggregate stability

In North West India, while studying the effect of crop residue and manure application of soil aggregation in rice wheat cropping system, Benbi and Senapati (2010) reported that application of rice straw and FYM resulted in increase in aggregation especially macro-aggregates, decrease in micro-aggregates and the effect was not significant for application of nitrogenous fertilizers. There were higher (32.5-54.5%) percentage of macro-aggregates than micro-aggregates (18.9-21.8%). Among the different macro-aggregates fractions, > 2 mm fraction was only 1.9 and 4.4%, whereas 17.4-22.1% was reported for 0.25-0.50 mm fraction. They further reported that at 0-5, 5-10 cm soil layer, macro-aggregate formation was enhanced significantly with application of rice straw and FYM. However, at 10-15 cm, the improvement in > 2 mm fraction was least. When assessed across different nitrogen rates, abundance of macro-aggregates was found with incorporation of rice straw at 0-5 cm soil layer. Similarly, in the arid lands of Loess Plateau of China, Wang *et al* (2015) reported that aggregate stability was high in 0-10 cm soil depth and decreased with increase in soil depth. In the two years of experimentation, aggregate stability in 0-10, 10-20, 20-30 cm soil layer were 5.0-23.2%, 10.3-32.1%, 10.6-47.9% respectively and significantly higher for straw incorporation treatments over control plot receiving only inorganic fertilizer. Moreover, aggregate stability increased with increase in rate of straw incorporation. Compared with 4.5 Mg ha^{-1}, aggregate stability under 13.5 Mg ha^{-1} was improved by 13.2-30.7% and 5.6-13.8% as compared with 9.0 Mg ha^{-1}. In another short-term study, Soona and Lupwayi (2012) reported that straw incorporation resulted in reduction of 2.0-0.25 mm aggregate fraction as compared to control plots. However, no any significant influence of straw incorporation on aggregates in the size range >2.0 mm or < 0.25 mm have been reported. Singh *et al* (2018) reported that compared with no residue treated plots, soil aggregation was improved in crop residue treated plot and had a higher proportion of large macro-aggregates than the small macro-aggregates. Of the total water stable aggregates in surface soil, greater than 35% was accounted for large macro-aggregate than the small macro-aggregates. Crop residue treated plot had 14% higher water stable macro-aggregates as compared to no residue treated plot.

While studying the effects of different mulching rates, Mulumba and Lal (2008) found that water stable aggregates were higher in 16 Mg ha^{-1} year^{-1} mulch rate, ranging from 38% to 67% and lowest under plot receiving 0 Mg ha^{-1} yr^{-1} mulch rate. Similar results have been reported for mean weight diameter (MWD) which was highest for mulch rate of 16 Mg ha^{-1} yr^{-1} (0.47-1.59 mm) over 0 Mg ha^{-1} yr^{-1}. Singh and Malhi (2006) in Canada reported that management of tillage practices had greater effect on improving soil structure than residue retention as indicated by aggregate size distribution. They reported the higher value of MWD under no tillage and residue retention and least under tillage without residue. Similarly, Wei *et al* (2006) showed that crop residues incorporation was the most effective measure for increasing the aggregate stability of rhizosphere. Sonnleitner *et al* (2003) and Karami *et al* (2012) also found that straw application improved the aggregate stability and other soil properties. However, Skidmore *et al (*1986) in a 14-years study at Kansas, did not find any significant effect of residue management on aggregation status of soil.

2.2.3 Effect on soil penetration resistance

In Bangladesh, Salahin *et al* (2014) reported that penetration resistance (PR) was significantly reduced by retention of higher amount of crop residue as compared to lower amount. PR in 0-5 and 5-10 cm soil layer under low amount of residue retention was 80, 152 N cm^{-2} and 69, 134 N cm^{-2} under high amount of residue retention. However at lower soil layers i.e. 10-15 cm, the effect was not significant. Similarly, Borresen (1999) in Norway reported that straw management treatments significantly improved the modulus of rupture. The corresponding values in A^{o}S and Øsaker were 8.2, 6.5, 7.5, 6.5 kPa and 13.2, 13.1, 16.8, 13.2 kPa for straw burnt, removal, incorporation up to 2 cm and incorporation up to 8 cm respectively. Incorporation of straw at 8 cm showed decrease in modulus of rupture in AºS but did not show any significant in Osaker location. However, Boguzas *et al* (2010) did not find any significant influence of straw incorporation on PR. At depth of 1.5-9.0 cm, PR was highest and changed drastically from 223 to 1115 kPa in straw removed plot and from 208 to 1053 kPa in straw incorporated plots, respectively. At depth 9.0-22.5 cm, PR changed from 1115 to 1175 kPa in straw removed plot and from 1053 to 1211 kPa in straw incorporated plots. In another study, Lal (2000) observed significantly lower PR under different rates of mulch treatments. At soil depth 0-5 cm, PR under control were 1.54 Kg cm^{-2} and reduced to 1.07 Kg cm^{-2} under 8 Mg ha^{-1} of mulched treatment. They also reported that PR tend to decrease with increase in soil depth up to 40 cm. Lower PR under higher mulch rate was attributed to wetness of soil profile because of reduction in soil evaporation and runoff. Conversely, while working on a silt loam soil of central Ohio, Blanco-Canqui and Lal (2007) did not find any significant effect of different mulch rates on cone index at 0-5 cm soil layer. However from 5 to 35 cm soil layer cone index decreased with 16 Mg ha^{-1} yr over control and corresponding averaged values were 0.2-0.3 Mpa and 0.4-0.5 Mpa, respectively. Cone index was statistically at par in control and 8 Mg ha^{-1} year^{-1} straw mulch but it was significantly higher than 16 Mg ha^{-1}year^{-1}. In a short term study, Lee *et al* (2010) reported only slight effect of management practices on PR in the first year of experiment but afterwards PR was significantly influenced by application of rice straw and green manure crops. The decreasing PR among different treatments at depth of 0.5 to 0.15 m followed the order -NTNT (no-tillage without rice straw) > TNT (conventional tillage without rice straw) > NTRS (No tillage with rice straw) and at 0.25-0.40 m layer, it was TNT (conventional tillage without rice straw) > NTRS (No tillage with rice straw).

2.2.4 Effect on hydraulic properties of soil

The hydraulic properties of soil viz. infiltration rate (IR), hydraulic conductivity and soil moisture have been reported to be affected significantly by crop residue incorporation. Sarkar and Kar (2011) reported the reduced BD in 0-15 cm soil depth with incorporation of rice and wheat straw with associated increase in saturated hydraulic conductivity (ks) because of increase in macro-porosity of soil. However at higher depth 15-30 and 30-45 cm, negligible effect of crop residue incorporation on hydraulic conductivity was reported. Incorporation of residue of both wheat and rice crop increased the IR of soil. Initial IR was maximum (7.0 mm hr^{-1}) where residue of both crops incorporated. After five hours, it varied from 2.0 mm hr^{-1} under less intensive tillage without crop residue to 4.0 mm hr^{-1} where residue of both crop where incorporated. In another study, Hassan *et al* (2013) reported the favourable effect of residue incorporation on infiltration because of presence of greater proportion of maco and mesopores and lowered soil bilk density in both Awagat and Shahpur soil. In Awagat soil, IR was increased by about 56% and by 46% in Shahpur soil in integrated nutrient management (INM) treatments without crop residue. Integrated nutrient management with crop residue incorporation resulted in increase in infiltration by 50% in Awagat soil and by 44% in Shahpur soil. The observed difference in two types of soil was mainly because of difference in soil texture and organic matter content. While studying the effect of different tillage treatments, Chan and Heenan (1993) reported that sorptivity of straw retained treatment was significantly lower than straw burnt treatment at lower potential (-40 mm). Hydraulic conductivity under straw-retained direct- drilled treatments was 4.1 times greater than that of straw-burnt conventional tillage treatments. This was mainly because of improvement in more transmitting macropores under straw retained direct drilled treatment. Significantly higher amount of available soil moisture was detected in straw retained direct drilled treatment as compared to straw burnt conventional till system. Similarly, Naresh (2013) on a sandy loam soil also reported that total as well as final infiltration were significantly higher with zero tillage in combination with crop residue retention as compared to conventional tillage.

While studying the effect of three types of crop residues, Salahin *et al* (2017) reported higher soil moisture content by 31% in the plot receiving residues of all three crops (wheat, rice and mungbean) than plot without crop residue incorporation. Soil depth of 0-5 and 10-15 cm did not reported any significant difference in soil water content between low and high amount of crop residue retention. However soil water content at 5-10 soil depth was significantly higher in high amount of crop residue treatment as compared to low amount of residue retention. Similarly, Mulumba and Lal (2008) reported that mulching rate significantly improved soil moisture content at low suction range. At saturation, moisture content was significantly higher for mulching rate of 8 and 16 Mg ha^{-1} and lowest under un-mulched and control. The difference in moisture content among different mulching rates at higher suction was least than at lower suction. Moisture content at wilting point was statistically uniform for all mulching rates. Available soil moisture content increased with increase in mulching rates, however beyond 2 Mg ha^{-1}, no any significant difference among different mulching rates was reported. However, Jordan *et al* (2010) in Spain did not find any significant difference in water content at mulching rate of 1 and 5 Mg ha^{-1} yr^{-1} over control. At higher mulching rates of 10 and 15 Mg ha^{-1} yr^{-1}, there were about 18% higher soil moisture for all suction intensities. At field capacity (FC), moisture content at 0, 1, 5 Mg ha^{-1} yr^{-1} was 27.7%, 31.4%, and 29.7%, respectively but it increased significantly with higher mulching rate of 10 and 15 Mg ha^{-1} yr^{-1} where it was 33.7 and 40.1%. Similarly, moisture content at wilting point was also higher for 10 and 15 Mg ha^{-1} yr^{-1}. However, no any significant difference was reported between 10 and 15 Mg ha^{-1} yr^{-1}. They also reported about 7.6% higher ks with mulching rate of 10 and 15 Mg ha^{-1} yr^{-1} as compared to control and low mulching rates and no any benefit was found beyond 10 Mg ha^{-1} yr^{-1} of mulch rate. Rahman *et al* (2005) in Japan studied the effect of rice straw mulch and nitrogen fertilization on soil moisture content during wheat growth and found that in surface soil, moisture content was reduced at faster rate in the plot without rice straw mulch i.e. from 33.2% at sowing to 14.1% after 20 days of sowing. The moisture content under 4 Mg ha^{-1} of rice mulch retained highest percentage of soil moisture i.e. 21% after 20 days of sowing. They reported significantly higher amount of soil moisture even after removal of rice straw from previously mulched plot. With increasing nitrogen fertilizer rate, soil moisture content decreased due to more crop growth and enhanced transpiration.

2.3 Effect on chemical properties of soil

2.3.1 Effect on soil organic carbon

In the 11 years of continuous rice-wheat rotation, Benbi *et al* (2012) reported that SOC content improved by 34% with incorporation of rice straw and application of FYM. Singh *et al* (2009) reported that sandy loam soil with low initial organic carbon had great potential for increasing SOC content as evident from 29.6% increase as compared to 11.6% in silt loam soil, in straw retained treatments compared with straw burning. Likewise, In NW China, Zhang *et al* (2014) reported that maize straw incorporation resulted in increase in SOC storage. SOC storage for straw incorporation @ 4500 Kg ha^{-1} was 7.71% in 2008 and it increased to 21.40% in 2010 over control. The study resulted that SOC storage increased from 6.19% in 2008 to 12.48% in 2010 and decrease with increases in soil depth. As compared to control, straw incorporation @ 4500 kg ha^{-1} showed a significant increase in SOC storage, but no any significant difference was found between straw incorporation @ 9000 and 13,500 Kg ha^{-1}. In another study, Villamil *et al* (2015) in USA also reported higher SOC stock where crop residue retained and incorporated as compared to complete and partial residue removal. In a long term research, Bhat *et al* (1991) showed that the organic-carbon content of soils was significantly increased with application of rice straw at the rate of 12 t ha^{-1} and wheat straw at the rate of 6 t ha^{-1}. Similarly, in cotton wheat system, Hassan *et al* (2013) reported significant increase in SOM with straw incorporation as compared with straw removal. This effect was more pronounced in coarse silty soil as compared to fine loamy soil. However, Ghimire *et al* (2017) in Nepal did not find any significant effect of crop residues incorporation to increase SOC in a conventionally tilled rice-wheat system. However, SOC content was 11% higher under no-tillage and residue added treatments than under conventional tillage and no residue added treatments.

In Southern Spain, while working with mulched treatments, Jordan *et al* (2010) did not find any significant difference for SOM content between mulching rates of 1 Mg ha^{-1} yr^{-1} and control. Increasing mulching rates from 5 Mg ha^{-1} yr^{-1} resulted in increase in percent organic matter ranged between 3.1-4.4% and highest increase was reported for mulching rates of 10 and 15 Mg ha^{-1} yr^{-1}. In a long term experiment at China, He *et al* (2009) reported that the mean SOM for no till with straw was 18.8 g kg^{-1} in the 0-0.05m soil depth which was significantly greater than conventional tillage plots i.e. 14.3 g kg^{-1}. Shafi *et al* (2007) reported that incorporation of crop residue increased the SOC content by about 4.8% but did not find any significant difference in SOC content between residues returned and removed treatments. Similarly, Shaha *et al* (2003) reported increased SOC with residue retention along with nitrogen inputs. Yuan *et al* (2014) found that with rice straw incorporation, SOM increased from 6.4% in 2008 to 12.2% in 2010.

2.3.2 Effect on available nitrogen, phosphorus, and potassium

In a long term study at Ludhiana, Punjab, Sidhu and Beri (1989) found that incorporation of crop residue resulted in higher concentration of total nitrogen as compared to treatments with residue removal or burning. Similarly, Avail P content was also greater in plots with residue incorporation as compared to its removal or burning. Burning of crop residue resulted in decreasing Avail P content because of its loss to atmosphere. Gotoh *et al* (1984) and Cassman *et al* (1995) also reported that total nitrogen content was significantly improved with rice straw incorporation as compared burning of crop residue. It was 3.28 t ha^{-1}, and 3.04 t ha^{-1} under straw incorporation and residue burnt treatment. In Vertisol soil type Dalal *et al* (1989) reported that total nitrogen and mineralizable nitrogen in 0-10 cm soil depth was significantly higher in treatment with no-tillage residue retention and increasing level of fertilizer nitrogen. Total nitrogen content with fertilizer nitrogen dose of 0, 23, 69 Kg ha^{-1} yr^{-1} were 1.56, 1.45 and 1.51 g kg^{-1} under no tillage residue burnt treatments and 1.60, 1.74, 1.78 g kg^{-1} under no-tillage residue retention treatment respectively. Similarly, Shafi *et al* (2007) reported 29.2% increase in mineral nitrogen with incorporation of crop residue. Similar results also have been reported by Kushwaha *et al* (2000). In Philippines, Surekha *et al* (2003) reported that all the plots receiving rice straw treatment showed significantly highest avail K ranging from 375 Kg ha^{-1} in 50% straw incorporation to 495 Kg ha^{-1} in residue burning over control 355 Kg ha^{-1}. In NW china, Liu (2010) reported that different nutrient management treatments had significantly improved the soil nutrient status as compared to control. Treatment comprising of Straw + N P, and FYM showed significantly higher nutrient content over control and other treatments. Total nitrogen content was 0.98, 1.11, 1.17, 1.22 g kg^{-1}, avail P was 5.76, 12.66, 14.25, 14.69 mg kg^{-1} and avail K was 144, 140, 169.5 and 193 mg kg^{-1} under treatments control, NP, NP+ straw, and FYM treatments respectively. Similarly, Li *et al* (2007) in NW China reported that no-tillage in combination with residue retention showed significantly higher total N and P by about 25.6% and 4.4% respectively. At 0-10 cm soil depth, total N and P were 0.668 and 0.738 g kg^{-1} under no-tillage with residue retention and 0.553 and 0.645 g kg^{-1} in conventional till without residue. Similarly, at 10-20 cm soil depth, total N and P content were 0.541, 0.608 and 0.415, 0.644 g kg^{-1} under no-tillage with residue retention and conventional till without residue, respectively.

2.4 Effect on enzyme activities and soil carbon pools

Soil enzymes are the vital components of the soil and can serve as the indicator of soil quality and portray the potential soil fertility under different management interventions. The activity of enzymes in soil is governed by the different management practices and ameliorative measures which affect the soil properties of biologically most active surface horizons.

In rice-wheat cropping system, Basak *et al* (2016) reported the highest activity DHA in rice straw incorporated treatment as compared to rice straw removal. Goyal *et al* (2009) in rice wheat system, also reported that DHA activity was 2 times higher in rice straw compost incorporated treatment as compared to no compost incorporated treatments. Similarly, significantly higher activity of DHA was observed in 0-30 cm soil depths with incorporation of wheat residue than its burning (Celik *et al* 2011). Chandra (2011) reported the higher microbial biomass and enzyme activities following rice straw incorporation as it act as a source of food and energy for microbes. In maize-wheat cropping system, Kumawat *et al* (2017) reported 14.6% higher activity of FDA enzyme in 0-5 cm soil depth under 75% crop residue retention as compared to without retention. In rice-wheat mungbean cropping system, Singh *et al* (2015) reported 18% increase in FDA activity after 9 years of crop residue and vermicompost incorporation than no straw and vermicompost incorporation. Dick *et al* (1988) under wheat-fallow cropping system reported that activity of acid phosphate enzyme decreased by straw burning as compared to straw incorporation. In another experiment, Zhang *et al* (2016) reported that incorporation of maize residue at the rate of 7.5 t ha^{-1} increased the activity of alkaline P by about 80% as compared to no residue. Similarly, Wei *et al* (2015) reported the significant improvement in alkaline P activity after incorporation of wheat straw.

Soil labile carbon pools are considered as the soil quality indicators and are influenced by crop residue management practices (Blair *et al* 1995 and Plaza-Bonilla *et al* 2014). While working in rice-wheat cropping system, Li *et al* (2016) reported that WSC increased by about 71-109% in rice straw incorporated treatments as compared to without rice straw incorporation. Similarly, Xu *et al* (2011) in China reported that, incorporation of 50% and 100% crop residue has significantly increased WSC content as compared to straw removal. It increased by 34 and 71% under 50 and 100% crop residue incorporation (Xu *et al* 2011). In another study, Singh *et al* (2015) in rice wheat and rice-wheat mung bean cropping system reported the higher BSR in FYM and crop residue amended plot. Ghimire *et al* (2017) also reported higher cumulative CO_2 under incorporation of crop residue at the rate of 10 t ha^{-1} as compared to control. Similarly, Ibrahim *et al* (2015) in an incubation study observed that BSR was significantly higher in rice straw incorporated treatments. Rice straw incorporation increased the BSR by 2.7-2.8% over no straw incorporation. Xu *et al* (2011) in china reported that incorporation of 50% and 100% rice straw increased (188.6, 227.2 mg kg^{-1}) the MBC as compared to control (140.7 mg kg^{-1}). The magnitude of increased was higher after ten years of rice straw incorporation than after two years. However TOC was not affected significantly by rice straw incorporation as compared to control after two years of experimentation, but after ten, years significant increment was reported. However, Mendham *et al* (2002), reported the minimal effect of crop residue retention on TOC content, but MBC was affected significantly in crop residue retained treatments. They also reported that the effect of crop residue retention was more pronounced after 1 year as compared to after 5 years.

It thus seems from the review of available literature that conflicting results have been reported on the impact of crop residue incorporation on soil physico-chemical properties. This is because of the dynamic nature of soil and climate, the initial properties of soil, type and amount of crop residue that is incorporated.

CHAPTER III

MATERIALS AND METHODS

The methodology for present investigation has been divided into following heads:

3.1 Experimental site
3.2 Weather and climate
3.3 Experimental layout and treatment details
3.4 Crop management
3.5 Soil samples collection and analysis
3.6 Simulation study
3.7 Statistical analysis

3.1 Experimental site

The present study entitled “Long term effect of rice straw incorporation on soil physical properties and crop productivity in the rice-wheat system” was conducted at the research farm, Department of Soil Science, Punjab Agricultural University, Ludhiana. The experimental site is located in the Ludhiana district of Punjab at an elevation of 247 m above mean sea level and lie at 30^{o} 54’ latitude and 75^{o} 40’ longitude which represents the central agro-climatic zone of Punjab.

3.2 Weather and Climate

The geographical location of Punjab is in the North-West Indian sub-continent with the western Himalayas to the North and the Thar Desert to the South-West. The periodic circulation of moist air masses in the South-West and North-West determines the occurrence of two wet periods each followed by a dry period. The South-Western current of the summer monsoon from the Bay of Bengal brings the rainy depressions from July to September. From October to June, conditions are generally dry with the exception of light showers from the North-Western depression during the winter months and a wet season from July to early September. May and June are the warmest months with intensive evaporation losses, while December and January are the coldest months. The site receives an average annual rainfall of 733 mm, which is not evenly distributed and most of which (78-80%) is received during the rainy season (July to September). The lowest monthly temperature of 13.7 ºC is reached in January and the highest of 42.2 ºC in May. The average monthly weather data recorded at the meteorological observatory of the School of Climate Change and Agro-meteorology during the experimental season are presented in Fig 3.1.

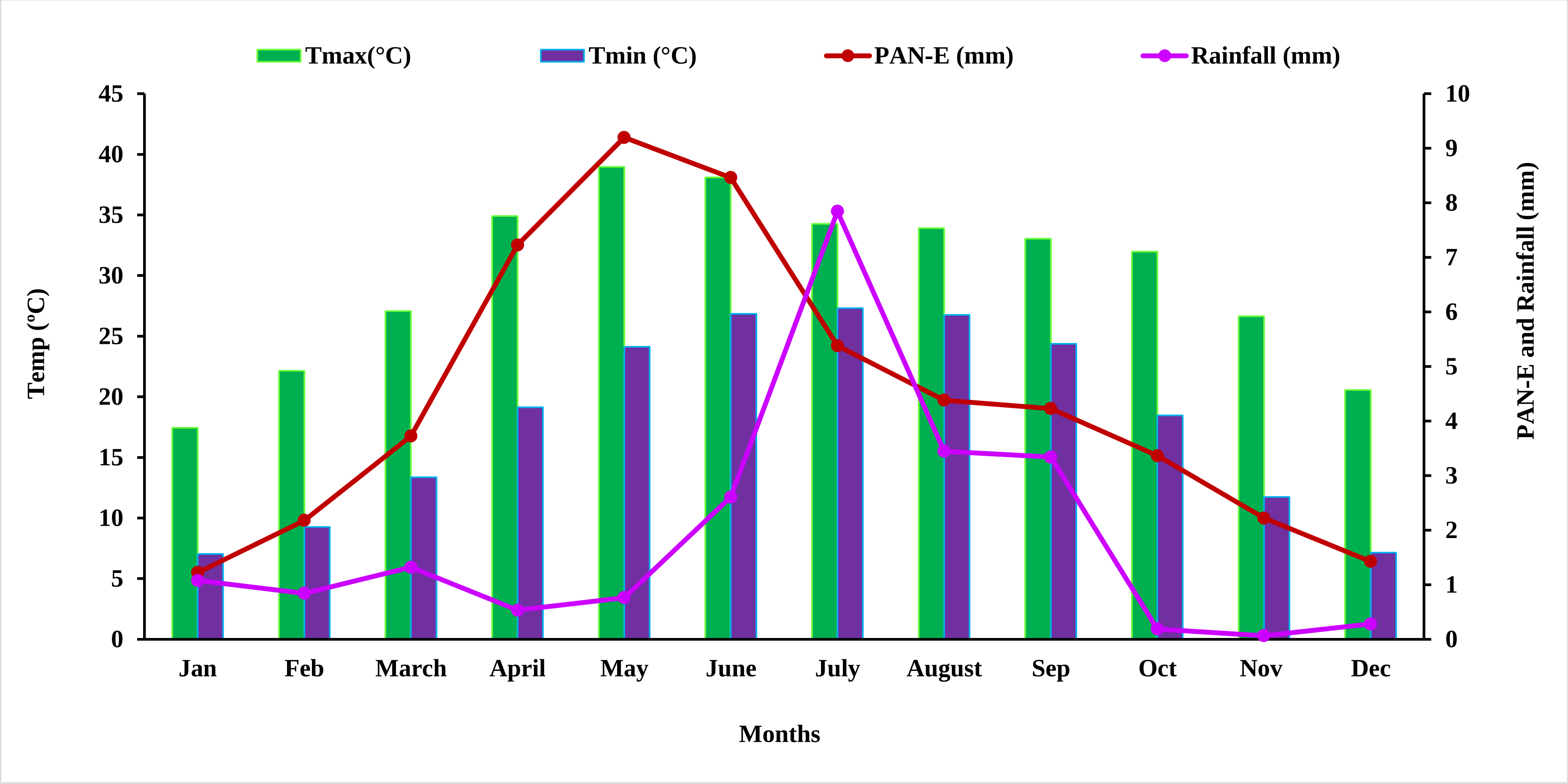

Fig 3.1 The monthly mean temperature, rainfall and pan evaporation in the study area.

Table 3.1 Soil profile characteristics of experimental site

Soil depth (cm)	Soil texture	pH	EC (ds m^{-1})	SOC (%)	BD (Mg m^{-3})	Porosity (%)	ks (cm hr^{-1})	FC (m^3m^{-3})	PWP (m^3m^{-3})	NH_4-N (ppm)	NO_3-N (ppm)	Avail P (Kg ha^{-1})	Avail K (Kg ha^{-1})
0-15	Sandy clay loam	7.25	0.15	0.45	1.55	39.3	0.93	0.20	0.085	14.58	42.51	20.1	95.5
15-30	Sandy clay loam	7.35	0.11	0.40	1.58	36	0.78	0.22	0.088	7.86	77.24	19.6	80.4
30-60	Sandy clay loam	7.76	0.09	0.30	1.73	30.4	0.15	0.21	0.079	21.65	49.26	17.9	101.3
60-90	Clay loam	7.09	0.10	0.30	1.88	28.35	0.25	0.23	0.080	7.33	14.38	19.3	100.6
90-120	Loam	7.45	0.11	0.27	1.74	30.02	1.5	0.23	0.075	28.64	7.84	18.2	76.33
120-150	Clay	6.4	0.09	0.30	1.86	29.39	0.095	0.18	0.072	14.35	20.33	15.6	69.8
150-180	Clay	7.49	0.08	0.20	1.83	28.52	0.084	0.16	0.060	7.54	28.64	19.10	53.08

BD- Bulk density, ks- Saturated hydraulic conductivity, FC- Field capacity, PWP- Permanent wilting point

The value of particle density ranged from 2.56-2.63 Mg m^{-3}.

3.3 Experimental layout and treatments

Treatments comprised of four rice straw incorporation rates (0, 5, 7.5, 10 t ha^{-1}) and four rates of nitrogen application (0, 90, 120, 150 Kg ha^{-1}). The experiment was laid out in a split-plot design with three replications. Rice straw was incorporated in the main plot and nitrogen levels were applied in the sub plot. A total of sixteen treatments were analyzed through a combination of rice straw and nitrogen levels.

Treatments details

Main plot- Rice straw incorporation	
0 t ha^{-1}	R_{st} 0
5 t ha^{-1}	R_{st} 5
7.5 t ha^{-1}	R_{st} 7.5
10 t ha^{-1}	R_{st} 10
Sub-plot- Nitrogen application	
0 Kg N ha^{-1}	N_0
90 Kg N ha^{-1}	N_{90}
120 Kg N ha^{-1}	N_{120}
150 Kg N ha^{-1}	N_{150}

Location- PAU Soil Science Research Farm
Plot- size- 6 x11 m
Crop- Wheat
Variety- PBW 621

3.4 Crop management

All the plots after wheat harvest remained fallow until pre-sowing irrigation for rice was applied in the first week of June. The preparatory tillage included two diskings followed by two passes of tyne cultivator in standing water to puddle the soil followed by planking. 30 day old rice seedling (variety PR 118) were transplanted manually at 15 cm × 20 cm spacing in the second week of the June each year.

Residue management

Rice was harvested manually at ground level and whole of the straw was removed from the plots. Rice straw was chopped with rice straw chopper, incorporated with rotavator into soil followed by pre-sowing irrigation and wheat was sown after proper soil moisture conditions were achieved. Zero till drill was used for planting wheat in rows 20 cm apart. Wheat was harvested close to the ground manually with sickles and all harvested biomass removed from the plots.

Fertilizer management

In rice different doses of nitrogen were applied as urea. Nitrogen was applied in 3 equal split doses at transplanting and at 3rd and 6th week after transplanting. A uniform dose of 13 Kg P ha^{-1} as diammonium phosphate (DAP), 25 Kg K ha^{-1} as muriate of potash (MOP) and 10 Kg of Zn ha^{-1} as zinc sulphate was applied to all the treatments. Sources of fertilizers N, P and K for wheat were the same as for rice. Along with different doses of nitrogen as per the treatment all the plots were supplied with 26 Kg P ha^{-1} and 25 Kg K ha^{-1}. One third of the total N and entire amount of the P and K fertilizers were drilled at planting of the wheat. The remaining 2/3rd of nitrogen was applied in two equal split doses immediately before first irrigation at 3 weeks (crown root initiation) and second irrigation at 8 weeks (maximum tillering) after planting.

Irrigation water management

Rice plots were kept flooded (50 mm of standing water) for the first two weeks after transplanting. Afterwards till physiological maturity the plots irrigated (50 mm depth) every time two days after the disappearance of the standing water from the previous irrigation. Wheat was irrigated (75 mm each) at critical growth stages (crown root initiation, maximum tillering, panicle initiation, Dough). Depending upon rainfall event 4 to 5 irrigations were given to wheat every year.

Crop yield

Both rice and wheat were harvested at physiological maturity in the 3rd week of October and first week of April, respectively. For yield measurement, a net plot area of 2.0 m × 5.0 m was harvested. In manually harvested plots, grains from the biomass were removed by using a plot-thresher. Grain yield of rice and wheat are reported at 14% and 10% moisture contents.

3.5 Soil sample collection and analysis

The soil samples were collected after the 10th cropping cycle of rice-wheat rotation, after harvest of the wheat. The soil samples were collected at three soil depths i.e. 0-15, 15-30 and 30-60 cm with three replications. The samples were collected from five different locations within the plots to represent the composite sample and used for determination of soil physico-chemical properties. The Soil samples were also collected and packed in metallic iron rings (length 7.5 cm, diameter 8 cm) for determination of saturated hydraulic conductivity (ks) of soil. For the determination of aggregate size distribution, big clods of about 40-50 cm diameter were also sampled using spade from the surface soil and are carefully transported to laboratory. The aggregate samples are allowed to fall on grassy ground from the height of 80-100 cm so that clods break along the surface of weakness zones. The resultant sample was then used for determination of aggregate size distribution.

3.5.1 Particle size distribution

The particle size distribution was determined by international pipette method (Piper 1966) and soil texture was determined using textural triangle given by International Society of Soil Science. A 20 g soil (sieved through 2 mm sieve) was taken in 600 ml beaker and 20 ml of hydrogen peroxide (H_2O_2) was added to it. After 8-10 minutes, the beaker was placed over hot water bath with continuously stirring the content. Additionally, 3-4 ml of hydrogen peroxide was added into the beaker as per requirement. The digestion of sample was carried out till the frothing stops. With the help of jet, the content adhering to inner side of beaker was thoroughly mixed in the sample. Thereafter, another treatment for complete dispersion was given using 100 ml of 5% sodium hexametaphosphate and volume was make up to 400 ml. The sample was then stirred on magnetic stirrer for 10 minutes and the content was transferred through 0.25 mm sieve into the 1 litre cylinder. The particles remaining on 0.25 mm sieve were considered as coarse sand. Thereafter the cylinder was filled with distil water up to the mark and using the Stokes law, sedimentation time for silt + clay and clay fractions were calculated by noting down the temperature of suspension before plunging. After plunging the sample, individual pipetting was done for silt + clay and clay according to the settling time. A 25 ml of suspension was pipette out from 10 cm depth and transferred to 100 ml of glass beaker and oven dried at 105^0C. The fine sand was calculated after subtracting the coarse sand and silt + clay from 100. The particle size distribution was expressed on percentage basis.

3.5.2 Bulk density

The bulk density (BD) of soil was determined by core sampler method (Blake and Hartge 1986). Cylindrical iron core of known volume (length 7.5 cm and internal diameter 8 cm) with collar ring at the top was placed into the clean soil surface using hammer, till the ring is completely embedded into the soil. Thereafter, the ring along with soil sample was taken out and smoothen from both ends using sharp blade and weighted. Simultaneously, few grams of same sample was taken in moisture box, weighted and oven dried at 105^0C to determine moisture content. After subtracting the moisture content from the core soil, the BD was calculated by dividing the dry weight of soil by it bulk volume.

3.5.3 Particle density

The particle density of soil was determined by Pycnometer method (Gupta and Dhakshinamoorthy 1980).

3.5.4 Total Porosity

The total porosity of soil was calculated from the bulk and particle density values using the formula gives as:

$$\text{Porosity (\%)} = \left(1 - \frac{\text{Bulk density}}{\text{Particle density}}\right) \times 100$$

3.5.5 Aggregate size distribution

The size distribution of aggregates was determined by wet sieving technique (Yoder 1936) and the sieves were mounted upon the rack in order- 2.0, 1.0, 0.5, 0.25, and 0.1 mm diameter. A separate soil sampling was done for determination of aggregate size distribution. The big clods were taken from the field and allowed to break naturally from the surface of weakness zones. The resultant aggregates were passed through 8 and 4 mm sieve and aggregates retaining on 4 mm sieve were used for determination of aggregate size distribution. The aggregate sample about 50 g was placed over 2 mm sieve of sieve set and sample is allowed to wet by capillarity for 10 minutes and apparatus was allowed to run for 30 minutes @ 30 vertical oscillations per minute. Afterward the set of sieves were taken out, and allowed to drain excess water by slightly inverting it. The sieves were then oven dried at 105^0C for 24 hours and weighted to determine weight of aggregates retained on each sieve.

$$\mathrm{MWD} = \frac{\sum_{i=1}^{n} diwi}{\sum wi}$$

Where, *di* is mean diameter of each size fraction in mm; *n* is number of size ranges and *wi* is the weight of aggregates of size fraction.

3.5.6 Saturated hydraulic conductivity

The saturated hydraulic conductivity was determined by constant water head method (Reynolds *et al* 2002). Soil samples were collected from field using the cylindrical iron cores (Soil column) of known length and diameter and are allowed to saturate for overnight. Thereafter, soil cores were placed on the flask stand and small iron ring were provided at the top of soil column to maintained constant head of water (Mariotte apparatus). The percolated water was collected and measured after every 15 minutes interval till the flux becomes constant and the ks was calculated using Darcy's equation as

$$\mathrm{ks} = \frac{\mathrm{QL}}{\mathrm{At(h + L)}}$$

Where,

ks -Saturated hydraulic conductivity (cm min^{-1})

Q -Quantity of water that flows out at a time interval of'‘t’ in ml

L -Length of the soil column in cm (7.5 cm)

h = Length of the hydraulic head in cm

A = Cross sectional area of the soil column in cm^2

($A = \pi r^2$, where r = radius of the soil column)

t = Time in minutes

3.5.7 Infiltration rate

The infiltration rate (IR) of soil was determined in situ by using double ring infiltrometer. Two concentric metallic cylinder made of iron sheets are used for measuring IR.

The outer and inner cylinder was installed in a selected area and are driven vertically downward without disturbing the soil. The measuring scale was also installed adjacent to innner ring. Simultaneously water were poured into both the rings. The IR was then determined by recording the water level in the inner ring at specified time interval, till the steady state infiltration was obtained.

3.5.8 Soil moisture constants

Soil moisture constants i.e. FC and PWP were determined by using pressure plate apparatus. Soil samples were saturated overnight on the respective porous ceramic plates and then the plates were installed inside the pressure chamber and outlet was provided to drain excess water. The desired pressure was passed to the pressure chamber from the air compressor for 24-48 hours untill the flow of water from outlet ceases and the equilibrium is reached. The soil moisture constants were determined by weighing the fresh weight and dry weight of sample.

$$\theta\ (m^3\ m^{-3}) = \frac{fresh\ weight(g) - dry\ weight(g)}{dry\ weight(g)} \times Bulk\ density\ (Mg\ m^{-3})$$

Where, θ is the volumetric moisture content.

3.5.9 Soil penetration resistance

Soil penetration resistance (PR) was measured in-situ in each plot at three randomly selected locations up to 35 cm soil depth using hand-held digital cone penetrometer (CP40II; Rimik electronics, RFM Australia).

3.5.10 Soil chemical properties

Table 3.2 Standard methods used to measure soil chemical properties

Soil Properties	**Method**	**Reference**
pH	Beckman’s glass electrode pH meter (1:2 soil-water suspension)	Jackson (1967)
Electrical Conductivity at 25 °C	Solubridge Conductivity Meter (1:2 soil-water supernatant)	Jackson (1967)
Soil organic carbon	Rapid Titration Method	Walkley and Black (1934)
Available nitrogen	Alkaline $KMnO_4$ Method	Subbiah and Asija (1956)
Ammonium and nitrate N	Kjeldahl Distillation Method	Keeney (1982)
Available phosphorus	0.5M $NaHCO_3$ (pH 8.5) Extraction Method	Olsen *et al* (1954)
Available potassium	Neutral Normal Ammonium Acetate Method	Page *et al* (1982)

3.5.11 Aggregate associated carbon pools and enzyme activities

Soil aggregates samples were analysed for determination of aggregate stability using wet sieving technique (Yoder 1936). The resultant sample were categories into three aggregates fractions: Large macro-aggregate (>2 mm), Macro-aggregate (2-0.25 mm) and Micro-aggregate (<0.25 mm). The enzyme activities i.e. dehydrogenases (DHA), alkaline phosphatase (Alk P) and fluorescein diacetate (FDA) and soil carbon pools were analysed in each of these aggregate fractions using standard procedures. DHA was analysed by 2-3-5-Triphenyl tetrazolium chloride (TTC) reduction technique as describes by Casida (1964). Phosphatase activity was measured by the method of Tabatabai and Bremner (1969) and FDA activity was assayed using the procedures given by Adam and Duncan (2001).

Aggregate associated carbon pools viz. vey labile, labile, less labile and recalcitrant, water soluble carbon were analyzed following the modified walkley black method as described by Chan *et al* (2001). Microbial biomass carbon (MBC) was determined using chloroform fumigation extraction method by Vance *et al* (1987). Basal soil respiration (BSR) 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). TOC was analyzed using microwave digestion method proposed by Islam and Weil (2000). The carbon management index (CMI) was calculated using the equations given by Venkatesh *et al* (2013) on the basis of oxidisable carbon fractions and TOC.

3.6 Simulation study

In order to accomplish the several objectives in sustainable agro-ecosystems and to enhance the understandings regarding the complexity of agricultural systems, interdisciplinary analysis by means of a systems approach is required (Kropff *et al* 2001). Model simulation is the specific techniques, it takes less time, is cost effective, and does not require running long-term field trials (Jones *et al* 2003). Most prominently, such studies could help to interpret experiments in more detail and explain why the observed results were attained and the factors that could be manipulated to achieve the specific goal.

3.6.1 Model Description

DSSAT (Decision Support System for Agrotechnology Transfer) models is among the most popular and commonly used process-based crop growth simulation models. It is a useful tool for selecting the soil, climate, and crop specific agricultural practices (Sarkar 2009). In terms of model structure, the DSSAT model is an assemblage of independent programs (such as soil, crop, weather and water modules) that operate collectively, with the cropping system model (CSM) as the core of the DSSAT model (Jones *et al* 2003). It requires a minimal amount of data that can be easily collected by experimentalists. The Crop Environment Resource Synthesis (CERES)-Wheat model described by Ritchie and Otter (1985) and Ritchie (1986) simulates the effect of variations in weather, crop genotypes, soil properties and management practices on growth and development of wheat. The simulation of growth and yield is based on the quantification of phasic development; photosynthesis;

respiration; morphogenesis; growth; biomass accumulation and partitioning; extension growth of leaves, stem, roots and grain; soil water extraction; evapotranspiration and plant nitrogen status. The model simulates in daily steps, wheat phenology development from pre-sowing to harvest; photosynthesis and plant growth; biomass allocation to root, stem, leaves and grains and soil water and nutrient movement.

Dry matter in the CERES models, is calculated as a linear function of intercepted photosynthetically active radiations (PAR). The potential production depends on the amount of biomass already produced and the leaf area index. The potential daily biomass is corrected for actual daily biomass by applying appropriate factors due to water stress, non-optimal temperature and nitrogen stress. The model calculates biomass accumulation as the product of radiation use efficiency and photosynthetically active intercepted radiation.

The model evaluates the soil water balance in daily steps as a function of precipitation, infiltration, transpiration, soil evaporation and drainage from the soil profile as described by Ritchie (1986). The model utilizes the lower and upper limit of plant extractable water to apportion total infiltrated water among the various soil layers by a simple cascading principle. The model user must compile several input files to run the simulation, in order to provide the information about the experiment, site, soil, climate and genotype.

3.6.2 Experiment file

The experimental detail file contains all the information needed for the simulation of different experiment treatments (location, sowing time and irrigation), conditions (field characteristics, soil analysis data, initial soil conditions, irrigation and fertilizer management, organic residue application, chemical application, harvest management) and simulation control.

3.6.2 Weather file

The weather data file contains all the available weather data, organized in standard format. Air temperature (maximum and minimum), rainfall, solar radiations are the minimum data required. Dew point temperature, wind speed and photosynthetic active radiation (PAR) are optional input.

3.6.3 Soil file

The file contains information regarding the soil at the experimental site. Soil data required for each soil layer are the layer-thickness (DLAYER, m), saturated water content (SAT, $cm^3\ cm^{-3}$), drained upper limit of soil water content (DUL, $cm^3\ cm^{-3}$), lower limit of plant extractable water (LL, $cm^3\ cm^{-3}$), soil bulk density (BD, $g\ cm^{-3}$), root distribution weighing factor (WR, unit less) and the initial soil water content at the start of simulation ($cm^3\ cm^{-3}$).

3.6.4 Genotype file

The genotype data file contains cultivar-specific genetic parameters needed to predict growth and development. Three morphological and physiological characters of a particular genotype are considered. They are: (1) specific characteristics of species (2) the "ecotype" characteristics within a species and (3) the specific cultivar characteristics within an ecotype grouping.

3.6.5 Output file

The output file contains the overview of input conditions and crop performance, summary of soil characteristics and cultivar coefficients, crop and soil status at the main development stages, temporal distribution of crop variables and soil water content. The model predicts the timing of vegetative and reproductive growth stages from emergence to physiological maturity, daily growth of plant components, leaf area index, specific leaf area and root distribution in the soil. In addition, daily soil water balance components namely soil water evaporation, transpiration, drainage and surface runoff are also estimated.

Simulations were made by first selecting a location and soil, then building crop rotations with management schedules. The location parameters included longitude, latitude, daily weather data files and ET models. The soil parameters included specification of soil layers, thickness, texture, BD, pH and volumetric water content at water potentials at FC (-30 kPa) and wilting point (-1,500 kPa). The management options in the model included cultivar selection, planting, irrigation, fertilization, tillage operations, harvest and chemical application. The methods selected in the simulation were Priestley Taylor/Ritchie-evapotranspiration; Soil Conservation Service-infiltration; Canopy curve (daily) photosynthesis; Ritchie Water Balance-hydrology; Ceres (Godwin)-organic matter; and Ritchie-Ceres-soil evaporation.

3.7 Statistical analysis

The data were analyzed using analysis of variance (ANOVA) with rice straw as main factor and nitrogen rates as sub-factor in the split plot design. Least significant difference (LSD) at $p=0.05$ were used for multiple comparison of treatment means. The Pearson correlation matrix between soil variable were calculated using "IBM SPSS v.20" statistics. The dimensionality reduction technique "Principle component analysis" (PCA) and relative variable importance in terms of mean increase error was performed on the set of data using "XLSTAT" (add-on for MS-Excel) software.

CHAPTER IV

RESULT AND DISCUSSION

The results of the study pertaining to “The effect of rice straw incorporation and nitrogen fertilization on soil physico-chemical properties” are presented under following heads:

4.1 Soil state properties

- 4.1.1 Soil bulk density
- 4.1.2 Total porosity
- 4.1.3 Aggregate size distribution
- 4.1.4 Soil penetration resistance

4.2 Hydraulic properties

- 4.2.1 Infiltration rate
- 4.2.2 Soil moisture retention
- 4.2.3 Saturated hydraulic conductivity

4.3 Soil chemical properties

- 4.3.1 Soil pH and EC
- 4.3.2 Soil organic carbon
- 4.3.3 Available nitrogen
- 4.3.4 Available phosphorus
- 4.3.5 Available potassium
- 4.3.6 Available micronutrients

4.4 Soil biochemical properties within soil aggregates fractions

4.5 Crop productivity

4.6 Principle component analysis

4.7 Simulation study

4.1 Soil state properties

4.1.1 Bulk density

The bulk density (BD) of soil in all three soil layers (0-15, 15-30 and 30-60 cm) increased significantly in all the rice straw incorporated treatments after 10th cycle of rice-wheat system (Table 4.1). Averaged across nitrogen levels, BD in surface layers (0-15 cm) increased from 1.53 Mg m^{-3} in $R_{st}0$ to 1.63 Mg m^{-3} in $R_{st}10$. However, in 15-30 cm, incorporation of rice straw has significantly increased the soil BD only up to $R_{st}5$ thereafter, it was statistically at par with $R_{st}7.5$ and $R_{st}10$. Similarly, in 30-60 cm, BD was significantly higher in $R_{st}10$, and the treatment $R_{st}0$ was statistically at par with $R_{st}5$ and $R_{st}7.5$. In general, the BD of soil increased with soil depth and rice straw rate (Fig 4.1). The increase in BD under rice straw incorporated treatments is attributed mainly to reduction of macro-pore volume, filling of large pores with finer soil particles and progressive densification of initial coarse texture soil (Gathala *et al* 2017). In the present study it seems that the irrigation water might have resettled the soil particles which were dispersed during tillage operation while incorporating residue. This results corroborates with the findings of Osunbitan *et al* (2005) who reported the 48% increase in BD with crop residue retention on surface and subsequent particle resettlement with rainfall. The resettlement of soil particles may also occur in no-till system as reported by Xu and Mermoud (2001), Dam *et al* (2005), Dao (1996), Unger and Jones (1998) and Starr and Timlin (2004). Contrary to our and the results of others, Singh *et al* (2007), Blanco-Canqui and Lal (2007) and Oliveira and Merwin (2001) reported lowered

Table 4.1 Effect of rice straw incorporation and nitrogen fertilization on bulk density (Mg m^{-3}) of soil.

0-15 cm					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	1.53	1.49	1.57	1.54	1.53^{d}
$R_{st}5$	1.52	1.60	1.61	1.57	1.58^{c}
$R_{st}7.5$	1.63	1.59	1.67	1.58	1.62^{a}
$R_{st}10$	1.59	1.61	1.68	1.64	1.63^{a}
Mean	1.57^{b}	1.57^{b}	1.63^{a}	1.58^{b}	
LSD (p=0.05)	R_{st}:0.044, N:0.03, R_{st}×N:NS				
15-30 cm					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	1.67	1.59	1.51	1.62	1.60^{d}
$R_{st}5$	1.72	1.60	1.63	1.76	1.68^{a}
$R_{st}7.5$	1.73	1.61	1.74	1.75	1.70^{a}
$R_{st}10$	1.76	1.66	1.62	1.75	1.70^{a}
Mean	1.72^{a}	1.62^{b}	1.62^{b}	1.72^{a}	
LSD (p=0.05)	R_{st}:0.023, N:0.02, R_{st}×N:0.04				
30-60 cm					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	1.83	1.66	1.68	1.86	1.76^{bc}
$R_{st}5$	1.71	1.75	1.76	1.80	1.75^{c}
$R_{st}7.5$	1.80	1.77	1.82	1.73	1.78^{b}
$R_{st}10$	1.81	1.80	1.85	1.87	1.83^{a}
Mean	1.79^{a}	1.75^{b}	1.78^{b}	1.82^{a}	
LSD (p=0.05)	R_{st}:0.03, N:0.03, R_{st}×N:0.06				

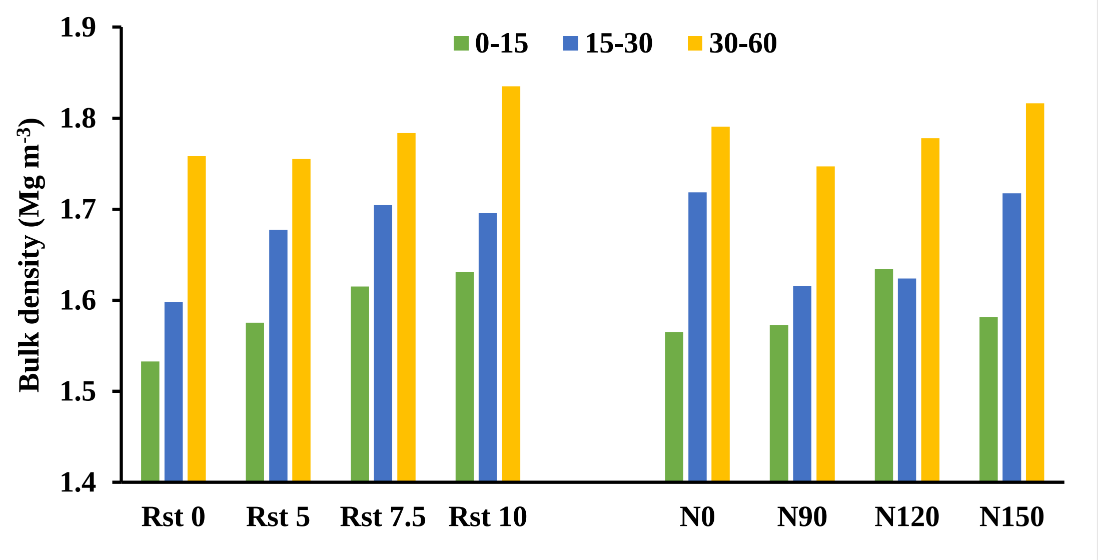

Fig 4.1 Depthwise distribution of soil bulk density (Mg m^{-3}) under rice straw and nitrogen fertilized treatments.

soil BD with crop residue due to physical presence of residue having weight lighter than soil and improved aggregation status of the soil. The effect of crop residue on BD of soil may also vary with soil textural and structural properties, which governs the distribution of soil separates and pore spaces, environmental conditions, and the machinery used for incorporating residue (Singh and Malhi 2006 and Dalal *et al* 2011). The effect of nitrogen on BD was inconsistent. The interactive effect of rice straw and nitrogen levels on BD of soil varied with depth. It was non-significant in 0-15 cm surface layer and significant only in 15-30 and 30-60 cm soil layer.

4.1.2 Total porosity

The total porosity of soil which is inversely related with BD was significantly affected by rice straw incorporation as well as nitrogen fertilization in 0-15 and 15-30 cm depth only (Table 4.2). In the surface layer (0-15 cm) total porosity decreased from 41.06 in $R_{st}0$ to 36.54% in $R_{st}10$ and it was statistically at par in $R_{st}7.5$ and $R_{st}10$ treatments. Similarly, in 15-30 cm layer, total porosity decreased with incorporation of rice straw as compared to control and rice straw incorporated treatments were statistically at par. The decrease in porosity of soil is evident from the increase in BD of soil (Table 4.1), as the two properties are inversely related with each other. The BD induced reduction in total porosity of soil was also supported by the studies of Horne *et al* (1992) and Alegre *et al* (1991). Contrarily, the research finding of Salahin *et al* (2017), Blanco-Canqui and Lal (2007) and Mandal *et al* (2004) reported the increase in soil porosity as a result of decrease in BD with incorporation of crop residue as compared to without incorporation or burning. Averaged across rice straw levels, the total porosity in 0-15 cm layer was statistically at par in N_0, N_{90} and N_{150} treatments. The total porosity was significantly low under N_{120} treatment in 0-15 cm layer and under N_{150} treatments in 15-30 cm layer. However, incorporation of either rice straw or nitrogen fertilizer did not significantly influenced the total porosity of soil in 30-60 cm layer. The interactive effect of rice straw and nitrogen levels on total porosity of soil was significant in all three soil depths (0-15, 15-30 and 30-60 cm). In general, all the nitrogen levels under $R_{st}0$ showed the maximum value of porosity, while combination of N_{120} with $R_{st}7.5$ and $R_{st}10$ showed the reduction in total porosity of soil in 0-15 cm layer. Similarly, treatment combination of N_0 and N_{150} under $R_{st}5$, $R_{st}7.5$ and $R_{st}10$ showed the minimum value of total porosity in 15-30 cm layer. In 30-60 cm layer, no particular trend was observed. Irrespective of rice straw and nitrogen levels, total porosity of soil decreased with soil depth (Fig 4.2).

Table 4.2 Effect of rice straw incorporation and nitrogen fertilization on total porosity (%) of soil.

0-15 cm					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	40.87	43.18	40.12	40.06	41.06^a
$R_{st}5$	40.67	37.56	34.84	39.33	38.10^b
$R_{st}7.5$	35.62	39.59	32.34	37.69	36.31^c
$R_{st}10$	37.21	37.94	33.42	37.60	36.54^c
Mean	38.59^a	39.57^a	35.18^d	38.67^a	
LSD (p=0.05)	R_{st}:1.8, N:1.22, R_{st}×N:2.5				
15-30 cm					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	35.65	37.14	39.52	36.67	37.2^a
$R_{st}5$	31.84	35.94	35.78	31.31	33.72^b
$R_{st}7.5$	33.48	38.92	32.91	31.83	34.28^b
$R_{st}10$	33.27	35.86	36.88	32.74	34.69^b
Mean	33.56^c	36.96^a	36.27^a	33.14^c	
LSD (p=0.05)	R_{st}:1.1, N:1.10, R_{st}×N:2.20				
30-60 cm					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	29.42	30.06	35.36	29.21	31.01
$R_{st}5$	34.89	30.42	32.19	32.50	32.50
$R_{st}7.5$	29.54	29.90	28.85	33.98	30.57
$R_{st}10$	30.95	28.52	25.64	28.90	28.50
Mean	31.20	29.72	30.51	31.15	NS
LSD (p=0.05)	R_{st}:NS, N:NS, R_{st}×N:3.63,				

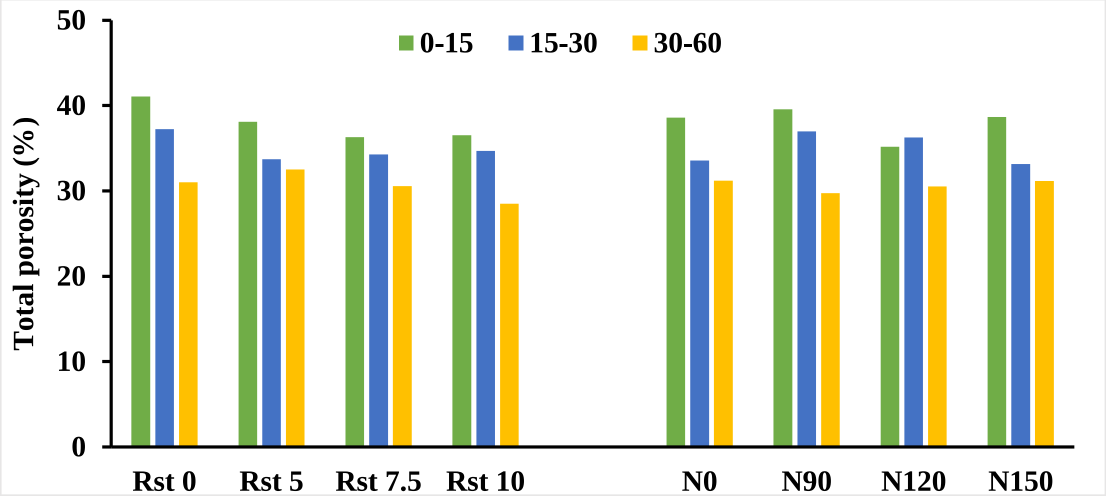

Fig 4.2 Depthwise distribution of total porosity (%) under rice straw and nitrogen fertilized treatments

4.1.3 Aggregate size distribution

Aggregate stability is a highly intricate parameter influencing a wide range of soil properties, including carbon stabilization, pore size distribution, hydraulic properties, aeration, soil compactibility, water retention, resistance to erosion by wind and water. Maintaining aggregate stability of soil is of utmost importance for preserving soil productivity and minimizing soil losses and degradation (Shaoshan *et al* 2010). Because of this, soil aggregate stability can be describe as the physical indicator of soil quality (Arshad and Cohen 1992). Soil aggregates size and their stability is govern by the SOM content and soil microbes which in turn influence soil porosity, gas, water and nutrient transport through soil system and root growth (Verhulst *et al* 2010). Aggregate stability can be influenced by a small change in SOC content (Singh *et al* 2005). However, under natural field conditions, organic matter is lost thorough various processes. Under such circumstances, incorporation of readily available rice straw could replenish the depleted SOM and helps to rebuild the stability of aggregates (Das *et al* 2014).

In present study, the incorporation of rice straw has significantly increased the total water stable aggregates (TWSA). It was 54% in $R_{st}0$ which increased to 62% in $R_{st}10$ (Table 4.4). TWSA were significantly higher in $R_{st}7.5$ and $R_{st}10$ compared to $R_{st}0$ and $R_{st}5$. The TWSA were mainly constituted by macro-aggregates (MaA) (>0.25 mm). Amongst the water stable macro-aggregates, 0.5-0.25 mm fraction was highest and of 2-1.0 mm was least (Fig 4.3). Rice straw incorporation influenced the aggregate fraction of size >2 mm more than other fractions. It increased from 1.67% in $R_{st}0$ to 3.11 in $R_{st}5$, 3.46 in $R_{st}7.5$ and 4.68% in $R_{st}10$ significantly. Similar trends were observed in other macro-aggregate fractions i.e. 2-1.0 mm, 1-0.5 mm and 0-5-0.25 mm. Though the fraction of macro-aggregate has increased yet the fraction of micro-aggregate (MiA) has decreased (from 30% in $R_{st}0$ to 28% in $R_{st}10$).

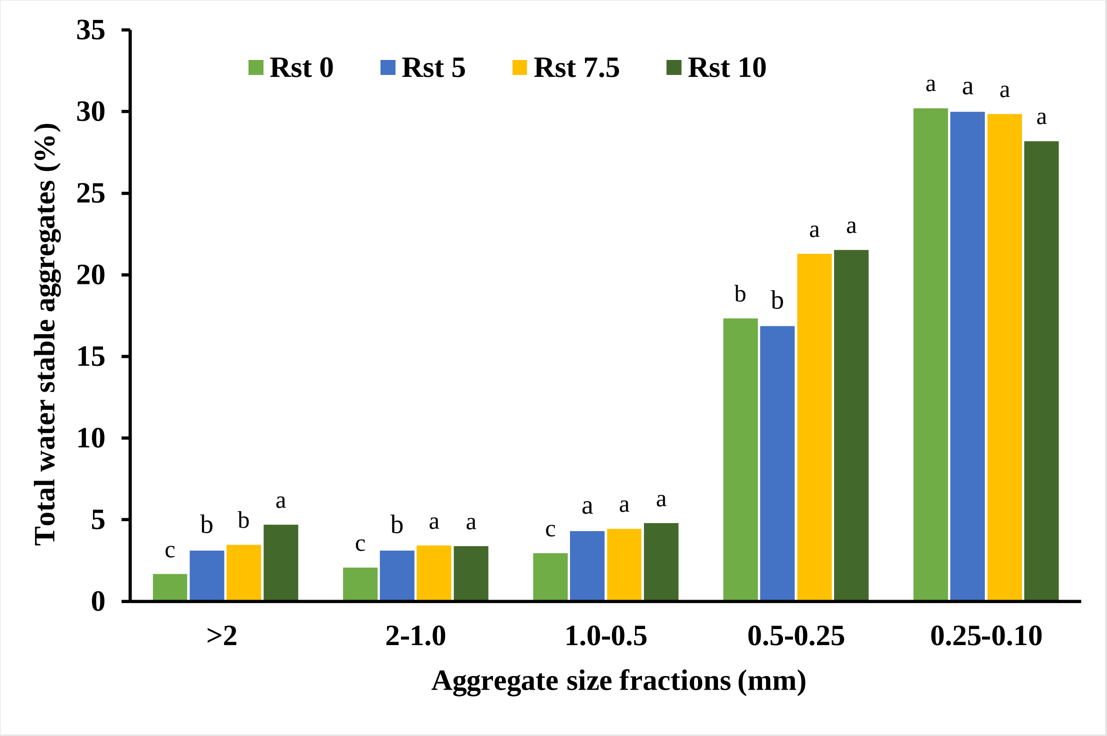

Fig 4.3 Effect of rice straw incorporation on soil aggregate size distribution (%) in 0-15 cm soil layers. Bars with the same letter, within the same aggregate size, are statistically at par.

Table 4.3 Effect of nitrogen fertilization on soil aggregate size distribution (%), mean weight diameter (mm), geometric mean diameter (mm) and aggregate ratio in 0-15 cm soil depth.

Treatments	**>2 mm**	**2-1.0 mm**	**1.0-0.5 mm**	**0.5-0.25 mm**	**0.25-0.10 mm**	**TWSA (%)**	**MWD**	**GMD**	**AR**
	(%)						**(mm)**		
N_0	3.64^a	2.58	3.82	17.80	23.45^a	51.30^a	0.51^a	0.41^a	1.29^a
N_{90}	2.74^b	2.95	4.26	19.19	30.69^b	59.82^b	0.42^b	0.29^b	0.99^b
N_{120}	2.63^c	2.75	3.66	18.65	31.41^b	59.09^b	0.41^b	0.28^b	0.89^b
N_{150}	3.92^d	3.70	4.73	21.33	32.69^b	66.38^c	0.48^a	0.37^a	1.05^b
LSD (p=0.05)	0.06	NS	NS	NS	4.23	5.58	0.03	0.04	0.18

TWSA-Total water stable aggregates, MWD- Mean weight diameter, GMD-Geometric mean diameter, AR-Aggregates ratio.

Increases in MaA and decrease in MiA could be due to supply of additional organic nitrogen from crop residue (Benbi and Senapati 2010, Golchin *et al* 1994, Six *et al* 1999) and binding of MiA units through increased biotic activity and release of organic acids and polysaccharides and some adhesive substances (Can Caesar-TonThat *et al* 2010) due to increase in SOM content (Huang *et al* 2010). It may also be due to increased microbial activity on release of freshly available carbon (Mikha and Rice 2004). Here in present study too, MaA increased due to increase in SOC with straw incorporation. Choudhary *et al* (2014) also reported that residue incorporation could improve 2.10 fold higher TWSA as compared to without straw incorporation. Application of nitrogen fertilizers did not influences the distribution of different aggregate size classes significantly except for > 2 mm and 0.25-0.10 mm fraction which were higher in N_{150} treatment (Table 4.3). The fraction 0-25-0.10 mm was statistically at par in N_0, N_{90} and N_{120} treatments. The TWSA were increased with nitrogen levels and it was maximum in N_{150} treatment followed by N_{90} and N_{120}. The treatments N_{90} and N_{120} were statistically at par with each other.

Mean weight diameter, Geometric mean diameter and Aggregate ratio

The mean weight diameter (MWD) and geometric mean diameter (GMD) among different straw incorporated treatments ranged from 0.41 to 0.50 mm and 0.28 to 0.40 mm respectively (Table 4.4). Both MWD and GMD were found to be highest (0.50 and 0.40 mm) in $R_{st}10$ and least in Rst0 (0.41 and 0.28 mm). Similarly, the aggregate ratio (AR) which indicate proportion of MaA over MiA was significantly higher in rice straw incorporated treatments over $R_{st}0$ and it followed the order- $R_{st}10$ (1.25) > $R_{st}7.5$ (1.10) > $R_{st}5$ (1.02) > $R_{st}0$ (0.86) mm. Increased in MWD and GMD may be attributed to increase in SOC content and the protective function of incorporated straw to aggregate breakdown through raindrop impact (Six *et al* 2006, Jacobs *et al* 2009). Higher MWD and GMD in straw incorporated treatments is supported by the studies of Verhulust *et al* (2010), Ozpinar and Cay (2006).

4.1.4 Soil penetration resistance

Soil penetration resistance was significantly affected by rice straw incorporation. In general it was higher in control treatment (ranging from 0.4-4.6 MPa) throughout 0-35 cm soil layer (Fig 4.4). In control treatment, PR increased continuously with soil depth and it increased in treatments with rice straw incorporation variably depending upon the rate of rice straw. For example the increase in PR was up to 20 cm soil depth in $R_{st}5$, $R_{st}7.5$ and 27 cm in $R_{st}10$. In 30-35 cm soil layer, PR was statistically at par in all the straw incorporated treatments and it followed the order -$R_{st}7.5 < R_{st}10 < R_{st}5 < R_{st}0$. The increase in PR with soil depth supports the findings of Gathala *et al* (2017) and Saha *et al* (2010). Averaged over soil depths, PR follows the order $R_{st}10$ (1.8 MPa) < $R_{st}5$ (1.9 MPa) < $R_{st}7.5$ (2.0 MPa) < $R_{st}0$ (2.3MPa). The decrease in PR with rice straw incorporation could be due to presence of significantly higher moisture content throughout the 0-60 cm soil depth. In the rice straw incorporated treatments, moisture content remained higher because of improved soil structure (Table 4.4). Similar to our findings, Verhulust *et al* (2010), Salahin *et al* (2014), Borresen (1999) and Lal (2000), Gathala *et al* (2017) also reported decrease PR with crop residue incorporation or surface retention as compared to burning or removal, because of presence of

Table 4.4 Effect of rice straw incorporation on soil aggregates size distribution (%), mean weight diameter (mm), geometric mean diameter (mm) and aggregate ratio in 0-15 cm soil depth.

	% Water stable aggregates (WSA) within aggregate fractions (mm)					**TWSA (%)**	**WS Macro (%)**	**WS Micro (%)**	**MWD**	**GMD**	**Aggregate Ratio**
Treatments	**>2**	**2-1.0**	**1.0-0.5**	**0.5-0.25**	**0.25-0.10**		**>0.25 mm**	**<0.25 mm**	**(mm)**		
$R_{st0}N_0$	2.68	1.83	2.50	17.08	24.86	48.94	24.09	24.86	0.47	0.36	1.16
$R_{st0}N_{90}$	0.68	2.12	3.28	18.87	30.86	55.81	24.95	30.86	0.35	0.20	0.84
$R_{st0}N_{120}$	2.17	2.26	2.85	14.67	30.97	52.91	21.94	30.97	0.39	0.25	0.71
$R_{st0}N_{150}$	1.17	2.07	3.16	18.66	34.16	59.22	25.06	34.16	0.41	0.31	0.73
Mean R_{st}0	**1.67^c**	**2.07^c**	**2.95^c**	**17.32^b**	**30.21**	**54.22^b**	**24.01^c**	**30.21**	**0.41^c**	**0.28^c**	**0.86^c**
$R_{st5}N_0$	2.62	3.35	4.67	16.16	18.84	45.63	26.80	18.84	0.51	0.43	1.59
$R_{st5}N_{90}$	1.85	2.12	3.36	15.30	34.28	56.91	22.63	34.28	0.37	0.22	0.65
$R_{st5}N_{120}$	2.35	3.00	4.08	16.97	33.09	59.49	26.40	33.09	0.39	0.25	0.82
$R_{st5}N_{150}$	5.64	3.96	5.06	18.97	33.73	67.35	33.62	33.73	0.51	0.40	1.00
Mean R_{st}5	**3.11^b**	**3.11^b**	**4.29^a**	**16.85^b**	**29.98**	**57.35^b**	**27.36^b**	**29.98**	**0.45^b**	**0.32^b**	**1.02^b**
$R_{st7.5}N_0$	3.45	2.88	4.32	19.45	26.08	56.18	30.10	26.08	0.47	0.36	1.16
$R_{st7.5}N_{90}$	3.30	3.85	4.84	20.65	30.19	62.82	32.63	30.19	0.46	0.34	1.09
$R_{st7.5}N_{120}$	2.76	3.39	4.31	18.16	31.12	59.74	28.62	31.12	0.44	0.31	0.93
$R_{st7.5}N_{150}$	4.34	3.55	4.29	26.87	32.01	71.06	39.04	32.01	0.46	0.35	1.23
Mean R_{st}7.5	**3.46^b**	**3.41^a**	**4.44^a**	**21.28^a**	**29.85**	**62.45^a**	**32.60^a**	**29.85**	**0.46^b**	**0.34^b**	**1.10^b**
$R_{st10}N_0$	5.81	2.28	3.79	18.52	24.03	54.44	30.40	24.03	0.58	0.49	1.26
$R_{st10}N_{90}$	5.11	3.69	5.56	21.94	27.44	63.75	36.31	27.44	0.49	0.38	1.37
$R_{st10}N_{120}$	3.25	2.36	3.38	24.81	30.44	64.23	33.79	30.44	0.43	0.30	1.11
$R_{st10}N_{150}$	4.56	5.21	6.42	20.83	30.85	67.88	37.02	30.85	0.52	0.43	1.24
Mean R_{st}10	**4.68^a**	**3.39^a**	**4.79^a**	**21.52^a**	**28.19**	**62.57^a**	**34.38^a**	**28.19**	**0.50^a**	**0.40^a**	**1.25^a**
LSD(p=0.05)											
R_{st}	0.51	0.17	0.38	1.96	NS	3.29	2.43	NS	0.01	0.02	0.08
R_{st}×N	1.2	1.03	1.5	3.9	NS	11.2	4.9	NS	0.06	0.08	0.36

higher moisture content in soil. With nitrogen levels, PR decreased significantly and followed the order- N_{150} (1.8) < N_{120} (1.9) < N_{90} (2.0) < N_0 (2.29) (Fig 4.5). Relatively lower PR in higher nitrogen levels may be due to increase root growth with nitrogen. The interactive effect of nitrogen levels and rice straw incorporation was also significant (Fig 4.6). It was higher in treatment combination of N_0, N_{90} and N_{120} under $R_{st}0$ and lower in treatment combination $R_{st}10N_{150}$.

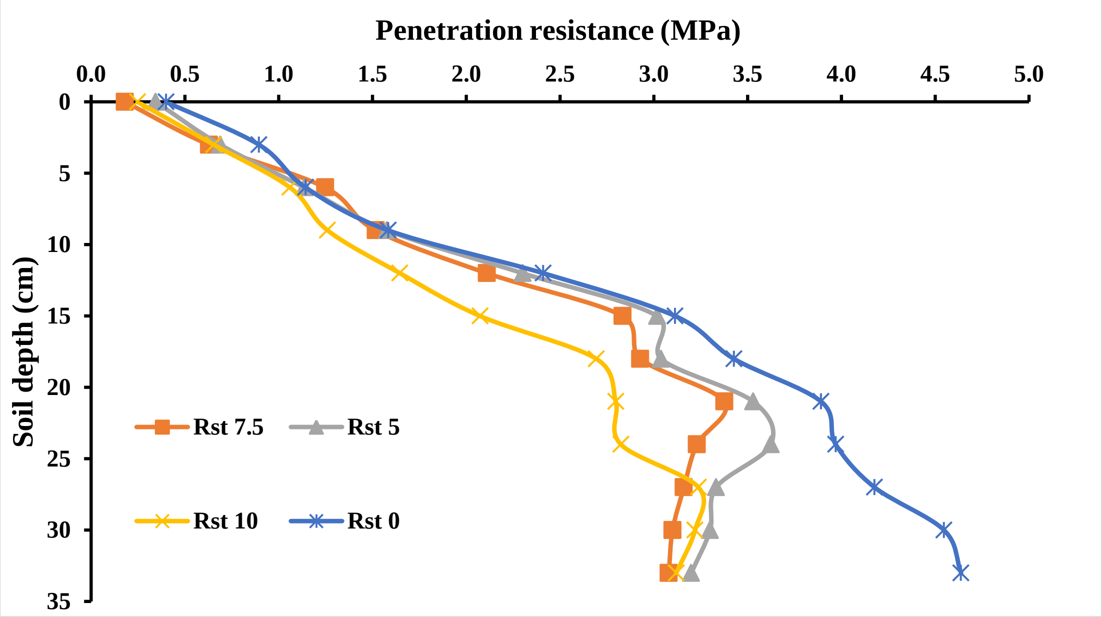

Fig 4.4 **Depthwise distribution of soil penetration resistance (MPa) under rice straw incorporated treatments.**

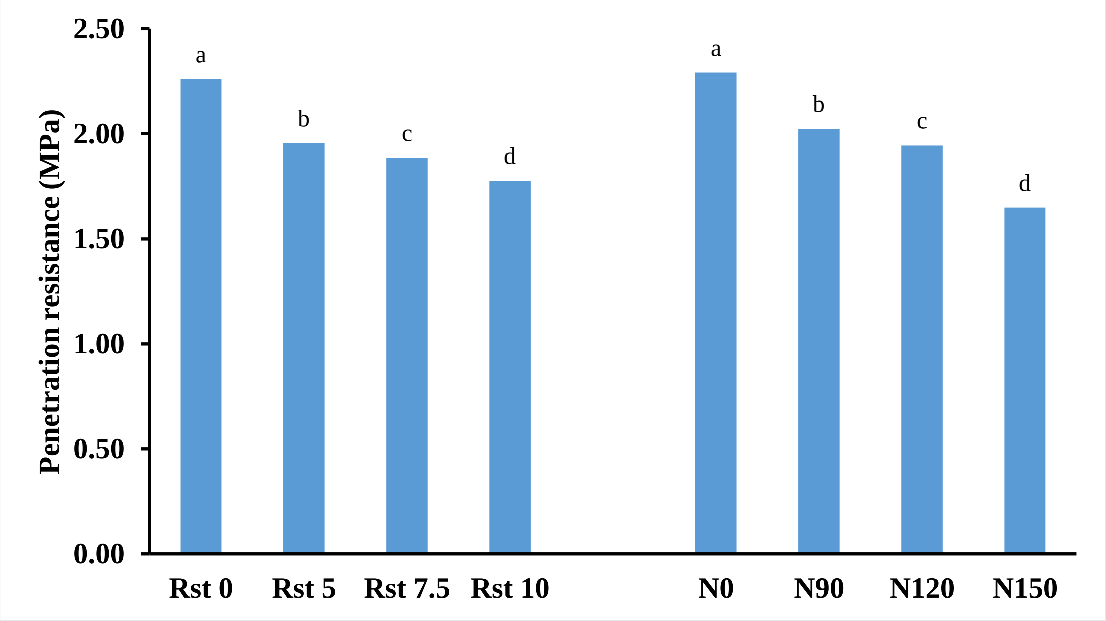

Fig 4.5 **Effect of rice straw incorporation and nitrogen fertilization on average soil penetration resistance (MPa). Bars with the same letter are statistically at par.**

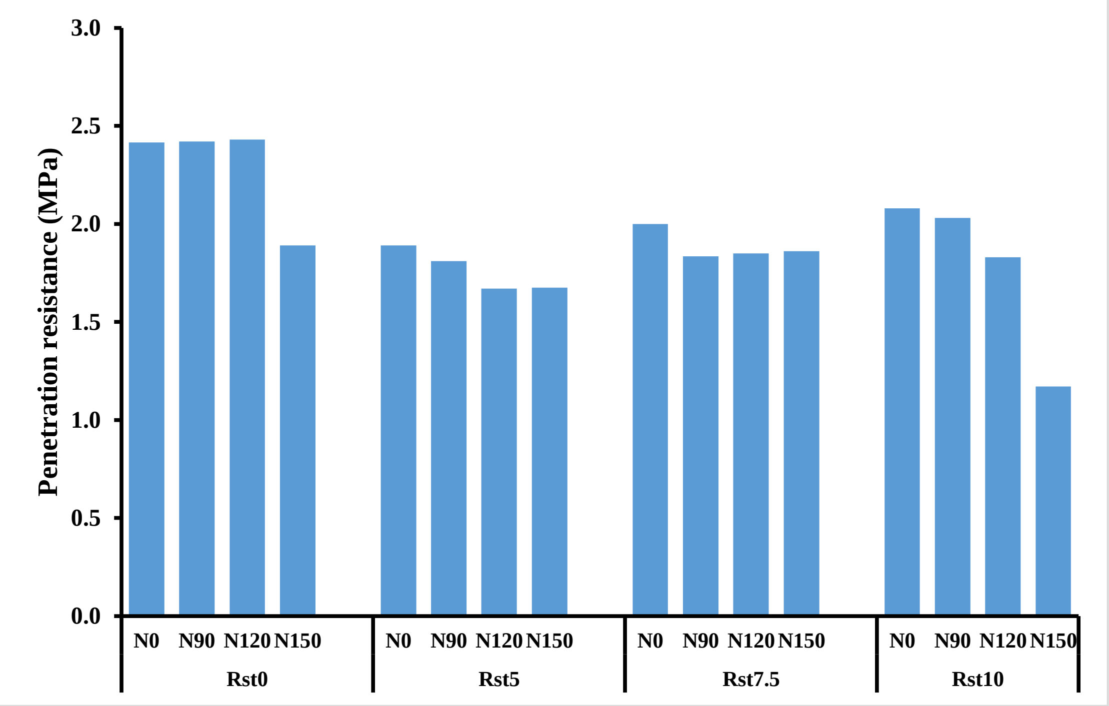

Fig 4.6 **Interactive effect of rice straw and nitrogen fertilization on average soil penetration resistance (MPa) of soil.**

4.2 Soil hydraulic properties

4.2.1 Infiltration rate of soil

The infiltration rate (IR) of soil was significantly affected by rice straw incorporation and nitrogen fertilization. Averaged across nitrogen levels, the initial IR which mainly depends on surface condition of soil was higher in straw incorporated treatments irrespective of rate of straw incorporation and progressively levelled off in all the treatments (Fig 4.7). Finally the steady state infiltration rate (SSIR) was marginally higher in $R_{st}10$ than other treatments. Higher IR in crop residue incorporated treatment has also been reported by number of researchers i.e. Gathala *et al* (2017), Hassan *et al* (2013), Govaerts *et al* (2009) and Jat *et al* (2013). They ascribe this to development of continuous pore space and higher soil moisture through improved water stable aggregates and minimum soil disturbance and compaction. Averaged across residue levels, with nitrogen levels the initial IR were similar, and SSIR was higher in N_{90} and N_{150} treatments over N_0 (Fig 4.8; Fig 4.9).

Cumulative infiltration

The cumulative infiltration (CI) was significantly affected by both rice straw incorporation and nitrogen fertilization. Averaged across nitrogen levels, CI after seven hours was lowest in control and followed the order $R_{st}10 > R_{st}7.5 > R_{st}5 > R_{st}0$ (Fig 4.10). When averaged across residue levels, CI increased with nitrogen levels as compared to control (Fig 4.11). It ranged from 106 to 134 cm min^{-1} under different treatments and was highest in N_{120} treatment followed by N_{90} and N_{150}.

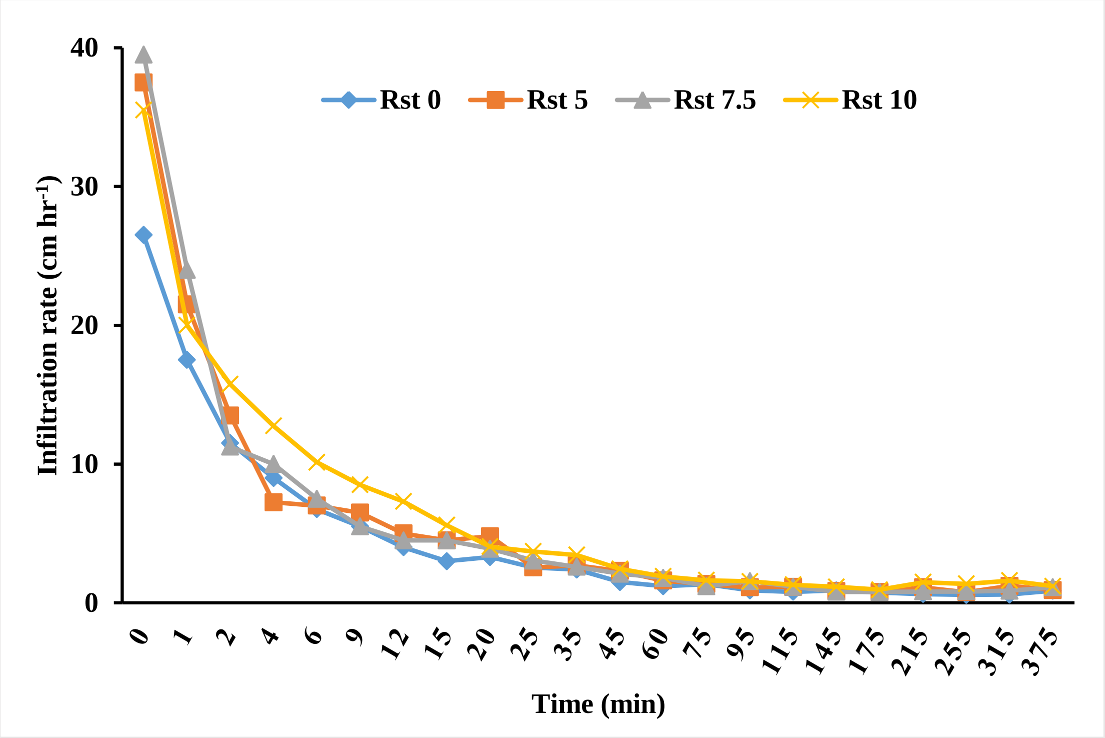

Fig 4.7 Effect of rice straw incorporation on infiltration rate (cm hr^{-1}) of soil.

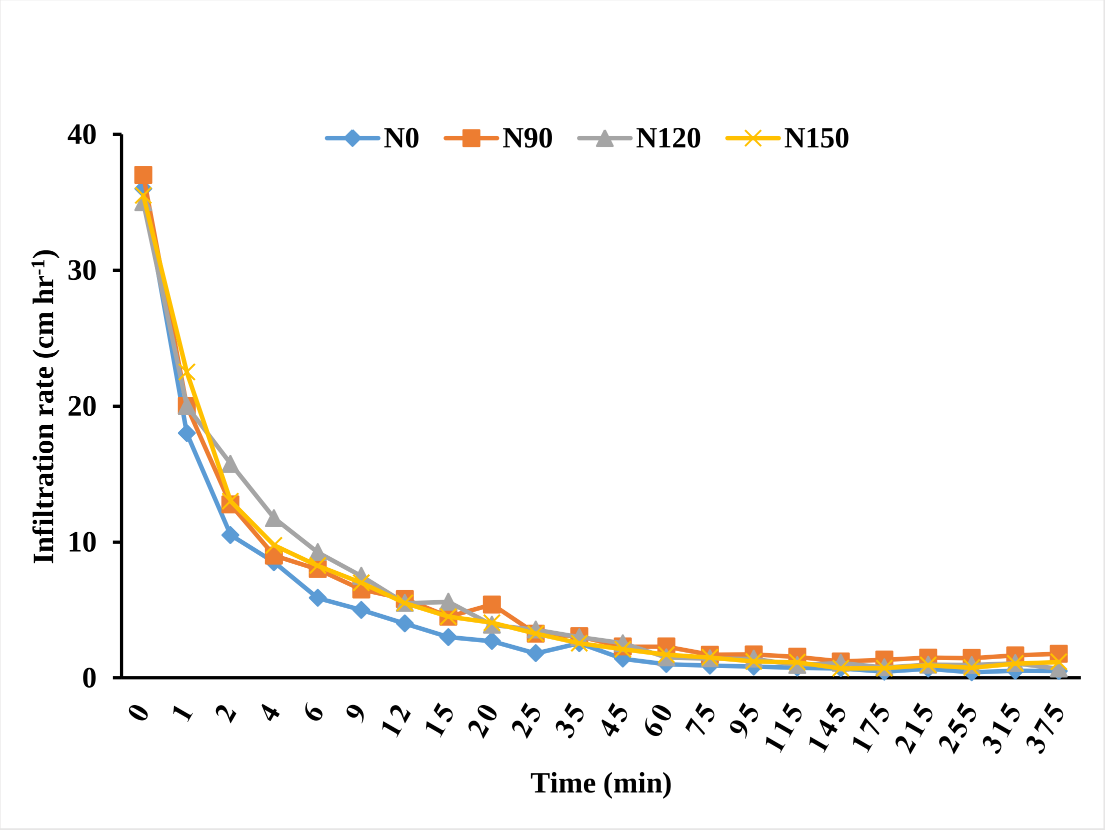

Fig 4.8 Effect of nitrogen fertilization on infiltration rate (cm hr^{-1}) of soil.

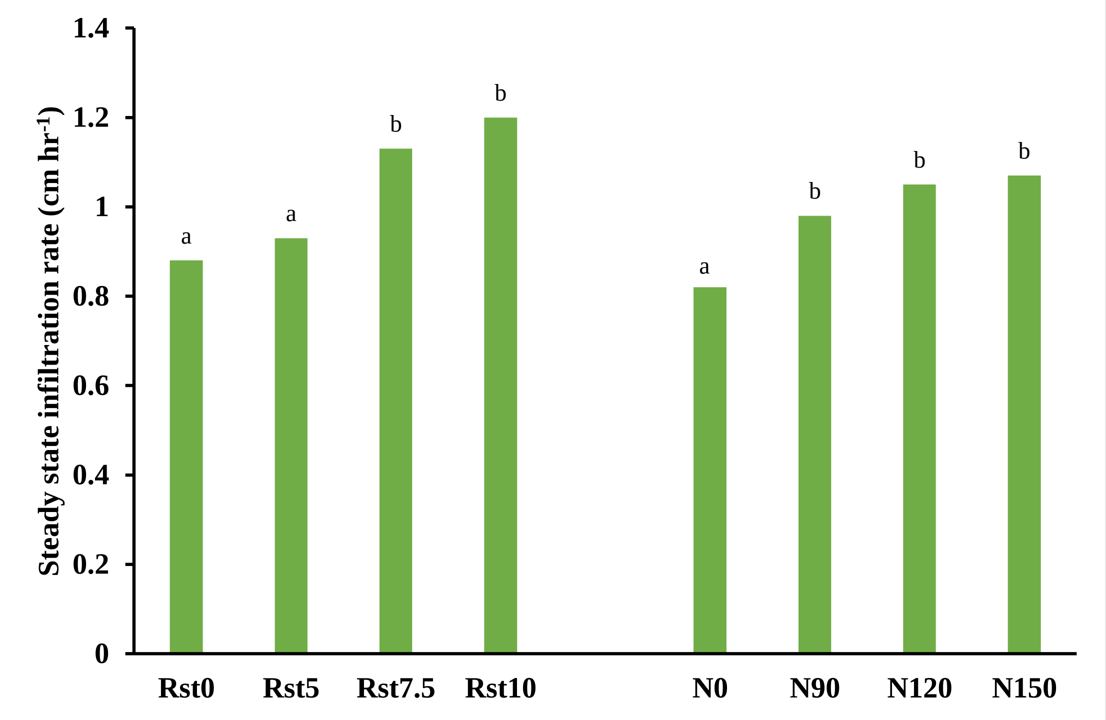

Fig 4.9 Effect of rice straw incorporation and nitrogen fertilization on steady state infiltration rate (cm hr^{-1}). Bars with same letter are statistically at par.

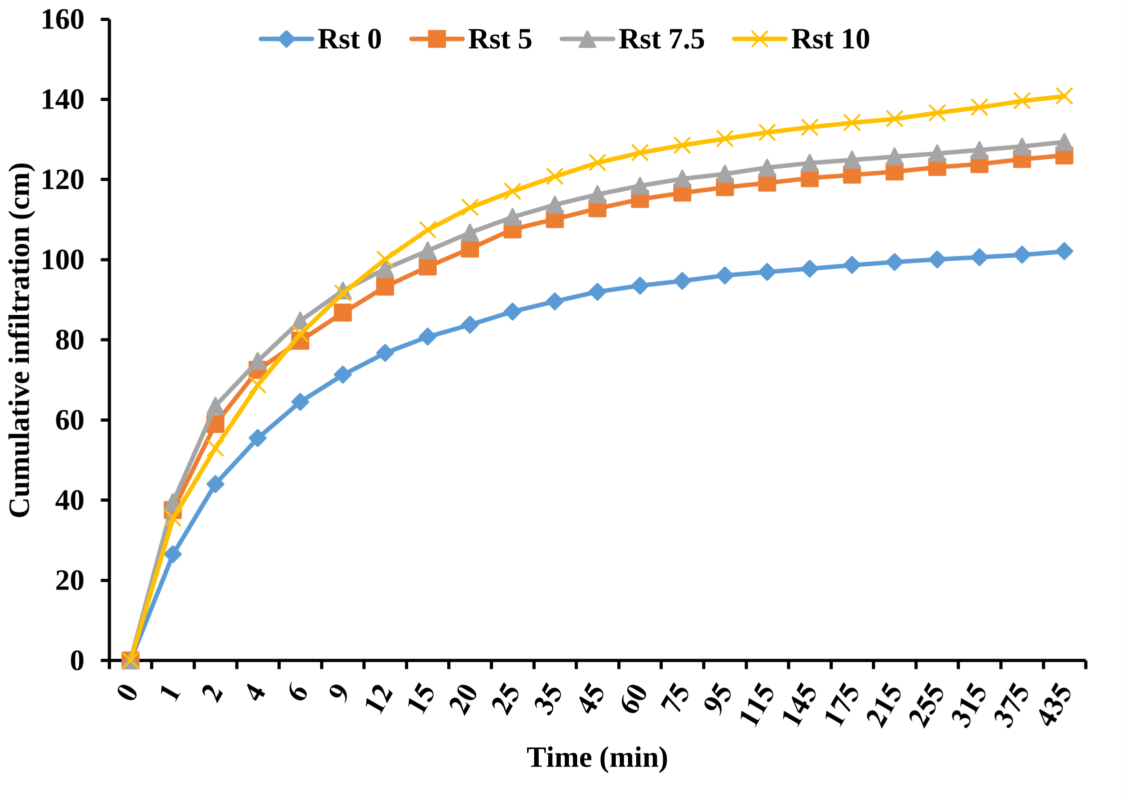

Fig 4.10 Effect of rice straw incorporation on cumulative infiltration (cm) of soil.

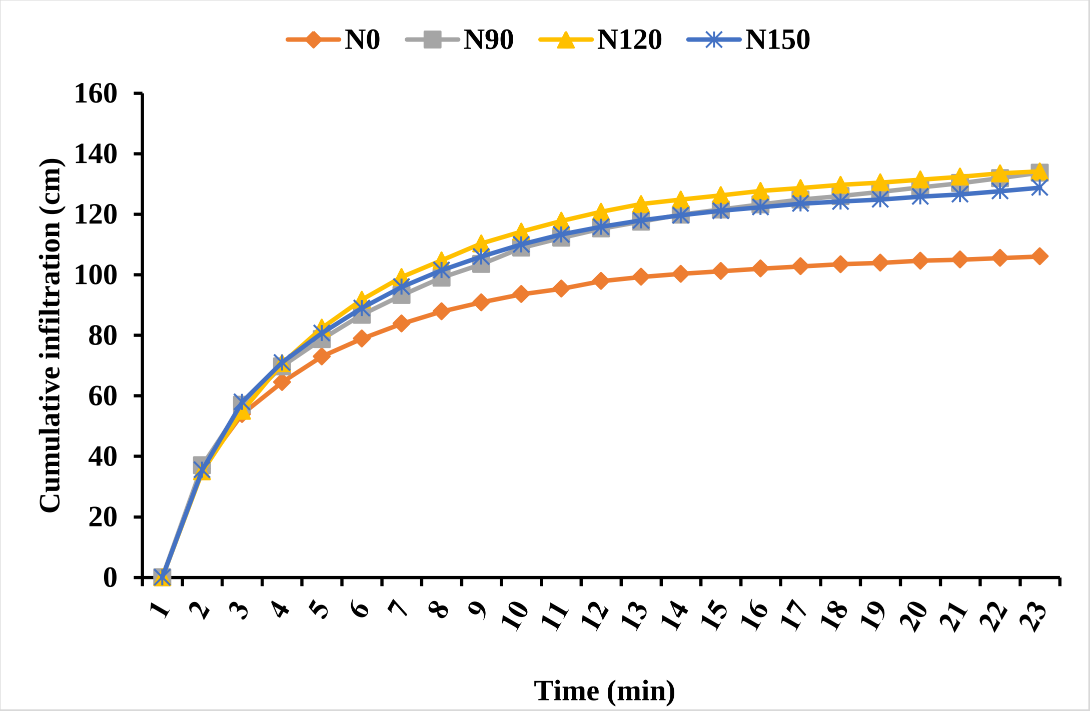

Fig 4.11 Effect of nitrogen fertilization on cumulative infiltration (cm) of soil.

4.2.2 Soil moisture retention

The relationship between volumetric moisture content and matric suction as depicted by soil moisture characteristics curve (SMC) reveals that, incorporation of rice straw has significantly influenced the moisture content at various matric suctions (0.3-15 bar) in all three soil depths (Fig 4.12). In 0-15 cm layer, at all matric suctions, moisture content in rice straw incorporated treatments followed the order- $R_{st}10 > R_{st}7.5 > R_{st}5 > R_{st}0$. Similar results were also obtained in 15-30 and 30-60 cm soil layers. Results also indicates that moisture content at all matric suctions was higher in 0-15 cm layer compared to 15-30 and 30-60 cm. When evaluated across rice straw levels, nitrogen levels has also affected SMC curve significantly (Fig 4.13). In 0-15 cm depth, SMC curve under nitrogen levels varied with matric suctions and was lowest in N_0 treatment. When compared within soil depths no any particular trend was observed.

Soil Moisture constants

Soil moisture constants i.e. field capacity (FC) and permanent wilting point (PWP), were significantly affected by rice straw incorporation and varied with soil depth. FC value under rice straw incorporation treatment was significantly higher in surface layer 0-15 cm (Table 4.5). FC followed the order- 0.300 m^3m^{-3} in $R_{st}10$ > 0.281 m^3m^{-3} in $R_{st}7.5$> 0.272 m^3m^{-3} in $R_{st}5$ > 0.224 m^3m^{-3} in $R_{st}0$ and was statistically at par in $R_{st}5$ and $R_{st}7.5$ treatment but significantly higher than $R_{st}0$. In 15-30 and 30-60 cm, although moisture content at FC increased with rate of rice straw incorporation, the effect was non-significant. FC was also

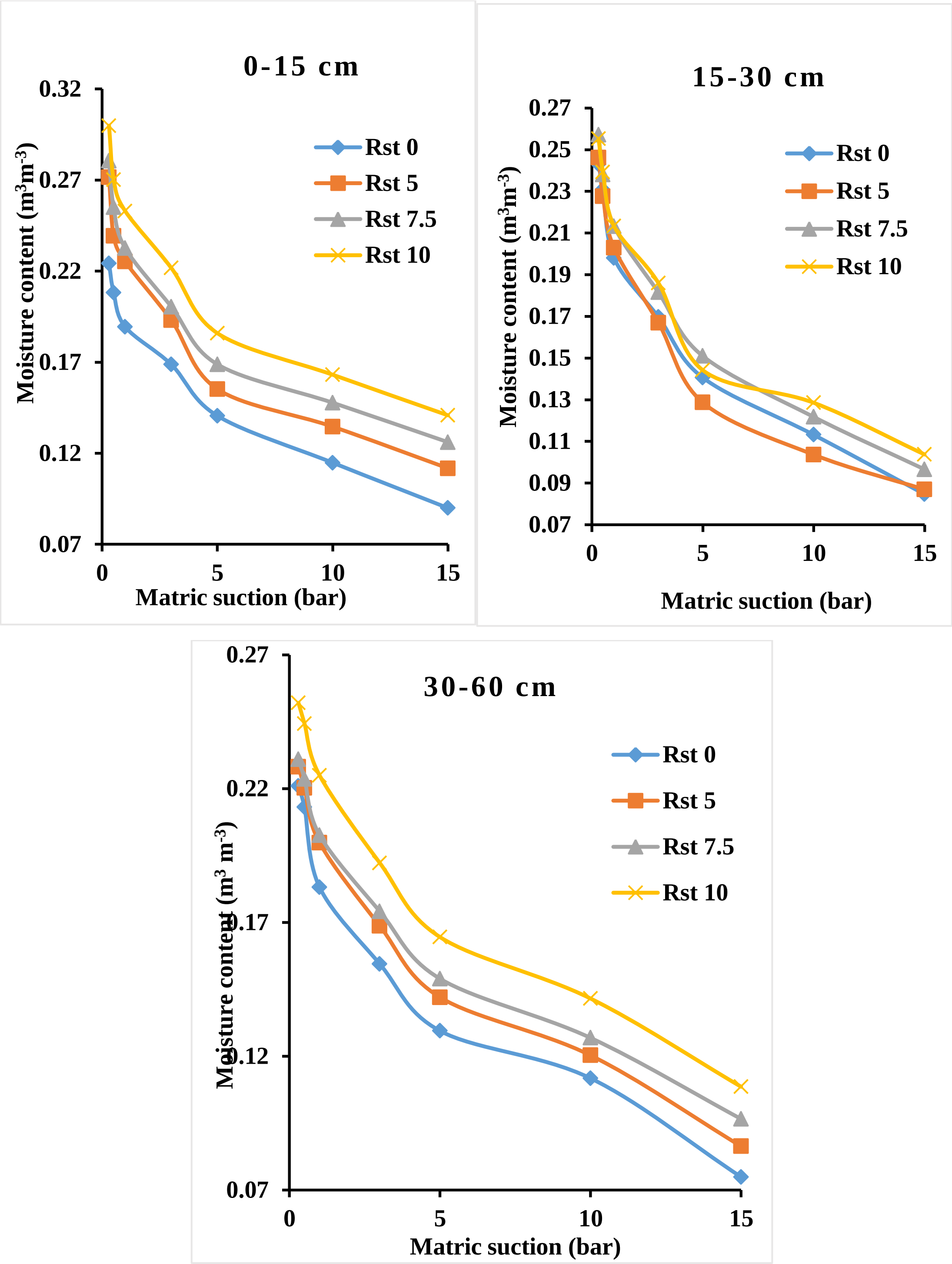

Fig 4.12 Effect of rice straw incorporation on soil moisture characteristics retention at different depths.

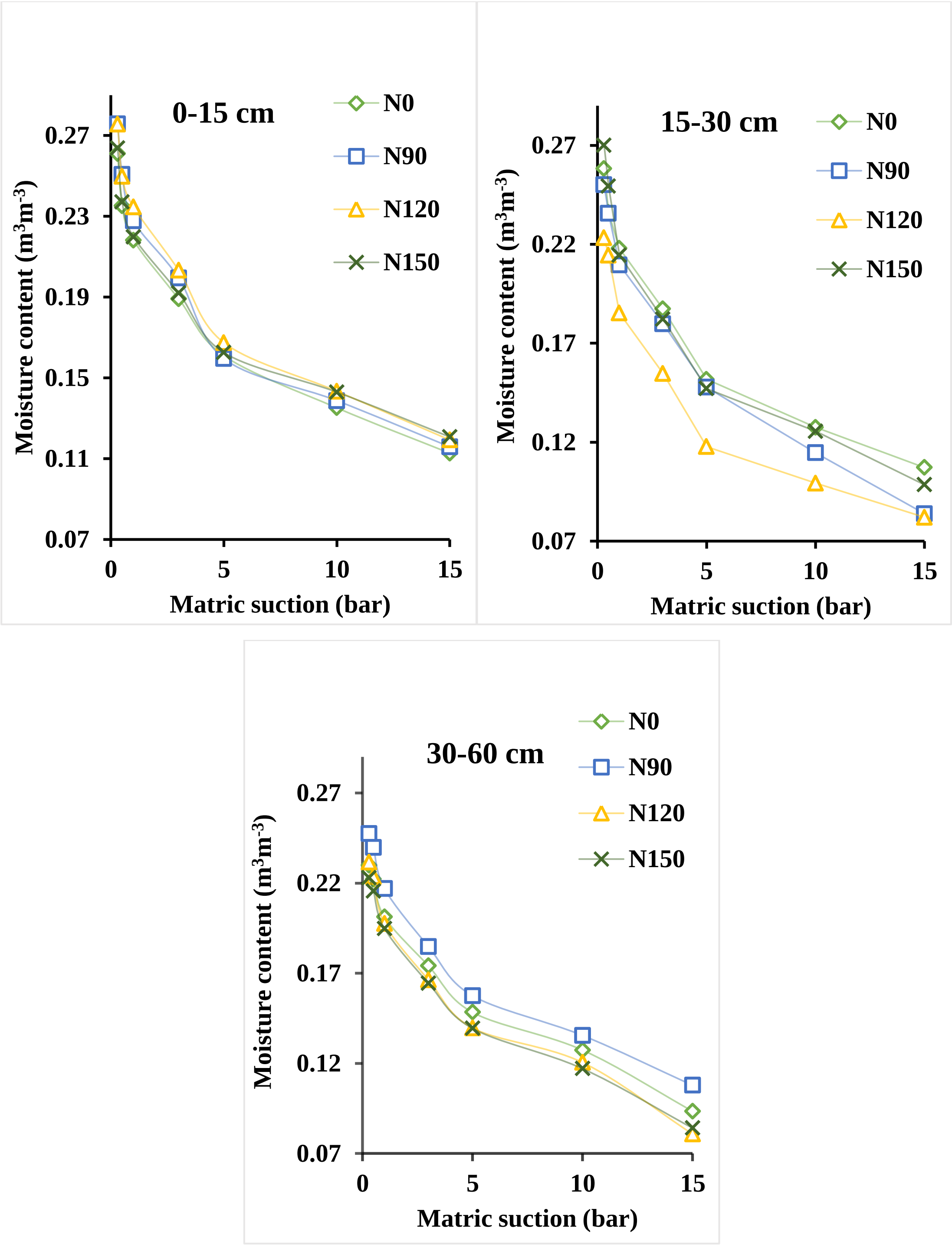

Fig 4.13 **Effect of nitrogen fertilization on soil moisture characteristics retention at different depths.**

Table 4.5 Effect of rice straw incorporation and nitrogen fertilization on field capacity ($m^3 m^{-3}$).

0-15 cm					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	0.22	0.24	0.22	0.22	0.22^{d}
$R_{st}5$	0.24	0.27	0.29	0.29	0.27^{b}
$R_{st}7.5$	0.28	0.28	0.29	0.27	0.28^{b}
$R_{st}10$	0.31	0.32	0.30	0.28	0.30^{a}
Mean	0.26	0.28	0.28	0.26	
LSD (p=0.05)	R_{st}:0.01, N:NS, R_{st}×N:NS				
15-30 cm					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	0.26	0.24	0.22	0.25	0.24
$R_{st}5$	0.24	0.25	0.22	0.27	0.25
$R_{st}7.5$	0.28	0.24	0.21	0.30	0.26
$R_{st}10$	0.25	0.27	0.24	0.26	0.26
Mean	0.26^{a}	0.25^{a}	0.22^{d}	0.27^{a}	
LSD (p=0.05)	R_{st}:NS, N:0.02, R_{st}×N:NS				
30-60 cm					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	0.24	0.20	0.23	0.21	0.22
$R_{st}5$	0.23	0.22	0.22	0.24	0.23
$R_{st}7.5$	0.23	0.27	0.23	0.19	0.23
$R_{st}10$	0.22	0.29	0.25	0.25	0.25
Mean	0.23	0.25	0.23	0.22	
LSD (p=0.05)	R_{st}:NS, N:NS, R_{st}×N:NS				

affected by nitrogen levels and soil depth. It was statistically at par in N_0, N_{90} and N_{150} treatments and was more in 15-30 cm layer than in other layers. PWP was significantly higher in 0-15 and 30-60 cm soil layers than control (Table 4.6). Similar to FC moisture constant, PWP also followed the same trend in 0-15 cm depth. The moisture content in 30-60 cm soil layer increased significantly with straw incorporated treatments and was maximum (0.109 m^3m^{-3}) in $R_{st}10$ which was statistically at par with $R_{st}7.5$. Like with straw incorporation rates, PWP was increased significantly with nitrogen levels in 15-30 and 30-60 cm soil layers. With the change in FC and PWP moisture constants, available water (AW) also changed accordingly and the changed was significant in 0-15 and 15-30 cm soil layer (Table 4.7). It was higher in N_{90} and N_{150} treatments in 0-15 and 15-30 cm depth respectively. There was a

Table 4.6 Effect of rice straw incorporation and nitrogen fertilization on permanent wilting point ($m^3 m^{-3}$).

0-15 cm					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	0.089	0.101	0.092	0.079	0.090^d
$R_{st}5$	0.095	0.107	0.115	0.131	0.112^c
$R_{st}7.5$	0.126	0.116	0.131	0.131	0.126^b
$R_{st}10$	0.142	0.140	0.140	0.142	0.141^a
Mean	0.113	0.116	0.119	0.121	
LSD (p=0.05)	R_{st}:0.006, N:NS, R_{st}xN:NS				
15-30 cm					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	0.122	0.062	0.074	0.080	0.085
$R_{st}5$	0.084	0.088	0.073	0.103	0.087
$R_{st}7.5$	0.113	0.091	0.072	0.110	0.097
$R_{st}10$	0.110	0.095	0.109	0.102	0.104
Mean	0.107^a	0.084^b	0.082^b	0.099^a	
LSD (p=0.05)	R_{st}:NS, N:0.008, R_{st}xN:0.01				
30-60 cm					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	0.072	0.078	0.072	0.078	0.075^d
$R_{st}5$	0.102	0.087	0.071	0.086	0.086^a
$R_{st}7.5$	0.105	0.119	0.080	0.082	0.097^a
$R_{st}10$	0.095	0.147	0.101	0.091	0.109^a
Mean	0.094^b	0.108^a	0.081^b	0.084^b	
LSD (p=0.05)	R_{st}:0.012, N:0.013, R_{st}xN:0.02				

significant interaction between rice straw incorporation and nitrogen levels in 15-30 and 30-60 cm layer of PWP. The improvement in water retention characteristics of soil after straw incorporation could be attributed to development of soil structural properties and reduction of total porosity of soil through conversion of macro-pores (typical characteristics of coarse texture soil) into more stable water transmitting micro- pores (Singh *et al* 2011). Moreover, presence of higher amount of SOM in straw incorporated plot also helps to hold more water at low and higher matric suctions. Straw incorporated treatments offers protection to soil from natural and anthropogenic disturbances, helps to maintain soil temperature and thus check the unproductive evaporative losses of water. The significantly higher saturated hydraulic conductivity (Fig 4.15) in control plot results in fast drainage of water from surface layer and this could be the reason for presence of lower amount of moisture at FC and PWP in control treatment.

When compared within soil depths, moisture content at FC was maximum in 15-30 cm layer in $R_{st}0$ and it tend to decreased with soil depth in straw incorporated treatments (Fig 4.14). Moisture content at PWP tend to decrease with soil depth in $R_{st}0$ and in straw incorporated treatments it was maximum in 0-15 cm layer and almost similar in 15-30 and 30-60 cm soil layer.

Table 4.7 Effect of rice straw and nitrogen fertilization on available water ($m^3\,m^{-3}$).

0-15 cm					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	0.13	0.14	0.13	0.14	0.13^d
$R_{st}5$	0.14	0.16	0.18	0.16	0.16^a
$R_{st}7.5$	0.15	0.17	0.16	0.14	0.16^a
$R_{st}10$	0.16	0.18	0.16	0.14	0.16^a
Mean	0.15^b	0.16^a	0.16^{ab}	0.14^{bc}	
LSD (p=0.05)	R_{st}:0.017, N:0.011, R_{st}xN:NS				
15-30 cm					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	0.14	0.18	0.15	0.17	0.16
$R_{st}5$	0.16	0.16	0.15	0.17	0.16
$R_{st}7.5$	0.17	0.15	0.13	0.19	0.16
$R_{st}10$	0.14	0.17	0.14	0.15	0.15
Mean	0.15^c	0.17^b	0.14^d	0.17^a	
LSD (p=0.05)	R_{st}:NS, N:0.02, R_{st}xN:NS				
30-60 cm					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	0.17	0.13	0.16	0.13	0.15
$R_{st}5$	0.13	0.13	0.15	0.15	0.14
$R_{st}7.5$	0.12	0.15	0.15	0.11	0.13
$R_{st}10$	0.13	0.14	0.15	0.16	0.14
Mean	0.14	0.14	0.15	0.14	
LSD (p=0.05)	R_{st}:NS, N:NS, R_{st}xN:NS				

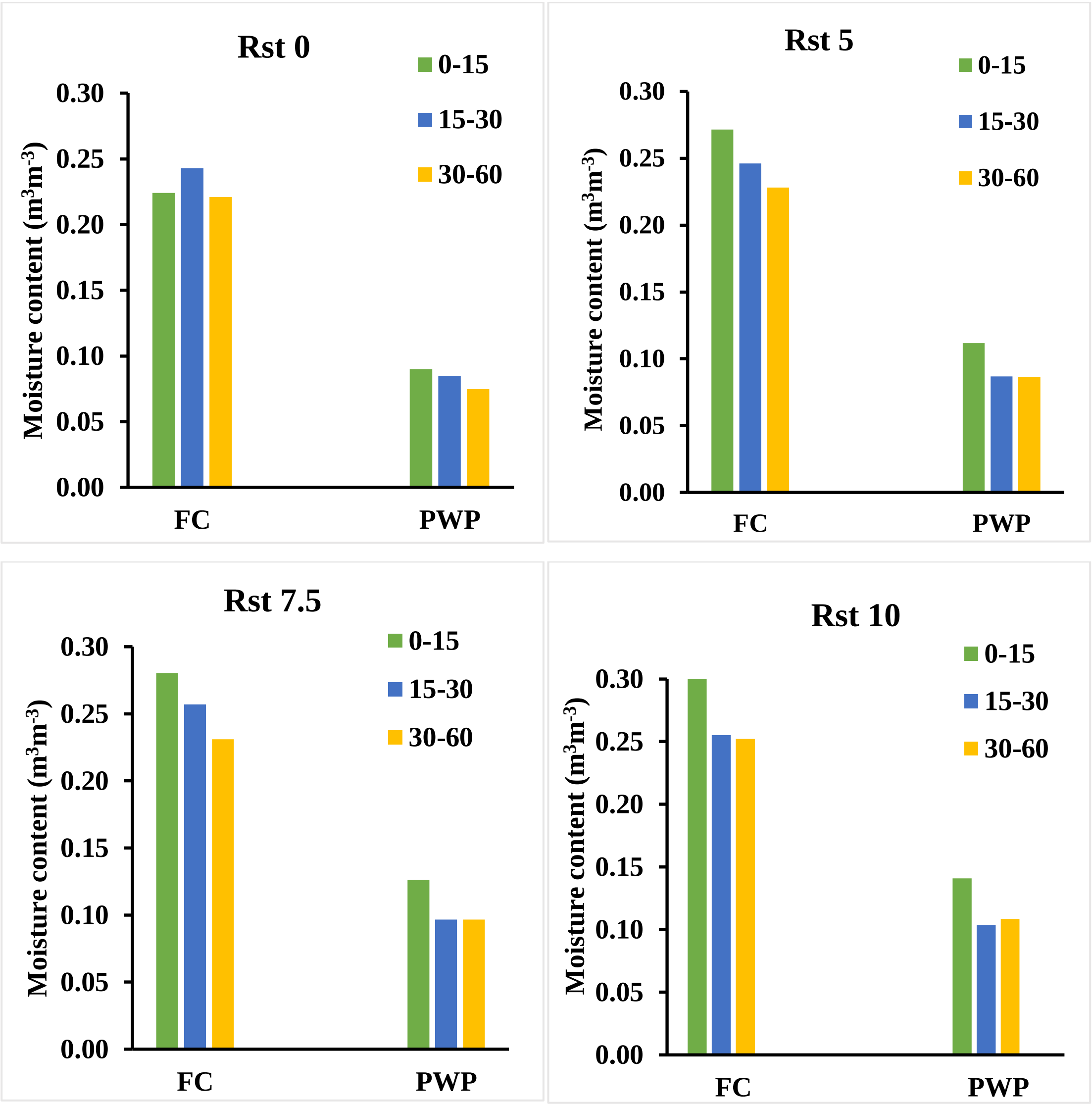

Fig 4.14 **Depthwise distribution of field capacity (m^3 m^{-3}) and permanent wilting point (m^3 m^{-3}) under rice straw incorporated treatments.**

4.2.3 Saturated Hydraulic Conductivity

Incorporation of rice straw and nitrogen fertilization has significantly influenced the saturated hydraulic conductivity (ks) of soil (Fig 4.15). It was 0.90 cm h^{-1} in R$_{st}$0 and it decreased with straw incorporated treatments to 0.54 in R$_{st}$5, 0.50 R$_{st}$7.5 and 0.46 cm h^{-1} in R$_{st}$10. In R$_{st}$5, R$_{st}$7.5 and R$_{st}$10 ks were statistically at par. Averaged across residue levels, ks decreased significantly with increasing nitrogen levels and it followed the order- N$_0$ (0.80) > N$_{90}$ (0.70) > N$_{120}$ (0.50) > N$_{150}$ (0.39) cm hr^{-1}. The interactive effect of rice straw and nitrogen levels revels that ks was significantly higher in treatment combination of nitrogen levels under R$_{st}$0 and was lower in N$_{90}$, N$_{120}$ and N$_{150}$ under R$_{st}$5, R$_{st}$7.5 and R$_{st}$10 (Fig 4.16).

The decrease in ks of soil with rice straw incorporation could be attributed to the reduction of macro-porosity of soil and its conversion into micro-pores (Table 4.3). The results of our study corroborates with the findings of Miller *et al* (1998), Angulo-Jaramillo *et al* (1997) who reported significant decrease in hydraulic conductivity and sorptivity of soil, on a sandy texture soil and are contrary to that of Valzano *et al* (1997), Sarkar and Kar (2011), Shaver (2010) who reported higher hydraulic conductivity in straw treated plot because of increase in macro-porosity of soil and decrease in BD. This could also be related to the transitory nature of soil structure after tillage, site history, initial and final water content (Azooz and Arshad 1996).

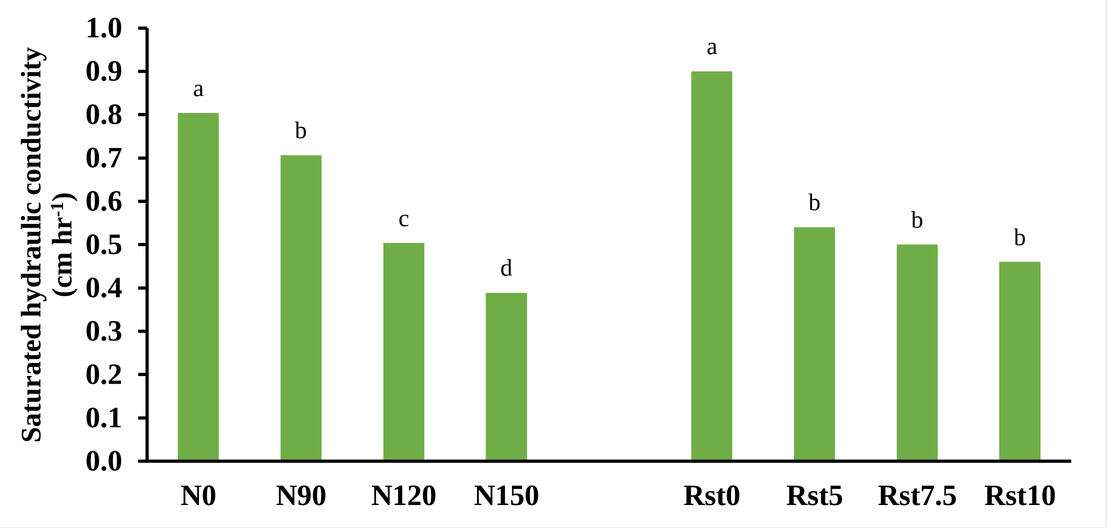

Fig 4.15 **Effect of rice straw and nitrogen fertilization on saturated hydraulic conductivity (cm hr^{-1}) of soil. Bars with same letter are statistically at par ($p<0.05$).**

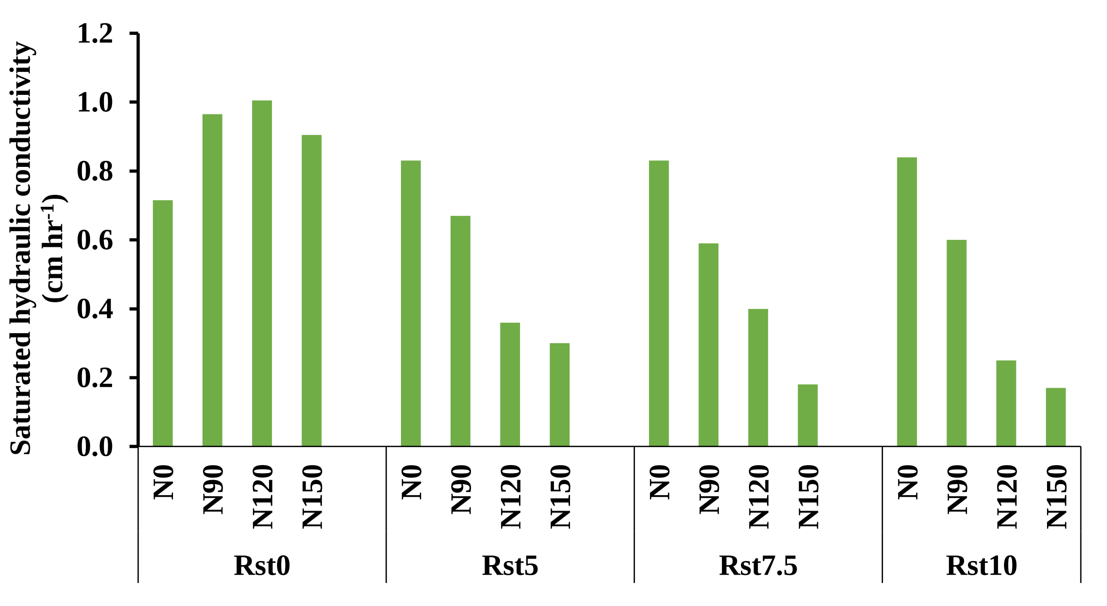

Fig 4.16 **Interactive effect of rice straw and nitrogen fertilization on saturated hydraulic conductivity (cm hr^{-1}) of soil.**

4.3 Soil chemical properties

4.3.1 Soil pH and EC

The influence of crop residue on soil pH is governed by the chemical composition of residue, its decomposition rate and soil properties (Xu and Coventry 2003, Butterly *et al* 2011). Incorporation of rice straw and nitrogen fertilization has significantly decreased the soil pH in 0-15 and 15-30 cm soil layers (Table 4.8). In surface layer (0-15 cm), it was 7.41 in $R_{st}0$ and decreased significantly to 7.29 in $R_{st}10$ and was statistically at par in $R_{st}0$, $R_{st}5$ and $R_{st}7.5$. Averaged across rice straw levels, soil pH was statistically uniform in N_0, N_{90} and N_{120} treatments and significantly lower (7.24) in N_{150} treatment. Similar trend was also observed in 15-30 cm soil layer. Incorporation of either rice straw or nitrogen fertilization did not influence the soil pH significantly in 30-60 cm soil layer. Irrespective of rice straw and

Table 4.8 Effect of rice straw incorporation and nitrogen fertilization on soil pH.

0-15 cm					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	7.54	7.30	7.30	7.52	7.41^b
$R_{st}5$	7.45	7.41	7.52	7.17	7.39^b
$R_{st}7.5$	7.48	7.54	7.28	7.26	7.39^b
$R_{st}10$	7.20	7.42	7.50	7.03	7.29^a
Mean	7.42^a	7.41^a	7.40^a	7.24^b	
LSD (p=0.05)	R_{st}:0.08, N:0.05, R_{st}×N:0.10				
15-30 cm					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	7.73	7.68	7.81	7.79	7.75^a
$R_{st}5$	7.77	7.73	7.76	7.48	7.68^b
$R_{st}7.5$	7.61	7.59	7.44	7.57	7.55^c
$R_{st}10$	7.47	7.46	7.38	7.32	7.41^d
Mean	7.64^b	7.62^b	7.60^b	7.54^a	
LSD (p=0.05)	R_{st}:0.06, N:0.04, R_{st}×N:0.052				
30-60 cm					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	7.83	7.87	7.80	7.82	7.83
$R_{st}5$	7.84	7.78	7.85	7.86	7.83
$R_{st}7.5$	8.00	7.70	8.03	7.89	7.91
$R_{st}10$	7.91	7.89	8.01	7.81	7.91
Mean	7.90	7.81	7.92	7.85	
LSD (p=0.05)	R_{st}:NS, N:NS, R_{st}×N:NS				

nitrogen levels, soil pH increased with soil depth and it was maximum in 30-60 cm soil layer (Fig 4.17). The decrease in soil pH with rice straw incorporation and nitrogen fertilization could be attributed to release of organic acids and CO_2 from the decomposition of crop residue and due to nitrification reaction. Similar results have also been reported by Rahman *et al* (2008) and Rhoton (2000). The electrical conductivity (EC) was remained unaffected by either incorporation of rice straw or nitrogen fertilization in all three soil depths (Table 4.9). Irrespective of treatments, EC was highest in surface soil depth and decrease with soil depth.

Table 4.9 Effect of rice straw incorporation and nitrogen fertilization on electrical conductivity of soil (ds m^{-1}).

0-15 cm					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	0.15	0.15	0.16	0.16	0.15
$R_{st}5$	0.17	0.17	0.16	0.14	0.16
$R_{st}7.5$	0.14	0.18	0.17	0.16	0.16
$R_{st}10$	0.17	0.17	0.14	0.17	0.16
Mean	0.16	0.17	0.16	0.16	
LSD (p=0.05)	R_{st}:NS N:NS, R_{st}×N:NS				
15-30 cm					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	0.09	0.13	0.11	0.08	0.10
$R_{st}5$	0.12	0.13	0.08	0.09	0.10
$R_{st}7.5$	0.10	0.11	0.10	0.13	0.11
$R_{st}10$	0.12	0.13	0.12	0.08	0.11
Mean	0.11	0.12	0.10	0.10	
LSD (p=0.05)	R_{st}:NS, N:NS, R_{st}×N:NS				
30-60 cm					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	0.10	0.09	0.09	0.08	0.09
$R_{st}5$	0.12	0.10	0.07	0.09	0.10
$R_{st}7.5$	0.10	0.10	0.09	0.10	0.10
$R_{st}10$	0.11	0.09	0.10	0.09	0.10
Mean	0.11	0.10	0.09	0.09	
LSD (p=0.05)	R_{st}:NS, N:NS, R_{st}×N:NS				

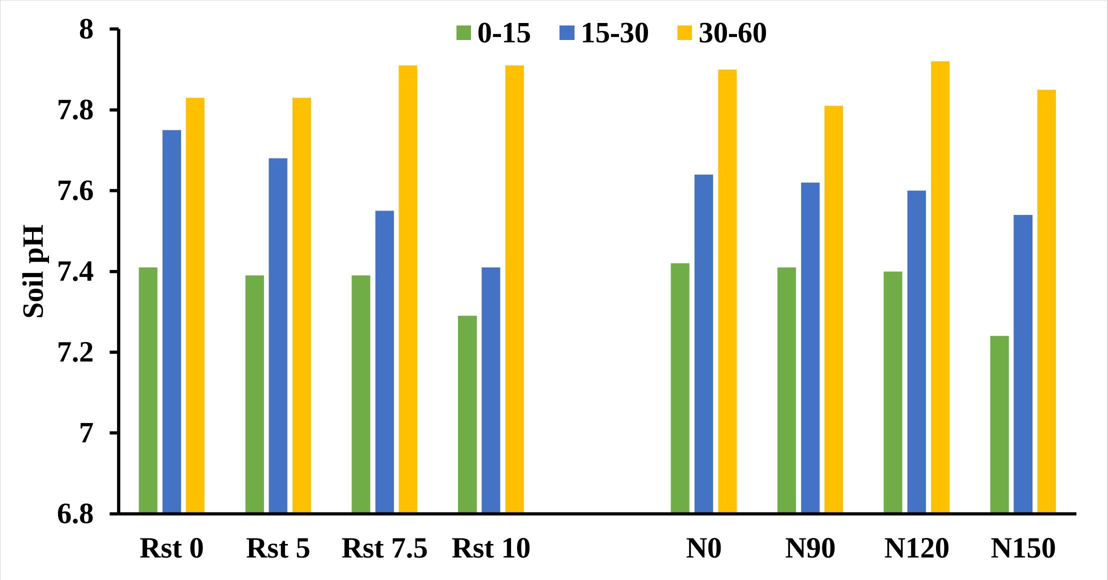

Fig 4.17 Depthwise distribution of soil pH under rice straw and nitrogen fertilized treatments.

4.3.2 Soil Organic carbon

Soil organic carbon (SOC) is considered as an important indicator of soil quality and agricultural sustainability because it improves soil aggregate stability and soil water retention, and provides a reservoir of soil nutrients (Liu *et al* 2006). Rice straw incorporation and nitrogen fertilization has significantly improved the SOC content in all three soil layers (Table 4.10). In 0-15 cm layer, SOC content ranged from 0.48 to 0.64%. Highest concentration (0.64%) of SOC was in $R_{st}10$ and lowest (0.48%) in control. In 15-30 and 30-60 cm depth it ranged from 0.41 to 0.50% and 0.27 to 0.35% and was again higher in $R_{st}10$ and least in control. In all three soil layers, SOC content followed the order- $R_{st}10 > R_{st}7.5 > R_{st}5 > R_{st}0$. These results are analogous with the findings of Choudhary *et al* (2014), Lehtinen *et al* (2014), Masto *et al* (2006) and Shafi *et al* (2007) who reported marked increase in SOC content with residue incorporation. The increase in SOC content may be due to more decay and release of carbonaceous material after incorporation of crop residue (Brar *et al* 2019). Similarly, averaged across rice straw levels, SOC content was significantly higher in N_{90}, N_{120} and N_{150} treatments as compared to control and it was statistically at par in N_{90}, N_{120} and N_{150} treatments. Similarly, the SOC content was also increased significantly in 15-30 and 30-60 cm, although the magnitude of increase were lower than in 0-15 cm depth. Irrespective of nitrogen or rice straw levels, SOC content decreased with the soil depth (Fig 4.18). Similarly, Zhang *et al* (2014) also reported decrease in SOC with soil depth because degree of straw incorporation was lower in deeper layers as compared to surface layer. Moreover lack of inadequate nutrients and biological activity in lower depths also constraint SOC. The interactive effect of rice straw and nitrogen levels was also significant in all three soil layers. SOC content was highest in the treatment combination of $R_{st}10N_{90}$ in all three soil layers

Table 4.10 Effect of rice straw incorporation and nitrogen fertilization on soil organic carbon (%).

0-15 cm					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	0.47	0.50	0.52	0.44	0.48^{d}
$R_{st}5$	0.55	0.58	0.60	0.61	0.58^{a}
$R_{st}7.5$	0.57	0.57	0.60	0.67	0.60^{a}
$R_{st}10$	0.59	0.70	0.63	0.65	0.64^{a}
Mean	0.54^{b}	0.58^{a}	0.59^{a}	0.59^{a}	
LSD (p=0.05)	R_{st}:0.07, N:0.03, R_{st}×N:0.06				
15-30 cm					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	0.34	0.45	0.44	0.41	0.41^{cd}
$R_{st}5$	0.42	0.47	0.48	0.41	0.45^{b}
$R_{st}7.5$	0.47	0.51	0.45	0.48	0.48^{a}
$R_{st}10$	0.47	0.55	0.49	0.48	0.50^{a}
Mean	0.42^{c}	0.49^{a}	0.46^{b}	0.45^{b}	
LSD (p=0.05)	R_{st}:0.04, N:0.02, R_{st}×N:0.04				
30-60 cm					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	0.28	0.27	0.23	0.29	0.27^{d}
$R_{st}5$	0.29	0.36	0.27	0.29	0.31^{c}
$R_{st}7.5$	0.36	0.30	0.33	0.31	0.33^{b}
$R_{st}10$	0.32	0.38	0.35	0.37	0.35^{a}
Mean	0.32^{a}	0.33^{a}	0.30^{c}	0.32^{a}	
LSD (p=0.05)	R_{st}:0.01, N:0.02, R_{st}×N:0.03				

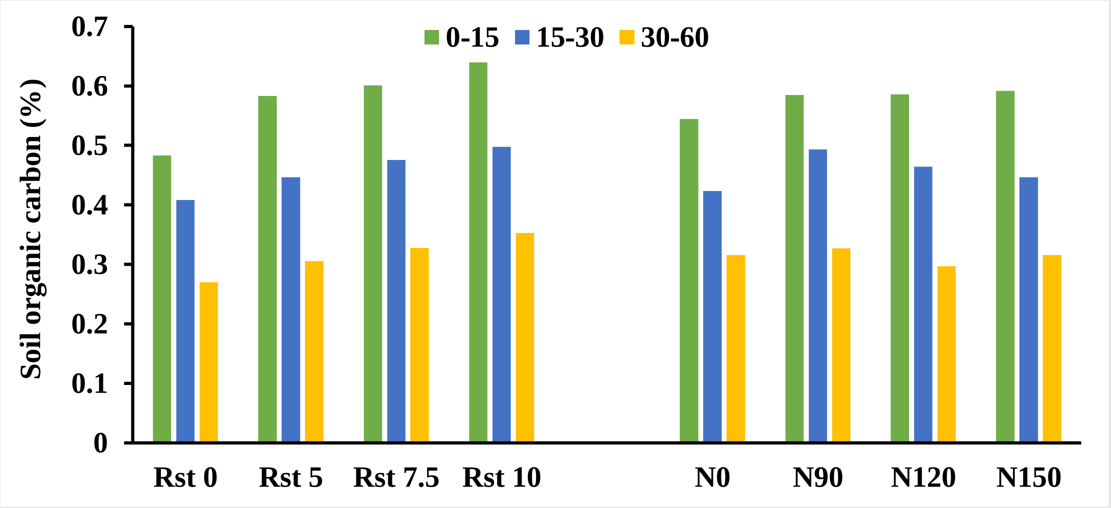

Fig 4.18 Depthwise distribution of soil organic carbon (%) under rice straw and nitrogen fertilized treatments.

(0-15, 15-30 and 30-60 cm). Similarly, Benbi *et al* (2012) also reported 84% increase in SOC content with incorporation of rice straw and application of N fertilizer.

4.3.3 Available nitrogen

Available nitrogen content was found to be significantly higher in 15-30 cm layer in all the three nitrogen levels (statistically at par) compared to control. Incorporation of rice straw did not influenced the available N content of soil significantly (Table 4.11).

Table 4.11 Effect of rice straw incorporation and nitrogen fertilization on soil available nitrogen (Kg ha^{-1}).

0-15 cm					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	119.17	109.76	90.94	81.54	100.35
$R_{st}5$	109.76	109.76	116.03	97.22	108.19
$R_{st}7.5$	109.76	112.90	97.22	106.62	106.62
$R_{st}10$	100.35	84.67	116.03	112.90	103.49
Mean	109.76	104.27	105.06	99.57	
LSD (p=0.05)	R_{st}:NS, N:NS, R_{st}×N:16.85				
15-30 cm					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	90.94	109.76	100.35	109.76	102.70
$R_{st}5$	65.86	112.90	100.35	87.81	91.73
$R_{st}7.5$	97.22	87.81	109.76	109.76	101.14
$R_{st}10$	84.67	84.67	100.35	100.35	92.51
Mean	84.67^a	98.78^b	102.70^b	101.92^b	
LSD (p=0.05)	R_{st}:NS, N:7.8, R_{st}×N:15.6				
30-60 cm					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	82.58	76.90	79.84	78.95	79.57
$R_{st}5$	80.24	82.10	77.85	76.82	79.25
$R_{st}7.5$	83.24	79.64	73.76	81.54	79.54
$R_{st}10$	81.54	83.47	83.85	75.67	81.13
Mean	81.90	80.53	78.82	78.24	
LSD (p=0.05)	R_{st}:NS, N:NS, R_{st}×N:NS				

4.3.4 Available phosphorus

Available phosphorus (Avail P) was significantly affected by both rice straw incorporation and nitrogen fertilization treatments in 0-15 and 15-30 cm soil layers (Table 4.12). Averaged across nitrogen levels, it increased significantly with increasing rate of rice

Table 4.12 Effect of rice straw and nitrogen fertilization on soil available phosphorus (Kg ha^{-1}).

0-15 cm					
Treatments	**N$_0$**	**N$_{90}$**	**N$_{120}$**	**N$_{150}$**	**Mean**
R$_{st}$0	9.4	25.4	22.8	25.3	20.7^{d}
R$_{st}$5	22.3	24.8	26.3	27.9	25.3^{b}
R$_{st}$7.5	26.2	31.7	31.2	21.5	27.6^{b}
R$_{st}$10	35.7	31.1	31.2	32.4	32.6^{a}
Mean	23.4^{c}	28.2^{a}	27.9^{ab}	26.8^{b}	
LSD (p=0.05)	R$_{st}$:2.4, N:1.3, R$_{st}$×N:2.6				
15-30 cm					
Treatments	**N$_0$**	**N$_{90}$**	**N$_{120}$**	**N$_{150}$**	**Mean**
R$_{st}$0	13.9	22.3	23.0	16.0	18.8^{c}
R$_{st}$5	15.0	25.6	26.9	25.1	23.1^{b}
R$_{st}$7.5	24.1	23.4	25.0	26.4	24.7^{ab}
R$_{st}$10	21.3	29.1	27.5	27.7	26.4^{a}
Mean	18.6^{d}	25.1^{a}	25.6^{a}	23.8^{a}	
LSD (p=0.05)	R$_{st}$:2.3, N:1.9, R$_{st}$×N:2.6				
30-60 cm					
Treatments	**N$_0$**	**N$_{90}$**	**N$_{120}$**	**N$_{150}$**	**Mean**
R$_{st}$0	7.7	28.0	22.7	15.6	18.5
R$_{st}$5	17.8	29.2	28.3	20.5	23.9
R$_{st}$7.5	21.0	25.4	26.2	24.6	24.3
R$_{st}$10	21.1	22.3	27.2	25.5	24.0
Mean	16.9^{d}	26.2^{a}	26.1^{a}	21.5^{b}	
LSD (p=0.05)	R$_{st}$:NS, N:3.7, R$_{st}$×N:NS				

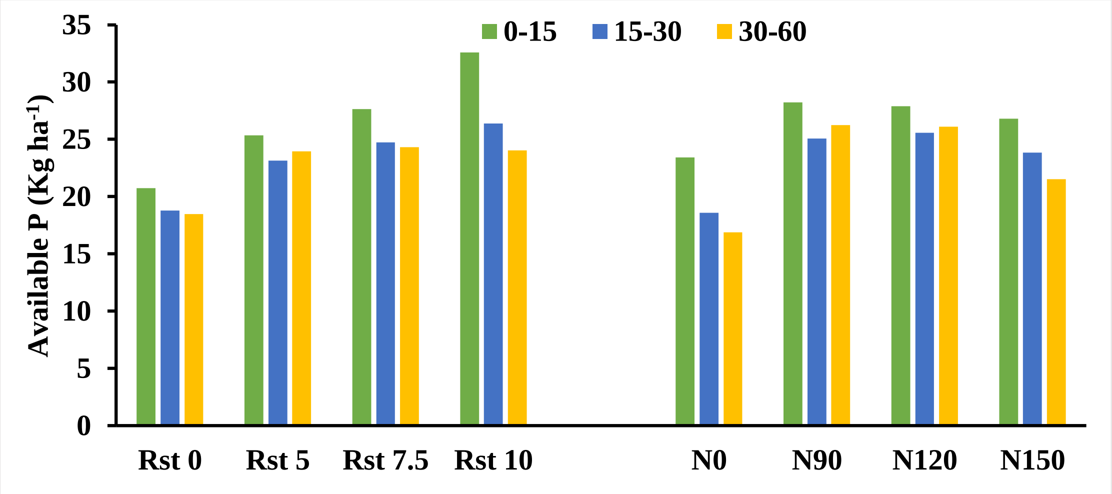

Fig 4.19 Depthwise distribution of soil available phosphorus (Kg ha^{-1}) under rice straw and nitrogen fertilized treatments.

straw incorporation and was highest (32.6 Kg ha^{-1}) in R$_{st}$10 in 0-15 cm soil layer. In 30-60 cm soil layer, it was non-significant. Irrespective of soil depths, Avail P followed the order- R$_{st}$10 > R$_{st}$7.5 > R$_{st}$5 > R$_{st}$0. Increase in Avail P with straw incorporation has already been reported by Liu *et al* (2010), Jiang *et al* (2011), Hu *et al* (2013), Singh *et al* (2009). They attributed it to release of various organic acids which solubilize various phosphate bearing minerals, reduced direct contact between Avail P and soil particles with rice straw incorporation and increase phosphate mineralization because of increased phosphatase enzyme activity (Lemanowicz 2011). Averaged across rice straw levels, application of nitrogen fertilizers also increased the Avail P content of soil in all three soil layers. In 0-15, 15-30 and 30-60 cm depths, Avail P was 28.2, 25.6, 26.2 Kg ha^{-1} in N$_{150}$ treatment and it was statistically at par with N$_{90}$ and N$_{120}$ treatments. Irrespective of rice straw and nitrogen levels, Avail P decreased with soil depths (Fig 4.19). The interactive effect of rice straw and nitrogen fertilizer was significant in 0-15 and 15-30 cm depths. In 0-15 cm layer, significantly highest Avail P was found in all nitrogen treatments under R$_{st}$10 as well as in N$_{120}$ and N$_{150}$ under R$_{st7.5}$. In 30-60 cm layer, N$_{90}$, N$_{120}$ and N$_{150}$ under R$_{st}$10 showed significantly higher Avail P content.

4.3.5 Available potassium

Available potassium (Avail K) was significantly affected by rice straw incorporation in 0-15 and 15-30 cm layer only (Table 4.13). Averaged across nitrogen levels, Avail K in 0-15 cm soil layer ranged from 100-148 Kg ha^{-1} and it increased with increasing rate of rice straw incorporation and highest value (148.4 Kg ha^{-1}) was in R$_{st}$10. Similar results were also found in 15-30 cm soil layer, but the magnitude of change was smaller than surface layer. Irrespective of soil depths, Avail K followed the order- R$_{st}$0 < R$_{st}$5 < R$_{st}$7.5 < R$_{st}$10. Averaged across residue levels, application of nitrogen fertilizers has reduced the Avail K of soil in 0-15 and 15-30 cm layer. However, it increased under N$_{150}$ treatment in 30-60 cm layer. Irrespective of rice straw and nitrogen levels, Avail K was maximum in 0-15 cm soil layer (Fig 4.20). This could be because rice straw was incorporated in surface soil which undergone rapid decay because of favourable conditions for decomposition in surface soil. Avail K was lower in 15-30 cm soil depth and leaching may be the reason for this. The interactive effect of rice straw and nitrogen fertilization was also significant in all three soil depths. In 0-15 cm, except for the treatment combination N$_{120}$R$_{st}$7.5, all the nitrogen levels in R$_{st}$7.5 and R$_{st}$10 showed significantly highest Avail K. Similar results were also found in 15-30 cm layer. In 30-60 cm, Avail K was highest and statistically at par in treatment combination of N$_{150}$R$_{st}$5, N$_{90}$R$_{st}$7.5, and N$_{90}$, N$_{120}$ under R$_{st}$10. The results of present study are analogous with the findings of Gathala *et al* (2017), Surekha *et al* (2003) and Liu *et al* (2010) who reported higher Avail K in crop residue managed treatments. The increase in Avail K after straw incorporation may be due to the fact that rice straw is a very rich source of potassium and

Table 4.13 Effect of rice straw and nitrogen fertilization on soil available potassium (Kg ha^{-1}).

0-15 cm					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	105.8	94.9	98.3	103.3	100.6^{d}
$R_{st}5$	130.5	117.9	131.3	107.0	121.7^{c}
$R_{st}7.5$	164.2	141.4	111.5	138.6	138.9^{b}
$R_{st}10$	159.7	152.9	140.3	140.6	148.4^{a}
Mean	140.1^{a}	126.8^{b}	120.3^{b}	122.4^{b}	
LSD (p=0.05)	R_{st}:8.7, N:6.7, R_{st}×N:13.4				
15-30 cm					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	77.7	78.1	70.2	68.9	73.7^{d}
$R_{st}5$	97.0	97.1	84.0	88.3	91.6^{c}
$R_{st}7.5$	110.3	104.1	101.3	103.9	104.9^{b}
$R_{st}10$	117.9	122.5	112.4	97.5	112.6^{a}
Mean	100.7^{a}	100.5^{a}	92.0^{b}	89.6^{b}	
LSD (p=0.05)	R_{st}:0.70, N:3.1, R_{st}×N:6.3				
30-60 cm					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	122.9	80.1	114.0	114.0	107.7
$R_{st}5$	115.4	99.7	117.6	130.8	115.9
$R_{st}7.5$	111.2	131.6	114.0	112.3	117.3
$R_{st}10$	96.5	127.8	128.6	119.7	118.2
Mean	111.5^{bc}	109.8^{c}	118.5^{ab}	119.2^{a}	
LSD (p=0.05)	R_{st}:NS, N:7.7, R_{st}×N:15.37				

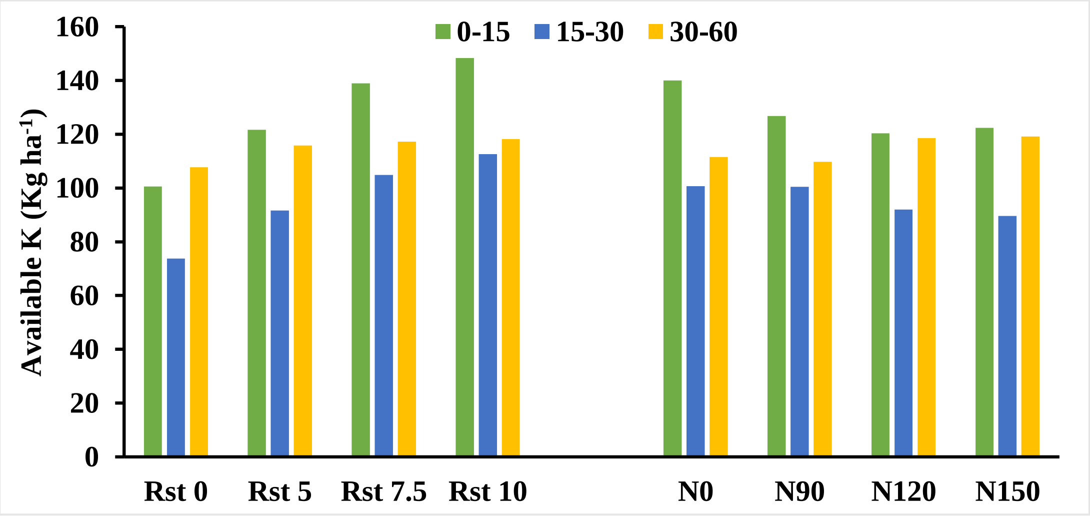

Fig 4.20 Depthwise distribution of soil available potassium (Kg ha^{-1}) under rice straw and nitrogen fertilized treatments.

about 80-85% of total plant K remains in vegetative part at crop maturity which may contribute to soil Avail K after microbial decomposition (Singh *et al* 2005).

4.3.6 Available micronutrients

Rice straw incorporation as well as nitrogen fertilization has significantly affected available micronutrients. Rice straw incorporation has significantly increased the available Fe, Mn and Zn content, whereas the effect on copper availability was non-significant in both the soil depths. Averaged across nitrogen levels, with $R_{st}10$ the available Fe, Mn and Zn content increased to 33.30, 8.61 and 2.7 ppm compared to 30.64, 6.09 and 2.43 ppm in control in 0-15 cm layer (Table 4.14); to 28.05 and 4.32 ppm from 26.91, 2.56 in control in 15-30 cm soil layer (Table 4.15). In general, available Fe, Mn and Zn content were statistically at par in $R_{st}5$, $R_{st}7.5$ and $R_{st}10$, but significantly higher than $R_{st}0$ in both the soil depths. However, in 15-30 cm depth the effect of straw incorporation on available Zn content was found to be non-significant. The increase in available micronutrient content with rice straw incorporation could be attributed to fact that about 50-80% of micronutrient cations (Zn, Fe, Cu and Mn) taken up by rice crop remains in the vegetative part after maturity and can be recycled through incorporated residue (Singh *et al* 2009). Moreover, addition of organic materials might have enhanced the microbial activity in the soil and consequently the release of complex organic substances like chelating agents that could have prevented micronutrients from precipitation, fixation, oxidation and leaching and thus increased the availability.

Averaged across rice straw levels, application of nitrogen fertilizers has significantly increased the available Fe, Mn, Zn and Cu content in both 0-15 and 15-30 cm soil depths. Available Fe content was higher in N_{150} i.e. 34.7 ppm in 0-15 and 29.70 ppm in 15-30 cm layer than N_{120}, N_{90} and N_0. Available Mn content was increased with increasing nitrogen levels in 0-15 cm depth and follows the order N_{150} (8.47) > N_{120} (7.69) > N_{90} (7.29) > N_0 (6.87) ppm. Available Zn content also followed the same trends. Unlike rice straw levels, nitrogen application has significantly increased the available Cu content in both the soil depths. Irrespective of nitrogen and straw levels available micronutrients decreased with the soil depth (Fig 4.21).

The available Fe, Mn, Zn in 0-15 cm depth and available Fe in 15-30 cm depth, were only significantly affected by interactive effect of rice straw and nitrogen fertilization. The available Fe was highest and statistically at par in treatment combination of $R_{st}10N_{120}$ and $R_{st}5N_{150}$ in 0-15 cm depth and in treatment combination of N_{150} under $R_{st}7.5$ and $R_{st}10$ in 15-30 cm depth. The available Mn and Zn content were highest in treatment combination of N_{120} and N_{150} under $R_{st}7.5$ and $R_{st}10$, $N_{150}R_{st}7.5$ and $N_{120}R_{st}10$.

Table 4.14 Effect of rice straw and nitrogen fertilization on available micronutrients (ppm) in 0-15 cm soil layer.

Fe					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	32.95	28.06	32.92	28.60	30.64^b
$R_{st}5$	28.25	27.35	31.32	41.14	32.02^a
$R_{st}7.5$	33.11	29.32	35.54	34.92	33.22^a
$R_{st}10$	27.72	32.55	38.67	34.27	33.30^a
Mean	30.51^b	29.32^b	34.61^a	34.73^a	
LSD (p=0.05)	R_{st}:1.70, N:1.98, R_{st}×N:3.9				
Mn					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	6.09	5.93	5.80	6.58	6.10^c
$R_{st}5$	6.48	7.23	8.20	7.82	7.43^b
$R_{st}7.5$	6.61	8.30	8.45	9.31	8.17^a
$R_{st}10$	8.28	7.72	8.30	10.18	8.62^a
Mean	6.87^d	7.29^c	7.69^b	8.47^a	
LSD (p=0.05)	R_{st}:0.7, N:0.3, R_{st}×N:0.6				
Zn					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	2.47	2.20	2.40	2.66	2.43^b
$R_{st}5$	2.77	2.56	2.66	2.64	2.66^a
$R_{st}7.5$	2.64	2.87	2.32	3.01	2.71^a
$R_{st}10$	2.68	2.76	2.95	2.65	2.76^a
Mean	2.64^{ab}	2.60^b	2.58^b	2.74^a	
LSD (p=0.05)	R_{st}:0.2, N:0.10, R_{st}×N:0.2				
Cu					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	1.18	0.90	1.20	1.08	1.09
$R_{st}5$	1.19	0.88	1.04	1.26	1.09
$R_{st}7.5$	1.14	0.93	1.19	1.15	1.10
$R_{st}10$	1.15	1.13	1.12	1.12	1.13
Mean	1.16^a	0.96^b	1.14^a	1.15^a	
LSD (p=0.05)	R_{st}:NS, N:0.1, R_{st}×N:NS				

Table 4.15 Effect of rice straw and nitrogen fertilization on soil available micronutrients (ppm) in 15-30 cm soil layer.

Fe					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	23.91	28.65	25.05	30.03	26.91^{c}
$R_{st}5$	28.42	27.67	29.43	27.69	28.30^{b}
$R_{st}7.5$	23.38	29.87	29.00	30.02	28.07^{a}
$R_{st}10$	24.71	29.54	26.89	31.08	28.05^{a}
Mean	25.10^{c}	28.93^{ab}	27.59^{b}	29.70^{a}	
LSD (p=0.05)	R_{st}:0.1, N:1.7, R_{st}×N:3.5				
Mn					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	2.57	3.26	1.96	2.47	2.56^{b}
$R_{st}5$	3.18	3.35	3.14	3.08	3.19^{b}
$R_{st}7.5$	3.49	4.10	2.68	3.21	3.37^{b}
$R_{st}10$	4.11	5.29	3.62	4.26	4.32^{a}
Mean	3.34^{b}	4.00^{a}	2.85^{c}	3.26^{b}	
LSD (p=0.05)	R_{st}:0.9, N:0.4, R_{st}×N:NS				
Zn					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	2.33	2.32	1.87	2.83	2.34
$R_{st}5$	3.03	2.02	2.47	2.65	2.54
$R_{st}7.5$	2.87	2.24	2.24	2.90	2.56
$R_{st}10$	3.06	2.18	1.94	3.10	2.57
Mean	2.82^{a}	2.19^{b}	2.13^{b}	2.87^{a}	
LSD (p=0.05)	R_{st}:NS, N:0.3, R_{st}×N:NS				
Cu					
Treatments	**N_0**	**N_{90}**	**N_{120}**	**N_{150}**	**Mean**
$R_{st}0$	0.47	1.01	0.52	0.75	0.69
$R_{st}5$	0.47	0.89	0.71	0.71	0.70
$R_{st}7.5$	0.43	1.01	0.72	0.67	0.71
$R_{st}10$	0.52	1.05	0.99	1.00	0.89
Mean	0.47^{c}	0.99^{b}	0.74^{a}	0.78^{a}	
LSD (p=0.05)	R_{st}:NS, N:0.1, R_{st}×N:NS				

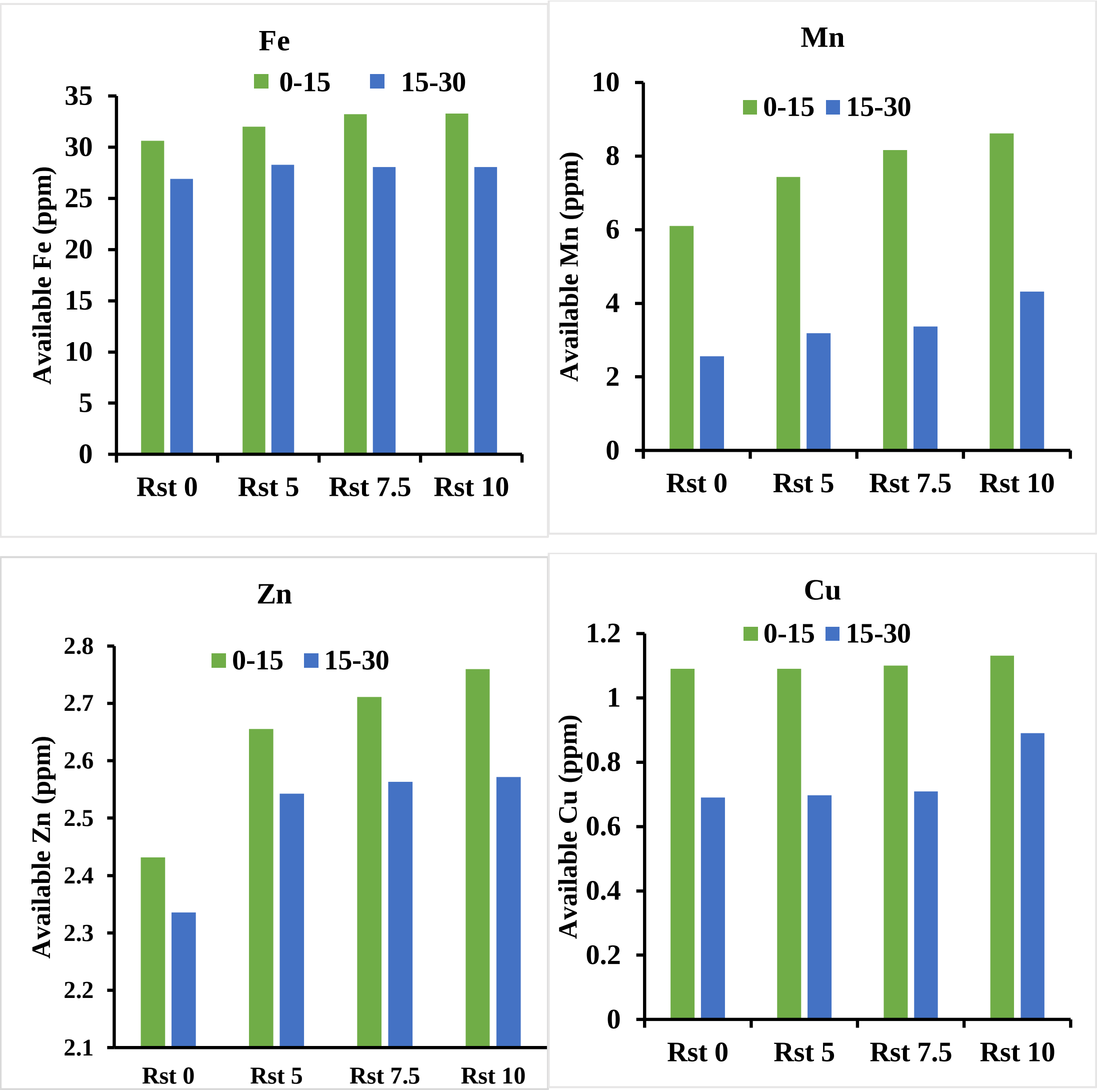

Fig 4.21 Depthwise distribution of soil available micronutrients (ppm) under rice straw incorporated treatments.

4.4 Soil biochemical properties within soil aggregates fractions

The aggregate size distribution, its stability and pores within and between aggregates affect the soil properties and the soil biotic activity (Tisdall 1992, Mikha and Rice 2004). At the same time, aggregate stability is govern by various factors such as soil type, climatic conditions, quality and quantity of organic matter. Similarly, Soil biotic activity also play an important role in aggregate formation and stabilization (Tang *et al* 2011). It has been proved that decomposition of crop residue releases fresh SOC that first accumulate in larger fractions. Higher organic carbon content supports greater microbial activity because of greater supply of energy and nutrients and provides better environment for stabilizing and protecting the enzymes (Chen *et al* 2009). The objective of this biochemical analysis within soil aggregates was to figure out the most important biochemical parameters and imposed treatments, which contributed more to soil aggregation.

As nitrogen application as well as interactive effect of rice straw incorporation and

nitrogen application did not affect significantly the enzyme activities and soil carbon pools within soil aggregate therefore, the effect of only rice straw incorporation on enzyme activities and carbon pools within aggregate fraction is discussed in the following section.
The soil aggregate sample was categorized into three size ranges as-
Large macro-aggregate (>2 mm), Macro-aggregate (2-0.25 mm) and Micro-aggregate (<0.25 mm).

4.4.1 Dehydrogenase activity

Present study revealed that dehydrogenase activity (DHA) was significantly higher in macro-aggregates fraction, followed by large macro-aggregates and micro-aggregates (Fig 4.22). As compared to $R_{st}0$, all straw incorporated treatments has significantly increased the dehydrogenase activity in all three soil aggregates fractions. However, the significance varied with straw incorporation rate and size of the aggregates. The positive effects of crop residue incorporation on dehydrogenase activity were also reported by number of researchers. Higher activity of DHA in rice straw incorporated treatments as well as in macro-aggregate may be due to higher substrate availability, labile carbon and microbial biomass carbon (Justin *et al* 2013) which act as a source of food and energy for microorganism (Chandra 2011, Mangalassery *et al* 2015) and greater biological activity (Colvan *et al* 2001). Significantly lowest activity was found in $R_{st}0$ which could be attributed to lower organic matter and lowest contents of very labile carbon fraction. A significant and positive correlation between MBC and DHA (r=0.78) indicate that DHA was associated with active microorganisms in the soil that are the major source of soil enzymes (Okur *et al* 2009) (Fig 4.23). Previous studies by Justin *et al* (2013) in central Himalayas found a higher positive correlation between DHA and MBC (r=0.86).

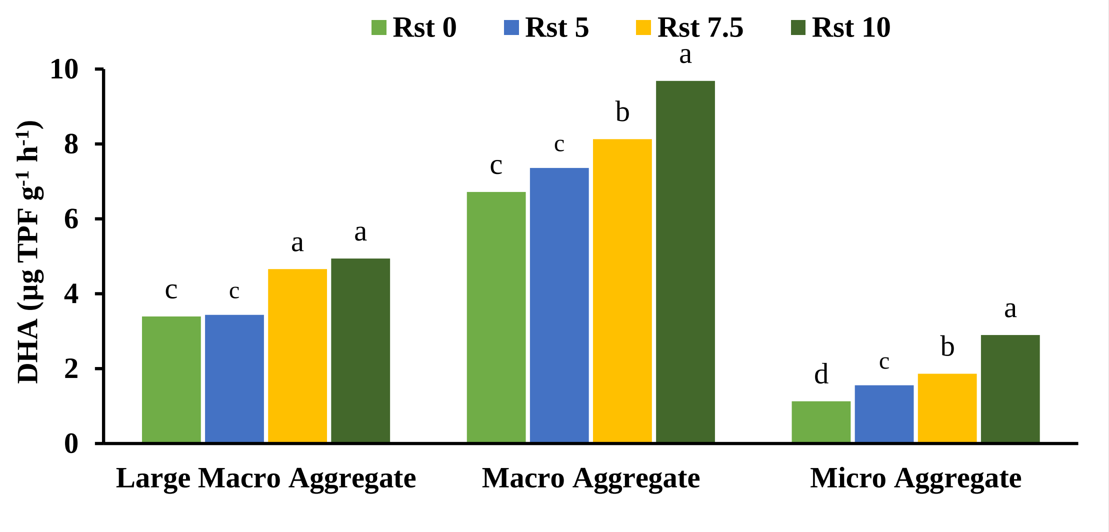

Fig 4.22 **Effect of rice straw incorporation on dehydrogenase activity (µg TPF g^{-1} h^{-1}) within soil aggregate fraction. Bars with the same letter, within the same aggregate size, are statistically at par.**

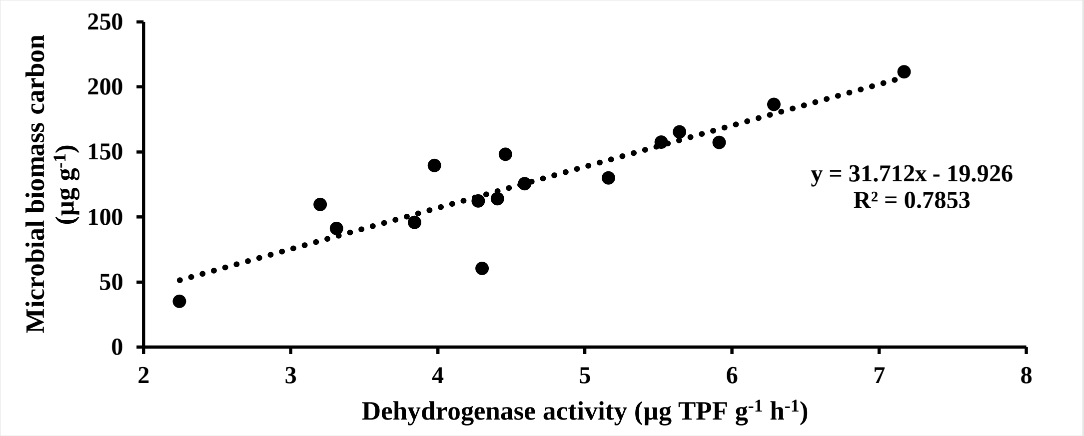

Fig 4.23 Correlation between dehydrogenase activity (µg TPF g^{-1} h^{-1}) and microbial biomass carbon (µg g^{-1}).

4.4.2 Fluorescein diacetate activity

Incorporation of rice straw has significantly increased the activity of fluorescein diacetate (FDA) in large macro and macro-aggregates fraction, whereas the effect was non-significant in micro-aggregates fraction of soil. However the magnitude of increase was highest in macro-aggregate fraction followed by large macro-aggregate and minimum in micro-aggregates (Fig 4.24). Similar to the present study of rice-wheat cropping system maximum activity of FDA in maize-wheat cropping system (Kumawat *et al* 2017) and maize-soybean cropping system (Perez-Brandan *et al* 2012) has been reported due to presence of more organic carbon and microbial activity.

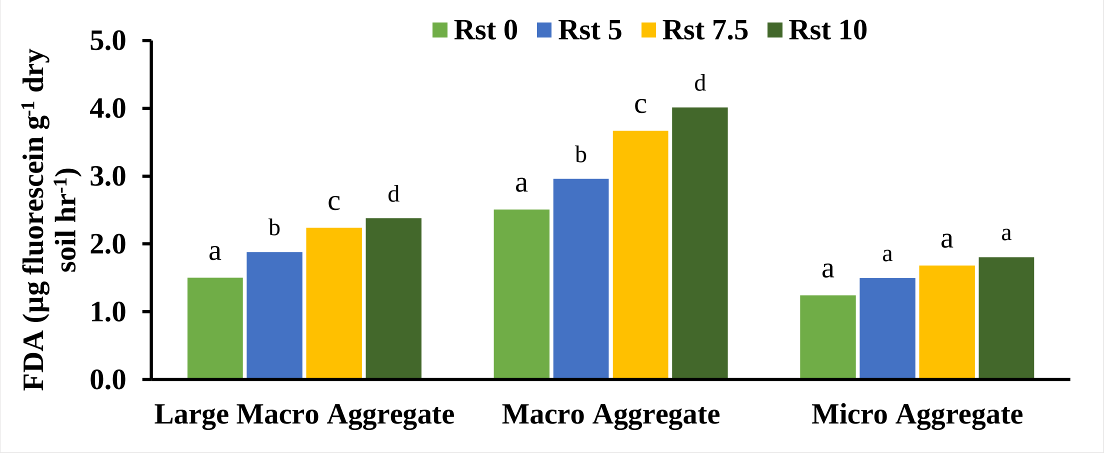

Fig 4.24 Effect of rice straw incorporation on fluorescein diacetate activity (µg fluorescein g^{-1} dry soil hr^{-1}) within soil aggregate fraction. Bars with the same letter, within the same aggregate size, are statistically at par.

4.4.3 Alkaline phosphatase

Similar to DHA, maximum activity of alkaline phosphatase was in macro-aggregate fraction followed by large macro-aggregates and micro-aggregates. Incorporation of rice straw has significantly increased the activity of alkaline phosphatase in large macro and macro-aggregates fraction, whereas effect was non-significant in micro-aggregates fraction of soil (Fig 4.25).

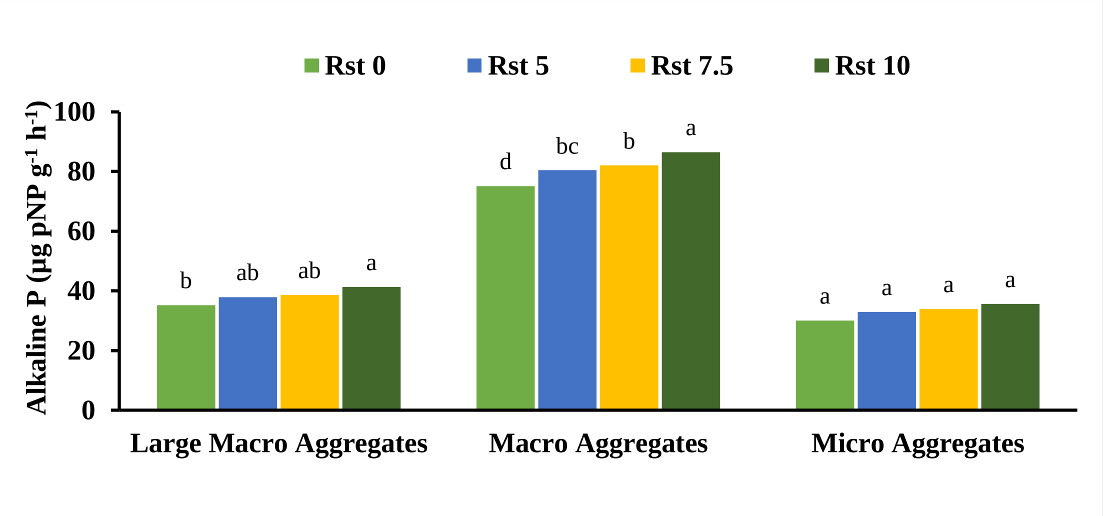

Fig 4.25 Effect of rice straw incorporation on alkaline phosphatase activity (µg pNP g^{-1} h^{-1}) within soil aggregate fraction. Bars with the same letter, within the same aggregate size, are statistically at par.

Irrespective of soil aggregates fractions, highest activity of alkaline phosphatase were reported by $R_{st}10$ followed by $R_{st}7.5$ and $R_{st}5$. Significantly lowest activity was found in control. Higher activity of alkaline phosphate in higher rate of straw incorporation is attributed to higher organic matter content in soil and resulting utilization of carbon and energy by soil microbes from decomposition of crop residue (Tao *et al* 2009, Qin *et al* 2010, and Sharma *et al* 2013). Manjaiah *et al* (2000) reported that activity of alkaline phosphate is closely related with the level of organic matter content in soil and in present study too, higher organic matter was built in rice straw incorporated treatments. Significantly higher labile carbon was stabilized in macro-aggregates and this could be the reason for highest activity of alkaline phosphate in macro-aggregates as compared to micro-aggregates.

4.4.4 Microbial biomass carbon

Microbial biomass carbon (MBC) was affected significantly by rice straw incorporation in all three aggregate fractions (Fig 4.26). MBC was significantly higher in macro-aggregates fraction followed by large macro and micro-aggregates. Irrespective of soil aggregate fractions, MBC increased significantly with increasing rate of straw incorporation and it follows the order- $R_{st}10 > R_{st}7.5 > R_{st}5 > R_{st}0$. The higher MBC in macro-aggregates and rice straw incorporated treatments may be due to higher root growth, and microbial activity leading to higher mineralization of C and N. This results corroborates with the finding of Kaur *et al* (2008), Mandal *et al* (2007), Zhu *et al* (2014) who reported greater microbial biomass in soil treated with straw.

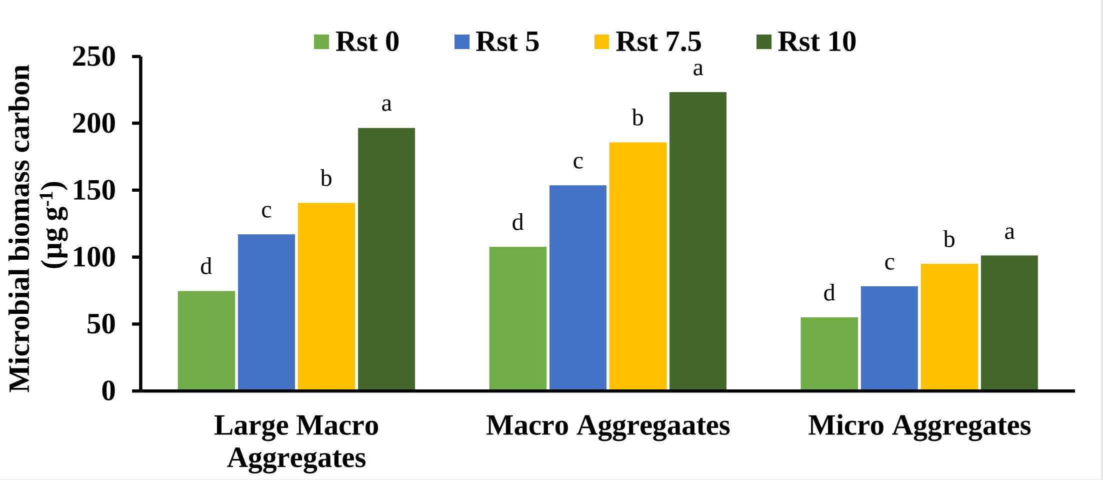

Fig 4.26 **Effect of rice straw incorporation on microbial biomass carbon ($\mu g\ g^{-1}$) within soil aggregate fraction. Bars with the same letter, within the same aggregate size, are statistically at par.**

4.4.5 Basal soil respiration

Rice straw incorporation has significantly influenced the basal soil respiration in all three aggregate fractions (Fig 4.27). It was significantly higher in macro-aggregate fraction followed by large macro and micro-aggregates. Higher rates of BSR was also reported by Liu *et al* (20014) in rice wheat cropping system, when rice straw were incorporated as compared to without incorporation. The higher rates of soil respiration in macro-aggregate and large macro-aggregate fraction can be attributed to increased carbon availability, higher microbial biomass and labile carbon fractions (Wang *et al* 2003). In contrast, lower rates of soil respiration under micro-aggregates could presumably be due to depletion of readily decomposable substrates for microorganism and decreased soil microbial biomass and activity (Lee and Jose 2003, Ding *et al* 2010).

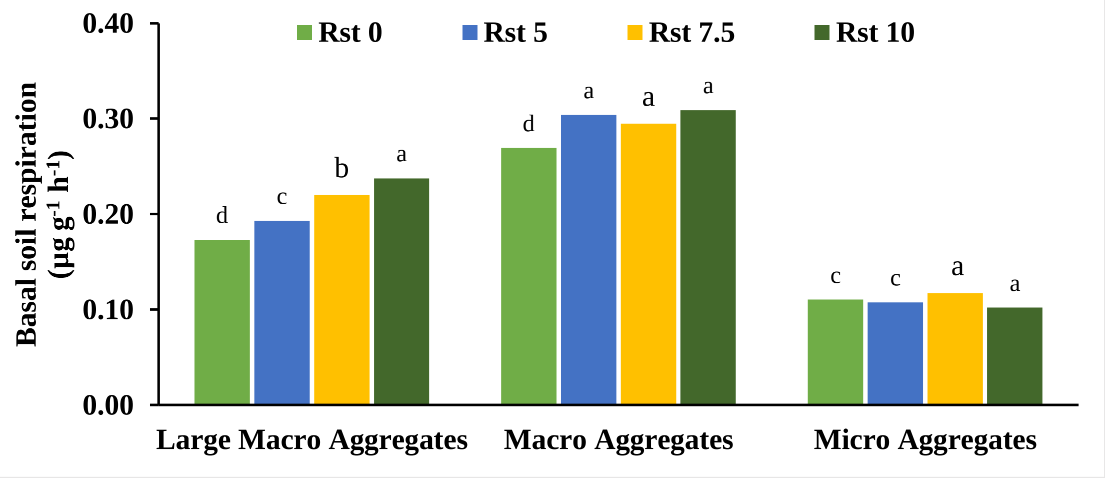

Fig 4.27 Effect of rice straw incorporation on basal soil respiration ($\mu g\ g^{-1}\ h^{-1}$) within soil aggregate fraction. Bars with the same letter, within the same aggregate size, are statistically at par.

4.4.6 Total organic carbon

Incorporation of rice straw has significantly increased the total organic carbon (TOC) content of different soil aggregates fractions. TOC was significantly higher in macro-aggregates fractions followed by large macro and micro-aggregates (Fig 4.28). Highest concentration of TOC was found in $R_{st}10$ in all three aggregates fractions which was 8.92 g Kg^{-1} in large macro-aggregates, 10.08 in micro aggregates and 1.48 g Kg^{-1} in micro-aggregates. Benbi and Senapati (2010) also reported higher carbon content in macro-aggregates fraction as compared to micro-aggregates. It may be due to lower decomposable soil organic matter associated with these aggregates and also the direct contribution of soil organic matter to the stability of macro-aggregates (Puget *et al* 1995). The increase in TOC with rice straw incorporation due to significant increase in carbon inputs is also supported by studies of Purakayastha *et al* (2008), Gong *et al* (2009), Buyanovsky *et al* (1994), Cambardella and Elliot (1993) and Mikha and Rice (2004).

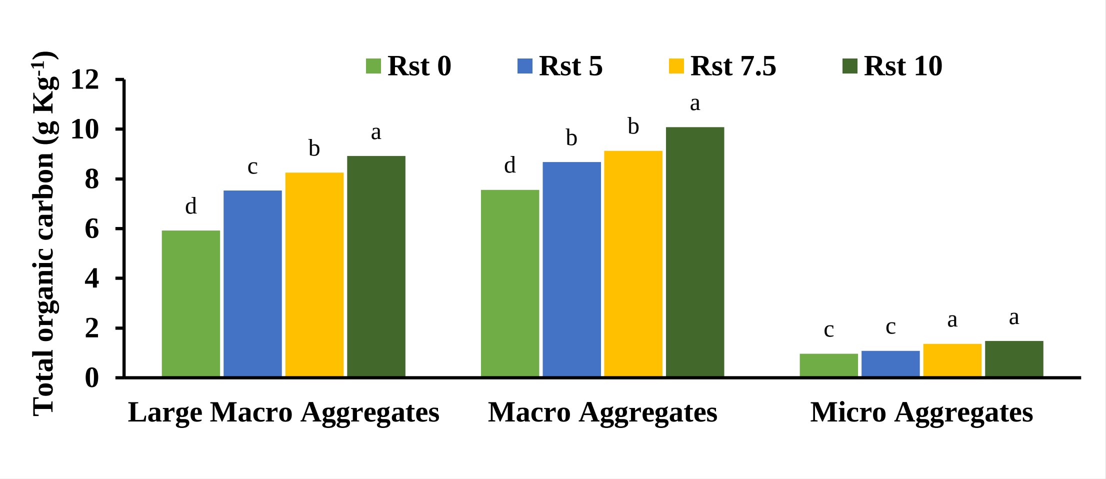

Fig 4.28 Effect of rice straw incorporation on total organic carbon (g Kg^{-1}) within soil aggregate fraction. Bars with the same letter, within the same aggregate size, are statistically at par ($p<0.05$).

4.4.7 Aggregate associated carbon pools

Incorporation of rice straw has significantly increased the concentration of different carbon pools within soil aggregates fractions as compared to no straw incorporated treatment (Fig 4.29). Carbon fractions within the macro-aggregates were in the order $R_{st}10 > R_{st}7.5 > R_{st}5 > R_{st}0$. Within macro-aggregates contribution of different carbon pools varied. For instance, very labile, labile less labile and recalcitrant fractions were 37-40, 25-27, 17-18 and 15-17%, respectively. Labile carbon fraction was least (2.86 g Kg^{-1}) in $R_{st}0$ and significantly increased with rate of incorporation. In $R_{st}10$ it was 3.83 g Kg^{-1}. All these carbon pools increased with increasing rate of rice straw incorporation. Similar trends were observed in large and micro-aggregates, however range of different carbon fractions varied. In general, very labile fraction was dominated in all three aggregates fractions. The higher concentration of carbon pools in macro and large macro-aggregates may be because of well protected soil organic matter in micro-aggregates bound together by organic binding agents within the macro-aggregates (Six *et al* 2004, Bhattacharyya *et al* 2011, Chivenge *et al* 2011, Hurisso *et al* 2013).

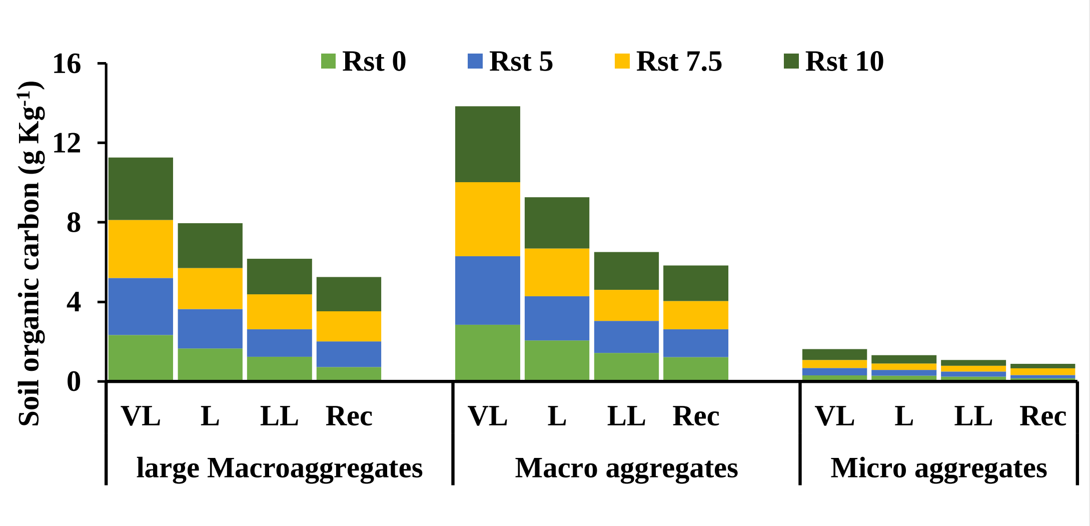

Fig 4.29 Effect of rice straw incorporation on carbon pools (g Kg^{-1}) within soil aggregate fraction. Bars with the same letter, within the same aggregate size, are statistically at par.

4.4.8 Water soluble organic carbon

The water soluble organic carbon (WSC) is the rapidly decomposing form of organic matter and it respond quickly to changes in carbon supply. The present study revealed that WSC was significantly affected by rice straw incorporation and aggregate size of the soil (Fig 4.30). WSC was significantly higher in macro-aggregates fractions followed by large macro-aggregates and micro-aggregates. The effect of rice straw incorporation on WSC in large

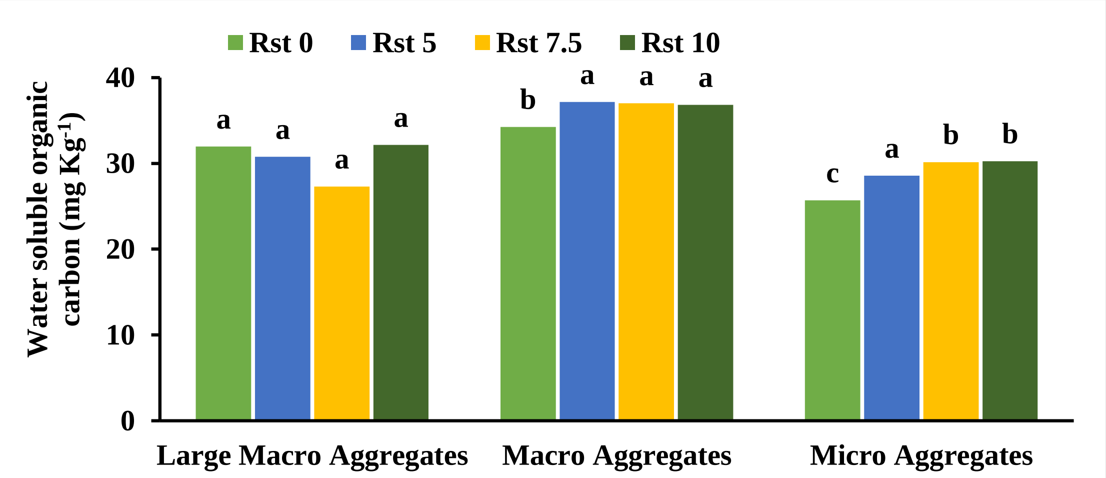

Fig 4.30 Effect of rice straw incorporation on water soluble organic carbon (mg Kg^{-1}) within soil aggregate fraction. Bars with the same letter, within the same aggregate size, are statistically at par.

macro-aggregates was non-significant. Similarly, WSC increased with increasing rate of rice straw incorporation in micro-aggregates, but the magnitude of increases was lower than macro or large macro-aggregates. Irrespective of soil aggregates fractions, WSC was found to be higher in $R_{st}10$ followed by $R_{st}7.5$, $R_{st}5$ and least in $R_{st}0$. In the literature evidences of increased WSC are also documented under Zero-till crop residue retained treatments as compared to conventional tilled treatment in sorghum monocropping system (Roldan *et al* 2005) and in rice-maize-cowpea cropping system (Neogi *et al* 2014) under no-till compared with conventional till.

4.4.9 Carbon management index

The carbon management index (CMI) which indicates the capacity of management system to promote soil quality was significantly affected by rice straw incorporation (Fig 4.31). Irrespective of aggregates fractions CMI were significantly increased in rice straw incorporated treatments and it was maximum in $R_{st}10$ followed by $R_{st}7.5$ and $R_{st}5$.

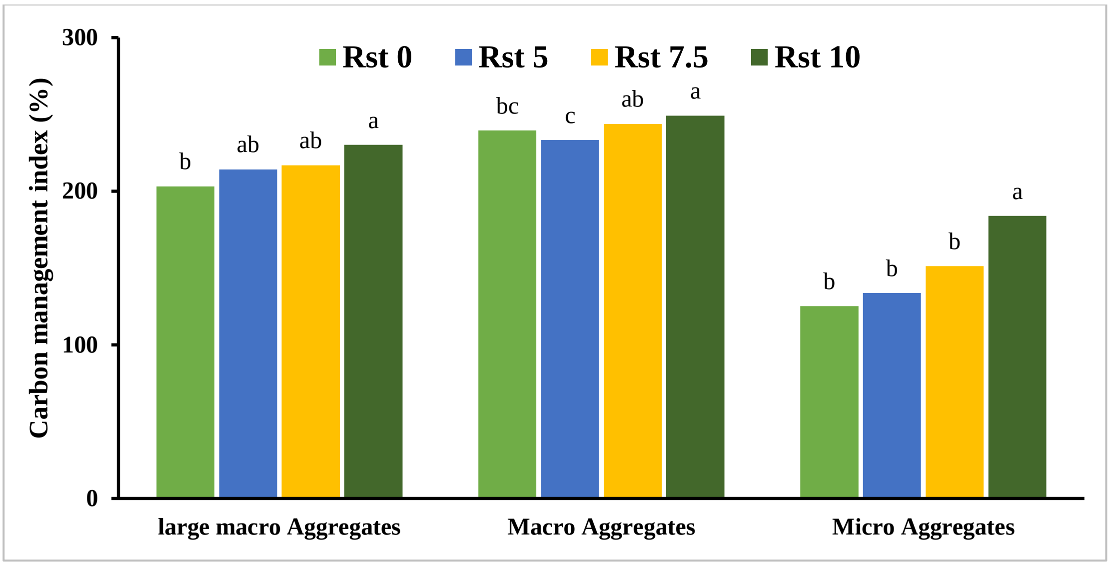

Fig 4.31 Effect of rice straw incorporation on carbon management index (%) within soil aggregate fraction. Bars with the same letter, within the same aggregate size, are statistically at par.

Among the different aggregates fractions, CMI were significantly higher in macro-aggregates followed by large macro-aggregates and least in micro-aggregates. It ranged from 203.1 to 230.06, 239.45 to 249.01, 125.26 to 183.88 in large macro, macro and micro-aggregates fraction of soil in treatments $R_{st}0$ and $R_{st}10$. It was least in $R_{st}0$. Higher CMI may be due to the increase in annual carbon input and its stabilization in macro and large-macro-aggregates (Tirol-Padre and Ladha 2004).

4.5 Effect of rice straw incorporation and nitrogen fertilization on yield of rice and wheat.

The grain yield of rice and wheat has affected significantly by rice straw incorporation and nitrogen fertilization (Table 4.16). The grain yield of wheat was about 1.65, 1.92 and 2.0 fold higher in N_{90}, N_{120} and N_{150} than N_0. It was statistically at Par in N_{120} and N_{150} treatments but higher than N_{90} and N_0. Incorporation of rice straw has also increased the grain yield of wheat. It was 10, 6.6, and 4.9% higher in $R_{st}10$, $R_{st}7.5$ and $R_{st}5$ than $R_{st}0$. However it was statistically at par in all three straw incorporated treatments. The grain yield of rice was 1.9, 1.07, 1.03 fold higher in N_{90}, N_{120} and N_{150} than N_0 and was statistically at par in N_{120} and N_{150} treatments. Similarly, it was increased by 13, 12.7 and 8.10% in $R_{st}10$, $R_{st}7.5$ and $R_{st}5$ as compared to $R_{st}0$ and was statistically at par in $R_{st}7.5$ and $R_{st}10$.

Table 4.16 Effect of rice straw incorporation and nitrogen fertilization on grain yield (t ha^{-1}) of rice and wheat.

Treatments	Grain yield of Wheat	Grain yield of Rice
N_0	2.9^c	3.2^c
N_{90}	4.88^b	5.74^b
N_{120}	5.57^a	5.96^{ab}
N_{150}	5.80^a	6.18^a
LSD (p=0.05)	0.40	0.24
$R_{st}0$	4.24^b	5.33^c
$R_{st}5$	4.46^{ab}	5.80^b
$R_{st}7.5$	4.54^a	6.11^a
$R_{st}10$	4.72^a	6.13^a
LSD (p=0.05)	0.28	0.30

Similar results have been reported by number of studies. Shafi *et al* (2007) in Pakistan reported that, incorporation of crop residue resulted in increase in grain yield of maize by 23.7% as compared to residue removal treatments. Kouyate *et al* (2000) reported about 37% increase in grain yield of cereals with crop residue incorporation as compared to without incorporation and application of nitrogen fertilizers to maize increased the grain yield by about 113% compared to control treatment. Sarkar and Kar (2011) in Eastern India reported that, grain yield of rice and wheat significantly improved with application of rice straw and wheat straw either separately or in combination as compared to without crop residue treatment. Similarly, Marinaccio *et al* (2015) reported higher grain yield under 130 and 190 Kg N ha^{-1}. This was mainly attributed to improvement in SOC levels, and development of soil structural as well as hydraulic properties. Consequently there was reduction in nutrient losses and improvement in soil microbial entities, altogether which helps in boosting the grain yield.

Correlation among soil physico-chemical properties and grain yield of rice and wheat

The data relating to correlation studies is depicted in the (Table 4.17). The correlation study revealed that, the grain yield of both wheat and rice were significantly (-0.719*, -0.723*) and negatively correlated with PR, as well as significantly (0.811*, 0.819*) and positively correlated with total water stable aggregates. The SOC was found to be highly positively correlated with BD (0.863**), FC (0.965**), PWP (0.958**), Avail P (0.949**), available Mn (0.930**) and Zn (0.855**). The total porosity and ks were significantly positively correlated with PR (0.726*, 0.968**).

4.6 Principle component analysis

The principal component analysis (PCA) was carried out for studying the degree of correlation among soil physico-chemical properties, grain yield of rice and wheat and different rice straw and nitrogen fertilized treatments. PCA was performed to describe the most variable parameter(s) based on factor loadings from each principal component (PC). The PCA is presented and explained as under.

4.6.1 PCA for soil physico-chemical properties

Analysis of principal components (PC) of the assessed variables showed that first and second principle component explain nearly 75% of the total variance (Fig 4.32). Factor loading up to 3 principle components showed the increased cumulative variability up to 97%, indicating that eigenvalues of 1.6 or more explained the maximum variability in the data.

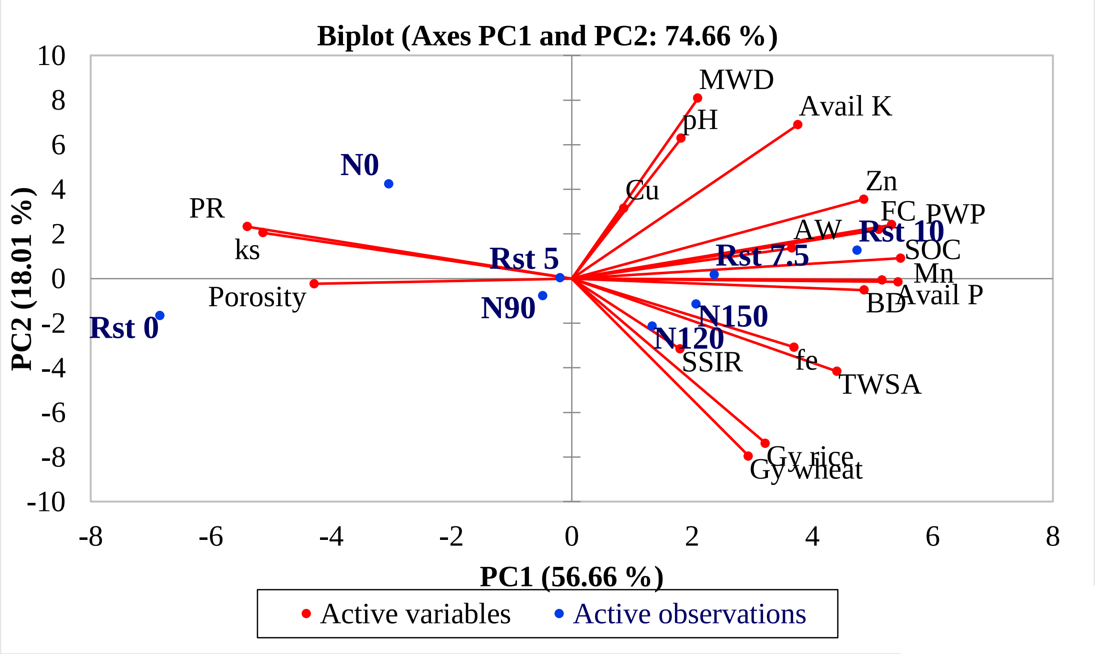

Fig 4.32 Principle component analysis of soil physico-chemical properties.

SOC-Soil organic carbon, BD-Bulk density, PR-Soil penetration resistance, FC-Field capacity, PWP-Permanent wilting point, TWSA-Total water stable aggregates, MWD-Mean weight diameter, SSIR-Steady state infiltration rate, ks-Saturated hydraulic conductivity, Avail K-Available potassium, Avail P- Available phosphorus, AW-Available water, Gy rice- Grain yield of rice, GY wheat- Grain yield of wheat.

Table 4.17 Correlation among soil physico-chemical properties and grain yield of rice and wheat.

	Gy W	Gy R	pH	SOC	BD	Porosity	SPR	FC	PWP	AW	TWSA	MWD	SSIR	Ks	Avail P	Avail K	Fe	Mn	Zn	Cu
Gy W	1																			
Gy R	.857**	1																		
pH	-.325	-.191	1																	
SOC	**.456**	**.526**	.354	1																
BD	.374	.425	-.031	.863**	1															
Porosity	-.312	-.321	.163	-.748*	-968**	1														
PR	**-.719***	**-723***	-.132	-932**	-.823*	.726*	1													
FC	.260	.364	.392	.965**	.860**	-.754*	-.812*	1												
PWP	.291	.362	.423	.958**	.858**	-.729*	-847**	.944**	1											
AW	.140	.284	.290	.765*	.661	-.608	-.576	.867**	.654	1										
TWSA	**.811***	**.819***	.187	.718*	.517	-.376	-868**	.531	.642	.249	1									
MWD	-.384	-.368	.727*	.374	.230	-.172	-.202	.387	.549	.074	.096	1								
SSIR	.422	.554	.400	.362	.000	.204	-.338	.325	.275	.345	.571	-.192	1							
Ks	**-.691**	**-.672**	-.145	-866**	-.763*	.706	.968**	-.719*	-.772*	-.477	-.850**	-.265	-.200	1						
Avail P	.471	.548	.272	.949**	.822*	-.665	-870**	.933**	.934**	.725*	.688	.266	.477	-.734*	1					
Avail K	-.240	-.125	.648	.718*	.645	-.548	-.459	.811*	.848**	.587	.230	.760*	.096	-.401	.678	1				
Fe	.651	.540	-.270	.549	.676	-.700	-.759*	.372	.512	.061	.658	.159	-.223	-837**	.434	.135	1			
Mn	.561	.583	.341	.930**	.789*	-.674	-955**	.815*	.912**	.490	.864**	.448	.311	-943**	.850**	.621	.727*	1		
Zn	.204	.257	.662	.855**	.637	-.535	-.768*	.794*	.879**	.503	.649	.736*	.214	-.799*	.713*	.791*	.505	.900**	1	
Cu	-.086	-.233	-.152	.067	.295	-.398	-.148	-.009	.190	-.318	-.017	.538	-.787*	-.287	-.064	.190	.643	.250	.289	1

******Correlation is significant at the 0.01 level (2-tailed)

*Correlation is significant at the 0.05 level (2-tailed)

Gy W-Grain yield wheat, Gy R-Grain yield of rice, SOC-Soil organic carbon, BD-Bulk density, PR-Soil penetration resistance, FC-Field capacity, PWP-Permanent wilting point, AW-Available water, TWSA-Total water stable aggregates, MWD-Mean weight diameter, SSIR-Steady state infiltration rate, ks-Saturated hydraulic conductivity, Avail P-Available phosphorus, Avail K-Available Potassium.

The PC 1 explained about 56.65% of the variability with eigen vector value of 11.33 and the variables with highest factor loading values and percent contribution were PR, Available Mn, SOC and PWP (Table 4.18). The PC2, explained about 18% of the variability with eigen vector value of 3.60 and the variables with highest factor loading values and percent contribution were pH, PWP and Avail K. Similarly, the PC3 explained about 14.34% variability with eigen vector values of 2.87 and the variables with highest factor loading values and percent contribution were SSIR, Available Cu and Fe.

All the assessed variables except PR, ks and total porosity of soil, showed positive correlation with PC1. In addition, the assessed variable viz. PWP, pH, available copper, Zn, Mn, K, SOC, FC, PWP, available water showed positive correlation with PC2. The analysis of PCA also showed that the variables, PR, ks and total porosity were negatively correlated to all other variables. The principal component analysis has clearly segregated the treatments and variables in the factorial space. The assayed variables are closely ordinated with the data points representing the high correlation among the various soil properties in the orthogonal space, which depicts that variables were highly influenced by R_{st}7.5 and R_{st}10 treatments as compared to R_{st}5 and R_{st}0 as well as all nitrogen fertilized treatments. The closeness in the distribution lines for FC, PWP, available water, SOC and R_{st}7.5 and R_{st}10 indicates the positive correlation among them and the significance of high rates of rice straw incorporation (R_{st}7.5 and R_{st}10) in improving soil physical health under rice-wheat cropping system in coarse texture semi-arid conditions. The principal component analysis revealed that rice straw incorporated treatments i.e. R_{st}7.5 and R_{st}10 showed a strong association with the PWP, pH, Avail K, FC, PWP, Available water, SOC and available Cu, Zn and Mn.

4.6.2 Principle component analysis for biochemical properties within soil aggregates

The principal component analysis (PCA) was carried out for studying the degree of correlation among soil aggregate indices (MWD and TWSA) and soil biochemical properties within each aggregate fraction under different rates of rice straw incorporation and nitrogen fertilization. PCA was performed on three soil aggregates sizes (large macro, macro and micro-aggregates) to describe the most important parameter(s) based on factor loadings from each principal component (PC). The PCA is presented and explained as under.

4.6.2.1 PCA for Large macro-aggregates fraction of soil.

Analysis of principal components (PC) of the assessed variables showed that first and second principle component explain nearly 78% of the total variance. Factor loading up to 3 principle components showed the increased cumulative variability up to 90%, indicating that eigen values of 1.6 or more explained the maximum variability in the data (Table 4.19).

Table 4.18 Loading values and percent contribution of assayed physico-chemical variables on axis identified by the principle component analysis.

Soil variables	**PC1**		**PC2**		**PC3**	
	Loading values	**Contribution of variables (%)**	**Loading values**	**Contribution of variables (%)**	**Loading values**	**Contribution of variables (%)**
Gy wheat	0.527	2.449	-0.804	17.956	0.042	0.062
Gy rice	0.578	2.945	-0.746	15.444	-0.138	0.663
pH	0.327	0.941	**0.636**	11.219	-0.544	10.326
SOC	**0.980**	8.482	0.092	0.234	-0.143	0.713
BD	0.872	6.709	-0.052	0.075	0.249	2.157
Porosity	-0.766	5.172	-0.024	0.016	-0.414	5.964
PR	**-0.966**	8.229	0.235	1.533	-0.049	0.083
FC	0.916	7.406	0.222	1.366	-0.184	1.178
PWP	**0.954**	8.024	**0.243**	1.644	-0.037	0.047
AW	0.656	3.803	0.137	0.524	-0.370	4.770
TWSA	0.791	5.524	-0.420	4.905	-0.099	0.341
MWD	0.376	1.248	0.817	18.518	0.155	0.836
SSIR	0.323	0.922	-0.319	2.829	**-0.856**	25.567
Ks	-0.919	7.447	0.207	1.193	-0.195	1.322
Avail P	0.925	7.553	-0.006	0.001	-0.219	1.668
Avail K	0.674	4.009	**0.697**	13.480	-0.111	0.433
Fe	0.663	3.877	-0.311	2.690	**0.659**	15.158
Mn	**0.973**	8.356	-0.015	0.007	0.062	0.133
Zn	0.871	6.689	0.359	3.571	-0.003	0.000
Cu	0.156	0.215	0.317	2.796	**0.905**	28.580
Eigen value		11.331		3.601		2.869
Variability (%)		56.657		18.005		14.343
Cumulative variance (%)		56.657		74.662		89.004

SOC-Soil organic carbon, BD-Bulk density, PR-Soil penetration resistance, FC-Field capacity, PWP-Permanent wilting point, TWSA-Total water stable aggregates, MWD-Mean weight diameter, SSIR-Steady state infiltration rate, ks-Saturated hydraulic conductivity, Avail K-Available potassium, Avail P- Available phosphorus, AW-Available water, Gy rice- Grain yield of rice, GY wheat- Grain yield of wheat.

Table 4.19 Loading values and percent contribution of assayed biological variables of large macro-aggregate (>2.0 mm) fraction towards the soil aggregation on axis identified by the principle component analysis.

Soil variables	PC1		PC2		PC3	
	Loading values	**Contribution of variables (%)**	**Loading values**	**Contribution of variables (%)**	**Loading values**	**Contribution of variables (%)**
TWSA	0.617	5.015	0.738	21.693	-0.111	0.763
MWD	0.668	5.871	-0.241	2.314	0.116	0.828
Alk P	-0.258	0.872	-0.031	0.039	**0.908**	51.058
DHA	0.751	7.422	**0.597**	14.204	-0.104	0.664
FDA	0.701	6.468	**0.574**	13.114	**-0.401**	9.955
MBC	0.813	8.689	0.455	8.222	0.356	7.866
BSR	0.791	8.227	0.201	1.615	**0.488**	14.761
TOC	**0.941**	11.656	-0.304	3.674	-0.015	0.014
WSC	-0.435	2.491	**0.710**	20.058	0.305	5.766
CFvl	0.855	9.610	-0.384	5.859	0.133	1.096
CFl	**0.906**	10.805	-0.319	4.056	0.255	4.039
CFll	**0.904**	10.746	-0.278	3.076	-0.192	2.283
CFrec	**0.960**	12.126	-0.228	2.077	-0.121	0.907
Eigen value		7.603		2.513		1.616
Variability (%)		58.481		19.329		12.428
Cumulative variance (%)		58.481		77.810		90.238

TWSA-Total water stable aggregates, MWD-Mean weight diameter, Alk P- Alkaline phosphatase, DHA-Dehydrogenase, FDA-fluorescein diacetate, MBC-Microbial biomass carbon, BSR-Basal soil respiration, TOC-Total organic carbon, WSC-Water soluble organic carbon, CFvl- Very labile carbon fraction, CFl- Labile carbon fraction, CFll- Less labile carbon fraction, CFrec-Recalcitrant carbon fraction.

The PC 1 explained about 59% of the variability with eigen vector value of 7.60 and the variables with highest factor loading values and percent contribution were recalcitrant carbon fraction, TOC and labile carbon fraction. The PC2, explained about 19% of the variability with eigen vector value of 2.51 and the variables with highest factor loading values and percent contribution were WSC, DHA and fluorescein diacetate enzymes. Similarly, PC3, the explained about 12.4% variability with eigen vector values of 1.6 and the variables with highest factor loading values and percent contribution were Alk P, BSR and FDA. The principal component analysis has clearly segregated the treatments and variables in the factorial space (Fig 4.33). The assayed variables are closely ordinated with the data points representing the high correlation among the various soil properties in the orthogonal space, which depicts that total water stable aggregates were highly influenced by $R_{st}10$ and N_{150} treatments and the main factors identified for stability of large macro-aggregates are recalcitrant C fraction, TOC and labile carbon fraction.

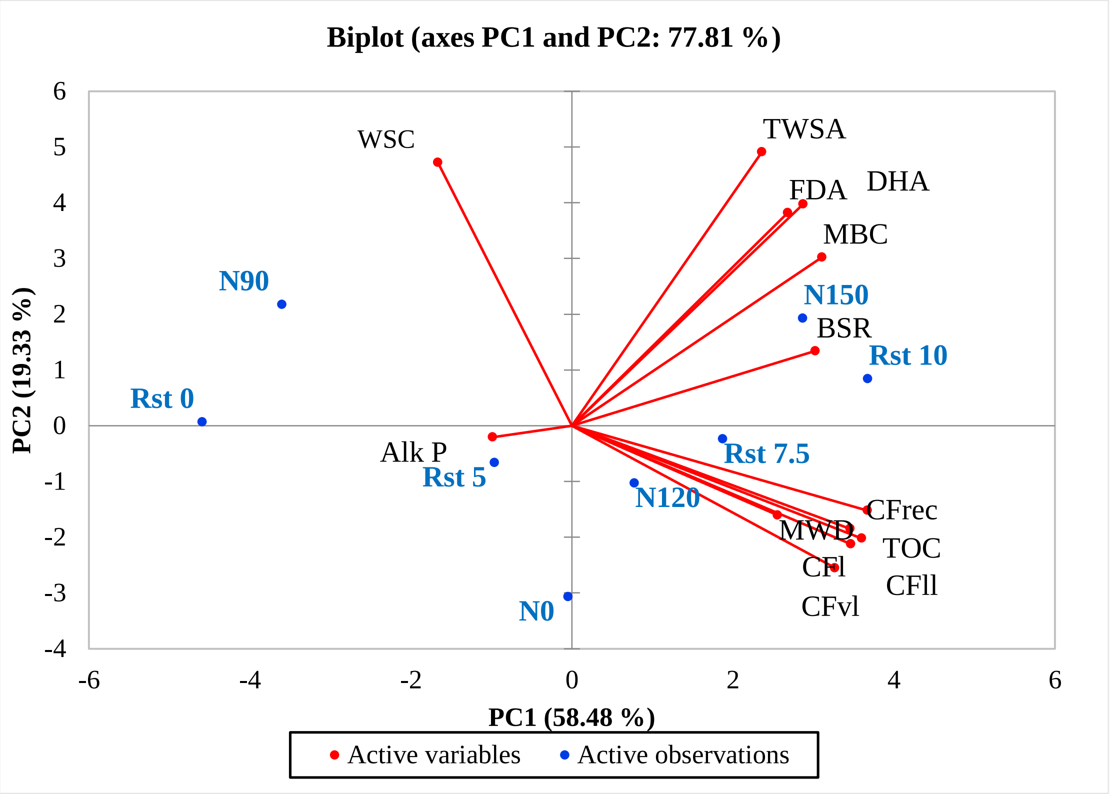

Fig 4.33 Principle component analysis of large macro-aggregates soil fraction.

TWSA-Total water stable aggregates, MWD-Mean weight diameter, Alk P- Alkaline phosphatase, DHA-Dehydrogenase, FDA-fluorescein diacetate, MBC-Microbial biomass carbon, BSR-Basal soil respiration, TOC-Total organic carbon, WSC-Water soluble organic carbon, CFvl- Very labile carbon fraction, CFl- Labile carbon fraction, CFll- Less labile carbon fraction, CFrec-Recalcitrant carbon fraction.

4.6.2.2 PCA for macro-aggregates fraction of soil.

The analysis of principal components (PC) of the assessed variables showed that first and second principle component explain nearly 79% of the total variance. Factor loading up to 3 principle components showed the increased cumulative variability up to 93%, indicating that eigenvalues of 1.78 or more explained the maximum variability in the data (Table 4.20). The PC 1 explained about 48.68% of the variability with eigen vector value of 6.32 and the variables with highest factor loading values and percent contribution were MBC, TOC and very labile carbon fraction. The PC2 explained about 30.7% of the variability with eigen vector value of 3.99 and the variables with highest factor loading values and percent contribution were DHA, FDA and Alk P. Similarly, PC3 explained about 13.7% variability with eigen vector values of 1.7 and the variables with highest factor loading values and percent contribution were labile and less labile carbon fractions. The principal component analysis has clearly segregated the treatments and variables in the factorial space (Fig 4.34). The assayed variables are closely ordinated with the data points representing the high correlation among the various soil properties in the orthogonal space, which depicts that total water stable aggregates were highly influenced by R_{st}7.5 and N_{150} followed by R_{st}10 treatments and the main factors identified for stability of large macro-aggregates are MBC, TOC and very labile C fraction.

Table 4.20 Loading values and percent contribution of assayed biochemical variables of macro-aggregate (2-0.25 mm) fraction towards the soil aggregation on axis identified by the principle component analysis.

Soil variables	**PC1**		**PC2**		**PC3**	
	Loading values	**Contribution of variables (%)**	**Loading values**	**Contribution of variables (%)**	**Loading values**	**Contribution of variables (%)**
TWSA	0.539	4.597	**0.824**	17.003	-0.089	0.440
MWD	0.719	8.178	-0.421	4.432	**-0.532**	15.829
Alk P	0.337	1.798	**0.881**	19.439	-0.284	4.533
DHA	0.481	3.662	0.739	13.692	0.381	8.151
FDA	0.416	2.734	**0.846**	17.934	-0.263	3.867
MBC	**0.927**	13.570	0.361	3.263	-0.027	0.040
BSR	0.695	7.622	-0.476	5.682	-0.325	5.919
TOC	**0.903**	12.898	-0.371	3.443	0.181	1.838
WSC	0.803	10.201	0.047	0.055	0.201	2.269
CFvl	**0.827**	10.814	-0.152	0.582	0.526	15.502
CFl	0.723	8.254	-0.196	0.966	**0.617**	21.311
CFll	0.748	8.847	-0.151	0.573	**-0.595**	19.856
CFrec	0.657	6.824	-0.718	12.935	-0.089	0.445
Eigen value		6.328		3.990		1.786
Variability (%)		48.678		30.694		13.735
Cumulative variance (%)		48.678		79.372		93.107

TWSA-Total water stable aggregates, MWD-Mean weight diameter, Alk P- Alkaline phosphatase, DHA-Dehydrogenase, FDA-fluorescein diacetate, MBC-Microbial biomass carbon, BSR-Basal soil respiration, TOC-Total organic carbon, WSC-Water soluble organic carbon, CFvl-Very labile carbon fraction, CFl- Labile carbon fraction, CFll- Less labile carbon fraction, CFrec-Recalcitrant carbon fraction.

4.6.2.3 PCA for micro-aggregates fraction of soil

The analysis of principal components (PC) of the assessed variables showed that first and second principle component explain nearly 75% of the total variance. Factor loading up to 4 principle components showed the increased cumulative variability up to 97.7%, indicating that eigenvalues of 1.04 or more explained the maximum variability in the data (Table 4.21).

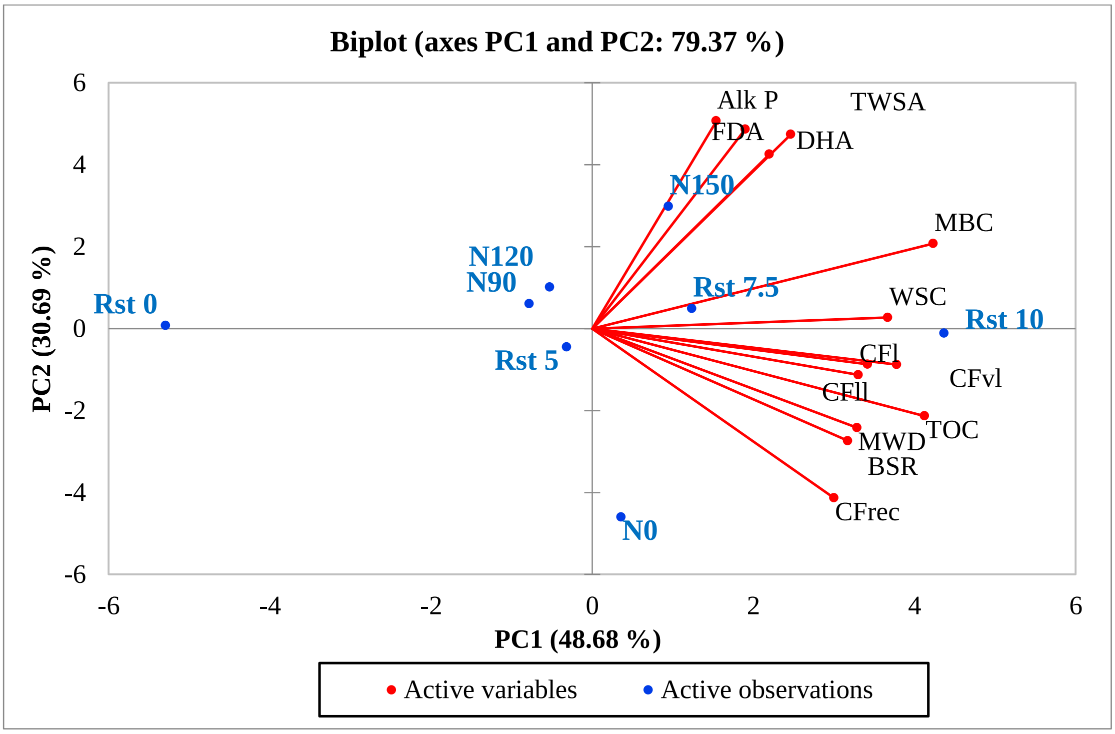

Fig 4.34 Principle component analysis of macro-aggregates soil fraction

TWSA-Total water stable aggregates, MWD-Mean weight diameter, Alk P- Alkaline phosphatase, DHA-Dehydrogenase, FDA-fluorescein diacetate, MBC-Microbial biomass carbon, BSR-Basal soil respiration, TOC-Total organic carbon, WSC-Water soluble organic carbon, CFvl-Very labile carbon fraction, CFl- Labile carbon fraction, CFll- Less labile carbon fraction, CFrec-Recalcitrant carbon fraction.

The PC 1 explained about 56.21% of the variability with eigen vector value of 7.30 and the variables with highest factor loading values and percent contribution were less labile carbon fraction, DHA and MBC. The PC2 explained about 18.36% of the variability with eigen vector value of 2.38 and the variables with highest factor loading values and percent contribution were BSR and WSC. Similarly, PC3 and PC4 explained about 15.14% and 8.06% variability with eigen vector values of 1.96 and 1.04 and the variables with highest factor loading values and percent contribution were labile, very labile carbon fractions and FDA under PC3 and recalcitrant carbon fraction and BSR under PC4.

Table 4.21 Loading values and percent contribution of assayed biochemical variables of micro-aggregate (<0.25 mm) fraction towards the soil aggregation on axis identified by the principle component analysis.

Soil variables	PC1		PC2		PC3		PC4	
	Loading values	Contribution of variables (%)	Loading values	Contribution of variables (%)	Loading values	Contribution of variables (%)	Loading values	Contribution of variables (%)
TWSA	0.945	12.229	-0.023	0.023	-0.308	4.807	0.047	0.212
MWD	0.158	0.340	0.970	39.412	0.114	0.655	-0.101	0.974
Alk P	0.866	10.251	-0.427	7.643	-0.217	2.385	-0.099	0.931
DHA	**0.936**	11.992	0.169	1.198	-0.008	0.004	-0.300	8.569
FDA	0.800	8.769	0.079	0.261	**-0.585**	17.362	-0.087	0.720
MBC	**0.908**	11.280	-0.063	0.168	-0.393	7.864	-0.004	0.001
BSR	0.162	0.360	**-0.854**	30.563	0.190	1.827	**0.398**	15.127
TOC	0.878	10.552	-0.042	0.075	0.455	10.515	0.098	0.924
WSC	0.675	6.233	**0.551**	12.695	0.342	5.923	0.217	4.484
CFvL	0.739	7.478	-0.253	2.690	**0.570**	16.488	-0.197	3.712
CFl	0.583	4.652	-0.130	0.709	**0.733**	27.253	-0.287	7.857
CFll	**0.952**	12.399	-0.025	0.025	-0.288	4.220	0.042	0.164
CFrec	0.503	3.465	0.329	4.538	0.117	0.697	**0.769**	56.324
Eigen value		7.308		2.388		1.969		1.049
Variability (%)		56.213		18.368		15.146		8.069
Cumulative variance (%)		56.213		74.581		89.728		97.797

TWSA-Total water stable aggregates, MWD-Mean weight diameter, Alk P- Alkaline phosphatase, DHA-Dehydrogenase, FDA-fluorescein diacetate, MBC-Microbial biomass carbon, BSR-Basal soil respiration, TOC-Total organic carbon, WSC-Water soluble organic carbon, CFvl- Very labile carbon fraction, CFl- Labile carbon fraction, CFll- Less labile carbon fraction, CFrec-Recalcitrant carbon fraction.

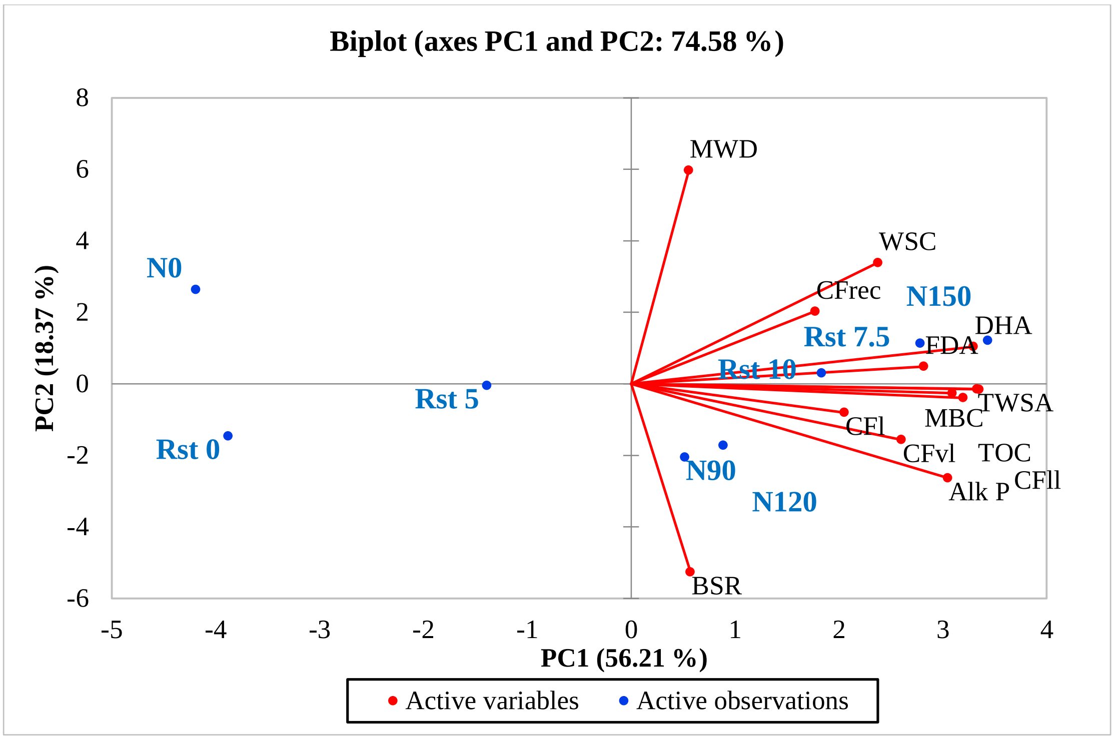

Fig 4.35 Principle component analysis for micro-aggregates fraction.

TWSA-Total water stable aggregates, MWD-Mean weight diameter, Alk P- Alkaline phosphatase, DHA-Dehydrogenase, FDA-fluorescein diacetate, MBC-Microbial biomass carbon, BSR-Basal soil respiration, TOC-Total organic carbon, WSC-Water soluble organic carbon, CFvl- Very labile carbon fraction, CFl- Labile carbon fraction, CFll- Less labile carbon fraction, CFrec-Recalcitrant carbon fraction.

The principal component analysis has clearly segregated the treatments and variables in the factorial space (Fig 4.35). The assayed variables are closely ordinated with the data points representing the highly correlation among the various soil properties in the orthogonal space, which depicts that total water stable aggregates were highly influenced by R_{st}7.5, R_{st}10 and N_{150} treatments and the main factors identified for stability of large macro-aggregates are less labile C fraction and DHA.

Correlation between soil physical and biochemical properties within soil aggregates

The correlation between soil physical properties (TWSA and MWD) and biochemical properties of three aggregates fraction is represented in (Table 4.22). In large macro-aggregates, the DHA activity was positively correlated with PWP (0.713*) and total water stable aggregates (0.949**). FDA was also positively correlated with total water stable aggregates (0.893**). In macro-aggregates fraction, the total water stable aggregates were positively correlated with Alk P, DHA and FDA (0.935**, 0.811*, 0.937**). In micro-aggregates fraction, the enzyme activities i.e. Alk P, DHA and FDA were highly correlated with total water stable aggregates (0.885**, 0.872**, 0.936**), MBC (0.907**, 0.839**, 0.945**), and less labile carbon fraction (0.882**, 0.905**, 0.926**) of soil.

Table 4.22 Correlation between soil physical properties (TWSA and MWD) and biochemical properties within soil aggregate fractions.

Biochemical properties ↓	Large Macro-aggregates (>2 mm)		Macro-aggregates (2-0.25 mm)		Micro-aggregates (<0.25mm)	
	TWSA	MWD	TWSA	MWD	TWSA	MWD
Alk P	.327	.173	.935**	.001	.885**	-.296
DHA	.389	-.831*	.811*	-.182	.872**	.342
FDA	.301	-.800*	.937**	.108	.936**	.151
MBC	.413	-.811*	.805*	.535	.969**	.025
BSR	.320	-.611	.027	.818*	.139	-.806*
TOC	-.417	-.711*	.160	.719*	.690	.130
WSC	.688	.179	.459	.421	.538	.672
CFvl	-.445	-.680	.285	.377	.508	-.058
CFl	-.312	-.621	.169	.301	.320	.083
CFll	-.460	-.666	.306	.934**	.996**	.122
CFrec	-.375	-.742*	-.239	.824*	.456	.317

**Correlation is significant at the 0.01 level (2-tailed)
*Correlation is significant at the 0.05 level (2-tailed)
TWSA-Total water stable aggregates, MWD-Mean weight diameter, Alk P- Alkaline phosphatase, DHA-Dehydrogenase, FDA-fluorescein diacetate, MBC-Microbial biomass carbon, BSR-Basal soil respiration, TOC-Total organic carbon, WSC-Water soluble organic carbon, CFvl- Very labile carbon fraction, CFl- Labile carbon fraction, CFll- Less labile carbon fraction, CFrec-Recalcitrant carbon fraction.

Variable importance for yield prediction

We conducted a classification and regression random forest analysis to identify the most important variables for predicting the yield of rice and wheat by evaluating the decrease in prediction accuracy (i.e. increase in the mean square error). The algorithm estimate importance of variable by looking at how much prediction error increases when data for that variable is permuted while others are left unchanged. In the present study, the random forest algorithm predicted SOC and PR to be the most important variables for yield prediction of rice and SOC and Avail K for wheat (Fig 4.36).

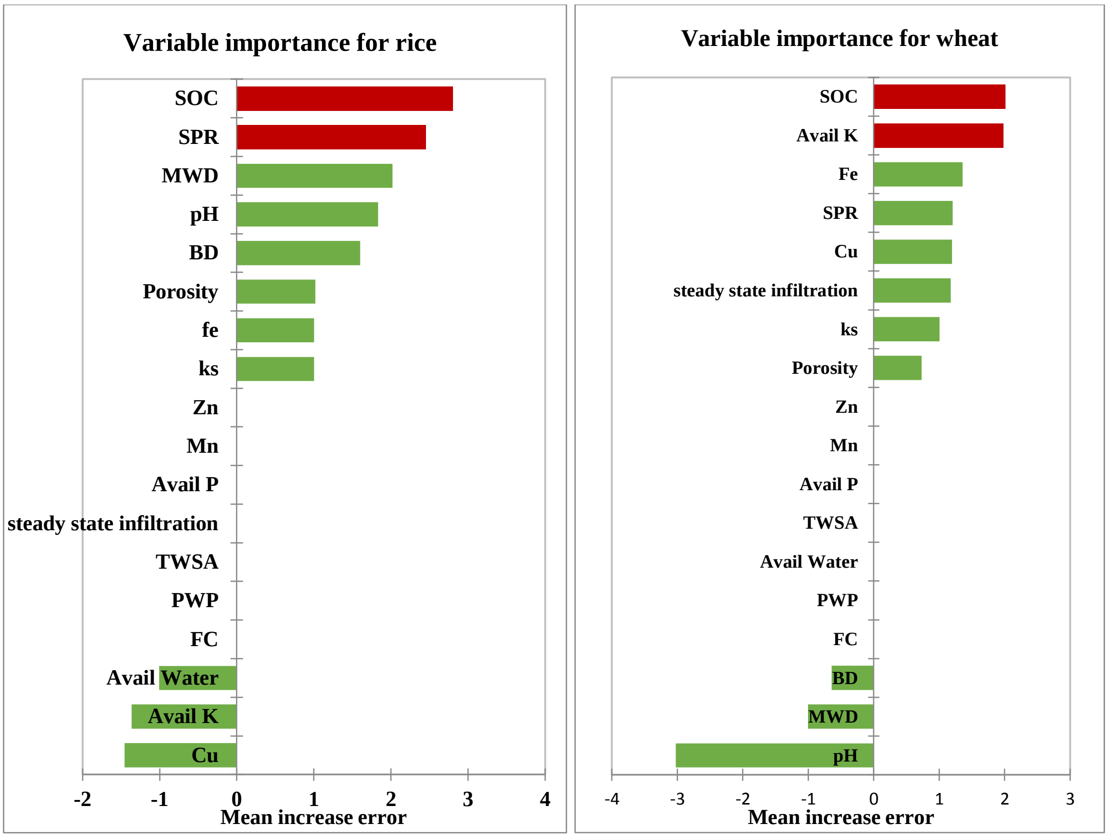

Fig 4.36 Relative importance of soil variables for predicting yield.

4.7 Simulation study

4.7.1 Model evaluation

The already calibrated and validated DSSAT model by Vashisht *et al* (2019) was used for evaluating the effects of rice straw incorporation on grain yield of wheat, water and nitrogen balance components during the past and present (1988-2018) as well as future time scenario (2021-2050). The simulation study was carried out on a changed soil properties with incorporation of rice straw @ 0, 5, 7.5 and 10 tonnes ha^{-1} under six time scenarios (Table 4.25).

Table 4.23 Description of time scenario and changed soil properties used in simulation study.

Time Scenario (Wheat growth season)	
TS I	1988-89 to 1997-98
TS II	1998-99 to 2007-08
TS III	2008-09 to 2017-18.
TS IV	2021-22 to 2029-30
TS V	2030-31 to 2039-40
TS VI	2040-41 to 2049-50
Changed soil properties with rice straw incorporation for 10 years	
Soil I	Incorporation of rice straw @ 0 t ha^{-1}
Soil II	Incorporation of rice straw @ 5 t ha^{-1}
Soil III	Incorporation of rice straw @ 7.5 t ha^{-1}
Soil IV	Incorporation of rice straw @ 10 t ha^{-1}

4.7.2 Grain yield of wheat

The grain yield of wheat under different time scenarios and changed soil properties with rice straw incorporation is depicted in (Table 4.27; 4.28). The simulation study revealed that, in the past and present, the grain yield of wheat increased by about 8, 10 and 18% in soil II, soil III and soil IV (Table 4.27) and in future it would increase by 17% in soil IV as compared to Soil I (Table 4.28). In the past and present time scenario (1988-2018) the grain yield of wheat varied from 4000 to 4800 Kg ha^{-1} in soils with changed properties (Soil I-Soil IV) following incorporation of rice straw for 10 years. As in future, climatic parameters i.e. precipitation, maximum, minimum and average temperature are likely to be increase (Table 4.26) which will affect the productivity of wheat. It is observed that in future (2020-21 to 2049-50) the wheat yield would decline by 10% as compared to past and present time scenario (Fig 4.37). To maintain present level of yield productivity or productivity potential of cultivars, incorporation of rice straw @ 10 t ha^{-1} would be helpful in mitigating the climate change.

Table 4.24 Past and future climate parameters under different time scenarios.

Past and present climate scenario (1988-2018)				
Time scenario (Wheat season)	**Ppt (mm)**	**Tmax (°C)**	**Tmin (°C)**	**Avg Temp (°C)**
1988-89 to 1997-98	303.6	24.9	11.2	17.6
1998-99 to 2007-08	269.1	25.5	11.7	18.2
2008-09 to 2017-18	190.8	24.6	11.0	17.3
Average	**254.5**	**25.0**	**11.3**	**17.7**
Future climate scenario (2021-2050)				
2021-22 to 2029-30	131.8	23.8	9.9	16.3
2030-31 to 2039-40	100	24.5	10.3	16.9
2040-41 to 2049-50	110.9	24.2	10.5	16.9
Average	**114.23**	**24.16**	**10.23**	**16.7**

Fig 4.37 Simulated grain yield (Kg ha^{-1}) under past and present (1988-2018) and future (2021-2050) climate change scenario within changed soils.

4.7.3 Water balance components

The simulated water balance components i.e. precipitation (Ppt), irrigation (I), evapo-transpiration (ET), transpiration (T) and evaporation (E) were affected by different soils in changing climates (Table 4.27; 4.28). In future the water balance components i.e. Ppt, E and T would increase as compared to past and present scenario (Fig 4.38). In the past and present time scenario, the T component increased by about 4% in soil IV and the E component decreased by about 34, 7 and 14% in soil II, III and IV as compared to soil I (Table 4.27). In future time scenario, the T component would increase by about 5% and E component would decrease by about 20% in soil IV, as compared to soil I (Table 4.28).

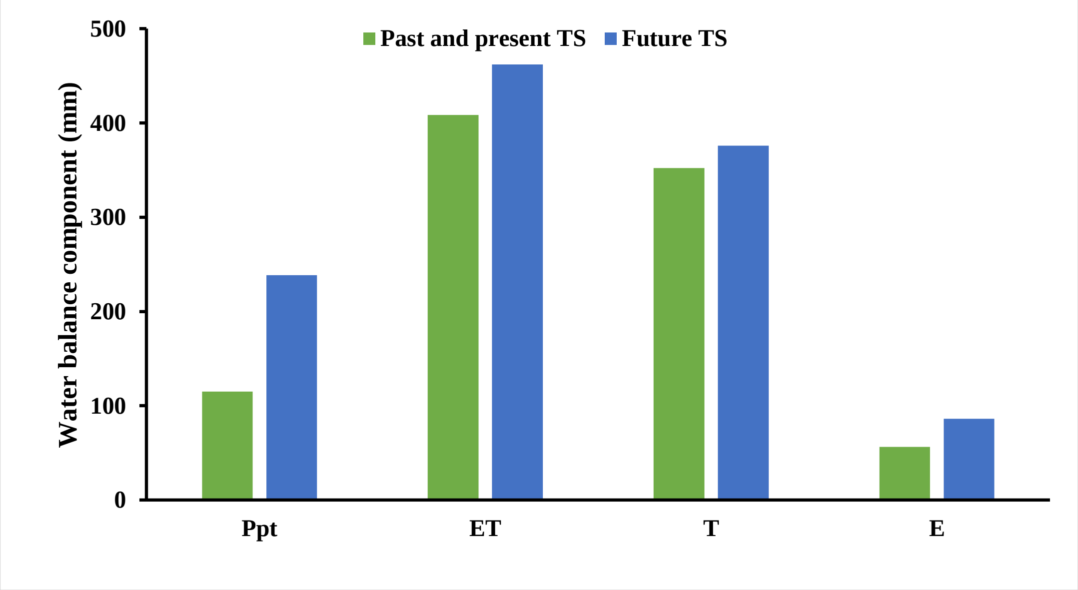

Fig 4.38 Simulated water balance components under past and present (1988-2018) and future (2021-2050) climate change scenario within changed soils.

Table 4.25 Simulated yield (Kg ha^{-1}) and water balance components (mm) as influenced by changed soil properties with rice straw incorporation in past and present time scenario (1988-2018).

Soil I (Without rice straw incorporation)							
TS	**Ppt**	**I**	**ET**	**T**	**E**	**WUE (Kg grain ha^{-1} mm^{-1})**	**Yield**
TS I	128.8	400	417.7	352.4	65.3	9.60	4011.6
TS II	100.0	400	407.6	343.6	63.9	9.66	3937.5
TS III	112.7	400	400.7	334.5	66.1	9.95	3990.3
Mean	**113.8**	**400**	**408.6**	**343.5**	**65.1**	**9.73**	**3979.8**
Soil II (Incorporation of rice straw @ 5 t ha^{-1})							
TS I	129.1	400	404.1	358.7	45.3	10.78	4357.3
TS II	97.4	400	396.7	354.1	42.6	10.84	4302.6
TS III	114.0	400	390.9	350.4	40.4	11.15	4358.1
Mean	**113.5**	**400**	**397.2**	**354.4**	**42.8**	**10.92**	**4339.3**
Soil III (Incorporation of rice straw @ 7.5 t ha^{-1})							
TS I	126.2	400	421.9	358.7	63.2	10.44	4408.0
TS II	97.2	400	416.9	355.5	61.5	10.38	4331.0
TS III	122.8	400	405.2	347.6	57.7	11.23	4554.1
Mean	**115.4**	**400**	**414.7**	**353.9**	**60.8**	**10.68**	**4431.0**
Soil IV (Incorporation of rice straw @ 10 t ha^{-1})							
TS I	118.6	400	425.8	369.4	56.4	11.66	4968.5
TS II	98.2	400	415.8	361.4	54.4	11.69	4862.7
TS III	136.7	400	399.5	341.7	57.9	12.07	4823.4
Mean	**117.8**	**400**	**413.7**	**357.5**	**56.2**	**11.80**	**4884.9**

Ppt-Precipitation, I-Irrigation, T-Transpiration, ET-Evapo-transpiration, WUE-Water use efficiency.
(TS- Time scenario, TS I-1988-1998, TS II-1998-2008, TS III-2008-2018)

Table 4.26 Simulated yield (Kg ha^{-1}) and water balance components (mm) as influenced by changed soil properties with rice straw incorporation in future time scenario (2021-2050).

TS	Ppt	I	ET	T	E	WUE (Kg grain ha^{-1} mm^{-1})	Yield
Soil I (Without rice straw incorporation)							
TS IV	283.4	400	454.8	363.5	91.3	7.80	3548.9
TS V	253.3	400	465.4	374.5	90.8	7.89	3673.0
TS VI	179.4	400	456.6	362.0	94.6	8.02	3661.8
Mean	**238.7**	**400**	**458.9**	**366.7**	**92.2**	**7.91**	**3627.9**
Soil II (Incorporation of rice straw @ 5 t ha^{-1})							
TS IV	283.4	400	457.4	372.1	85.3	8.35	3817.4
TS V	253.3	400	469.2	382.6	86.6	8.40	3941.7
TS VI	179.4	400	462.1	372.1	90.0	8.62	3981.1
Mean	**238.7**	**400**	**462.9**	**375.6**	**87.3**	**8.45**	**3913.4**
Soil III (Incorporation of rice straw @ 7.5 t ha^{-1})							
TS IV	283.4	400	457.4	372.5	84.9	8.50	3886.8
TS V	253.3	400	470.1	382.0	88.1	8.50	3993.4
TS VI	179.4	400	461.9	371.3	90.6	8.71	4021.1
Mean	**238.7**	**400**	**463.1**	**375.3**	**87.9**	**8.57**	**3967.1**
Soil IV (Incorporation of rice straw @ 10 t ha^{-1})							
TS IV	283.4	400	457.1	382.6	74.5	9.33	4264.3
TS V	252.7	400	468.6	390.9	77.7	9.31	4361.3
TS VI	178.9	400	462.9	383.3	79.7	9.70	4491.0
Mean	**238.3**	**400**	**462.9**	**385.6**	**77.3**	**9.45**	**4372.2**

Ppt-Precipitation, I-Irrigation, T-Transpiration, ET-Evapo-transpiration, WUE-Water use efficiency.
(TS- Time scenario, TS IV-2021-2030, TS V-2031-2040, TS VI-2041-2050)

4.7.3 Nitrogen balance components

Nitrogen balance components like mineralized N, uptake N, volatilized and leached N are influenced by changed soil properties with incorporation of rice straw as well as time scenario. In the past and present time scenario, compared to soil I, the mineralised N increased by about 4% in soil II and 6% in soil III and IV, the uptake of N increased by about 4, 6.4 and 7% in soil II, III and IV but the leaching of N decreased by about 5, 8 and 12% in soil II, III and IV (Table 4.29). In future time scenario, as compared to Soil I, mineralized N and plant uptake N would increase by 7 and 9% and leaching would decrease by 10% in Soil IV (Table 4.30). Averaged over soils, in future there would be an increase in leaching of nitrogen and reduction in uptake of N as compared to past and present climate scenario (Fig 4.39).

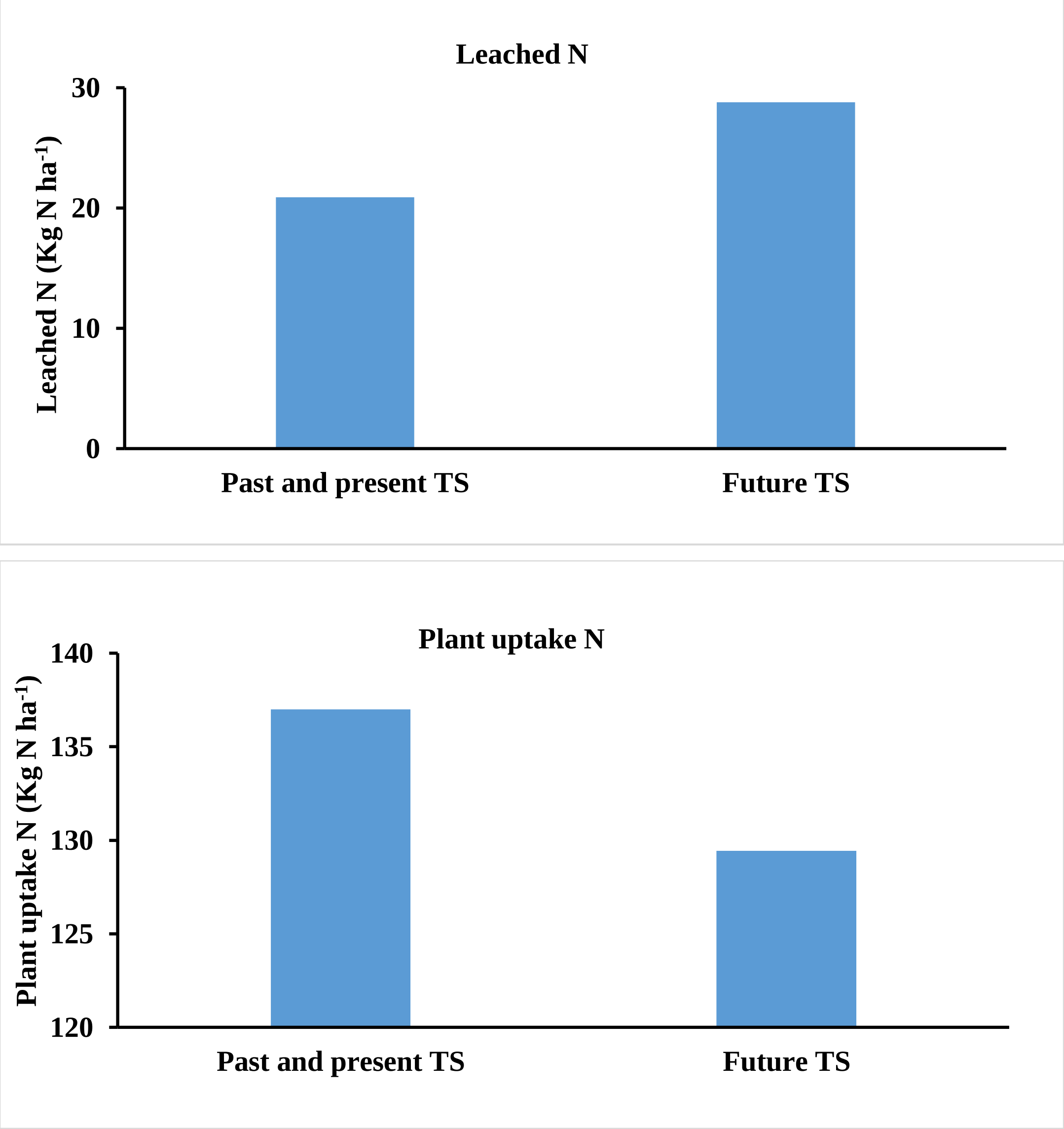

Fig. 4.39 Simulated nitrogen balance components (Kg N ha^{-1}) under past and present (1988-2018) and future (2021-2050) climate change scenario within changed soils.

Table 4.27 Simulated nitrogen balance components (Kg N ha^{-1}) as influenced by changed soil properties with rice straw incorporation in past and present time scenario (1988-2018).

Soil I (Without rice straw incorporation)					
TS	**Mineralized N**	**Leached N**	**Plant uptake N**	**Volatilise N**	**Yield (Kg ha^{-1})**
TS I	75.6	24.1	133.9	8.8	4011.6
TS II	75.7	21.2	135.0	9.1	3937.5
TS III	72.0	21.4	123.3	9.3	3990.3
Mean	**74.4**	**22.2**	**130.7**	**9.1**	**3979.8**
Soil II (Incorporation of rice straw @ 5 t ha^{-1})					
TS I	77.7	23.6	137.0	9.3	4357.3
TS II	78.5	19.3	141.8	9.1	4302.6
TS III	74.0	20.5	128.6	8.9	4358.1
Mean	**76.7**	**21.2**	**135.8**	**9.1**	**4339.3**
Soil III (Incorporation of rice straw @ 7.5 t ha^{-1})					
TS I	79.9	22.5	140.7	9.0	4408.0
TS II	80.3	18.5	145.1	8.8	4331.0
TS III	76.0	20.5	133.0	8.7	4554.1
Mean	**78.7**	**20.5**	**139.6**	**8.8**	**4431.0**
Soil IV (Incorporation of rice straw @ 10 t ha^{-1})					
TS I	81.3	20.3	146.7	8.8	4968.5
TS II	81.1	18.8	148.7	8.6	4862.7
TS III	73.9	19.7	128.6	8.8	4823.4
Mean	**78.8**	**19.6**	**141.3**	**8.7**	**4884.9**

Ppt-Precipitation, I-Irrigation, T-Transpiration, ET-Evapo-transpiration, WUE-Water use efficiency.
(TS- Time scenario, TS I-1988-1998, TS II-1998-2008, TS III-2008-2018)

Table 4.28 Simulated nitrogen balance components (Kg N ha^{-1}) as influenced by changed soil properties with rice straw incorporation in future time scenario (2021-2050)

TS	**Mineralized N**	**Leached N**	**Plant uptake N**	**Volatilise N**	**Yield (Kg ha^{-1})**
Soil I (Without rice straw incorporation)					
TS IV	84.8	36.7	120.6	1.7	3548.9
TS V	86.7	31.2	126.9	2.4	3673.0
TS VI	85.4	24.1	122.9	2.8	3661.8
Mean	**85.6**	**30.7**	**123.5**	**2.3**	**3627.9**
Soil II (Incorporation of rice straw @ 5 t ha^{-1})					
TS IV	87.4	34.5	124.6	1.4	3817.4
TS V	89.5	29.2	131.3	2.0	3941.7
TS VI	88.1	22.8	127.5	2.7	3981.1
Mean	**88.3**	**28.8**	**127.8**	**2.0**	**3913.4**
Soil III (Incorporation of rice straw @ 7.5 t ha^{-1})					
TS IV	89.7	33.5	128.3	1.5	3886.8
TS V	91.9	29.1	134.4	2.3	3993.4
TS VI	90.4	22.4	130.4	2.7	4021.1
Mean	**90.7**	**28.4**	**131.0**	**2.1**	**3967.1**
Soil IV (Incorporation of rice straw @ 10 t ha^{-1})					
TS IV	91.0	32.0	132.9	1.5	4264.3
TS V	93.2	28.3	138.1	2.1	4361.3
TS VI	91.9	22.2	135.5	2.2	4491.0
Mean	**92.0**	**27.5**	**135.5**	**1.9**	**4372.2**

Ppt-Precipitation, I-Irrigation, T-Transpiration, ET-Evapo-transpiration, WUE-Water use efficiency.
(TS- Time scenario, TS IV-2021-2030, TS V-2031-2040, TS VI-2041-2050)

CHAPTER V

SUMMARY

In Punjab, India the sustainability of rice-wheat cropping system in recent some years, has come into question because of reduction in soil organic matter, multi-nutrient deficiencies, adoption of unsuitable soil and crop management strategies, declining ground water table and more recently the burning of crop residue. In this region about 7-8 million metric tonnes of rice straw is burnt every year which leads deterioration of productive potential of soil as well as rice wheat cropping system. For sustaining the productive potential, it is essential that the management practice should aim at improving overall soil health through build-up of soil organic matter which is recognised as the nucleus for improving soil physico-chemical and biological condition and sustaining agriculture production. On farm incorporation/recycling of crop residue is the pre-eminent management practice for restoring and enhancing the declined soil organic matter. Keeping this in view a study from a long term experiment under rice straw incorporation under rice wheat system was planned with the following objectives.

I. To investigate the effect of rice straw incorporation on soil physical properties in rice-wheat system.

II. Simulation of changed soil physical properties with rice straw management on the crop productivity, water and nitrogen balance components.

Soil samples were collected after the 10th cropping cycle of rice-wheat rotation from three soil layers 0-15, 15-30 and 30-60 cm and analysed for different physico-chemical properties of soil and biochemical properties within soil aggregates. The simulation study for yield, water and nitrogen balance was carried out with changed soil properties after rice straw incorporation under climate change scenarios.

The salient findings of this study are summarised as:

- The bulk density of soil increased significantly with increasing rate of rice straw incorporation with concomitant decrease in total porosity.
- Total water stable aggregates were significantly higher in R_{st}7.5 and R_{st}10 and are mainly constituted by macro-aggregates. Rice straw incorporation highly influenced the aggregate size of >2 mm. Mean weight diameter, geometric mean diameter and aggregate ratio were highest in R_{st}10 and least in control.
- Incorporation of rice straw and nitrogen levels significantly decreased the penetration resistance variably depending upon the rate of rice straw and nitrogen level. Average penetration resistance was lowest in R_{st10} and in N_{150} treatment.
- Initial infiltration rate was higher in rice straw incorporated treatments over control and progressively levelled off in all the treatments. The steady state infiltration rate was

marginally higher in $R_{st}10$. With nitrogen levels the initial infiltration rate were similar, and steady state infiltration rate were higher in N_{90} and N_{150} treatments.

- Soil moisture retention at various matric suctions was higher in $R_{st}10$ treatment and variable within nitrogen levels. Field capacity was highest in $R_{st}10$ treatment and nitrogen levels did not influenced it significantly. Permanent wilting point were higher in $R_{st}10$ and N_{150} treatment.
- Soil organic carbon increased significantly with increasing rate of rice straw incorporation in all three soil depths. With nitrogen levels soil organic carbon increase over control, but nitrogen levels were statistically at par.
- The analysis of enzyme activities i.e. dehydrogenase, fluorescein diacetate and alkaline phosphatase as well as basal soil respiration, microbial biomass carbon, water soluble organic carbon and oxidizable carbon fractions within soil aggregates reveals that, these parameters were significantly higher in macro-aggregate fraction followed by large macro-aggregate and least in micro-aggregates and all of which increased within each aggregate fraction with rate of rice straw incorporation.
- The principal component analysis revealed that rice straw incorporation ($R_{st}7.5$ and $R_{st}10$) showed a strong association with the mean weight diameter, field capacity, permanent wilting point and soil organic carbon.
- The random forest algorithm identified soil organic carbon and penetration resistance and available potassium to be important variables (based on mean increase error) for predicting the grain yield of rice and wheat.
- The simulated yield, water and nitrogen balance components were affected by crop residue incorporation in changing climates. The simulation study revealed that, in the past and present time scenario (1988-2018), the grain yield of wheat increased by about 8, 10 and 18% in soils with crop residue incorporation @ 5 t ha^{-1} (Soil II), 7.5 t ha^{-1} (Soil III) and 10 t ha^{-1} (Soil IV) and in future it would increase by 17% in soil IV as compared to Soil I (0 t ha^{-1}). Averaged over soils, in future (2021 to 2050) the wheat yield would decline by 10% as compared to past and present time scenario. In future there would be an increase in precipitation, evapotranspiration, evaporation, nitrogen leaching and decrease in uptake of nitrogen as compared to past and present climate scenario.

Conclusions

The results of present study concluded that, incorporation of rice straw has significantly improved the soil physical environment by increasing bulk density, aggregation status, infiltration rate, soil moisture retention, and decreasing total porosity, penetration resistance and saturated hydraulic conductivity. It also increased the fertility status of soil as well as crop productivity. Random forest analysis identified soil organic carbon, penetration resistance and available potassium to be the most important variables for yield prediction.

Simulation study revealed that, there would be an increase in precipitation, evapotranspiration, evaporation, nitrogen leaching and decrease in uptake of nitrogen in future as compared to past and present time scenarios. However, wheat grain yield would decline in future, which could be sustained with incorporation of rice residue over a longer period of time. Therefore, for sustaining the productive potential of soil as well as rice wheat sequence, surplus rice straw could be incorporated into soil @ 7.5 and 10 t ha^{-1} along with 150 Kg N ha^{-1}. This approach can also be adopted as an alternative to residue burning.

Future aspects

All soil properties increased with rice straw incorporation. Majority of soil properties did not exhibit additional improvement beyond @ 7.5 t ha^{-1}. However, few soil properties viz. soil moisture constants, penetration resistance, available phosphorous and potassium resulted in higher improvement beyond 7.5 t ha^{-1} (i.e. 10 t ha^{-1}). Therefore the study provides a scope for further research identifying the optimum rate of rice straw incorporation to improve the mentioned soil properties. Also there is scope for understanding the optimum depth of residue incorporation for variety of soil and agro-ecological conditions.

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VITA

Name of the student : Ramteke Pratik Rukmanand

Father’s name : Mr. Rukmanand Ramteke

Mother’s name : Mrs. Jyoti Ramteke

Nationality : Indian

Date of birth : 18.12.1995

Permanent home address : Ram Nagar, Ward No. 20,
Gadchiroli (Maharashtra)

EDUCATIONAL QUALIFICATIONS

Bachelor degree : B. Sc. Agriculture

University : Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola (Maharashtra),

Year of award : 2017

OCPA : 8.21/10.00

Master’s degree : M. Sc. (Soil Science)
Minor (Soil and Water Engineering)

University : Punjab Agricultural University, Ludhiana

Year of award : 2019

OCPA : 8.13/10.00

Title of Master’s Thesis : “Long term effect of rice straw incorporation on soil physical properties and crop productivity in rice-wheat system”

Awards / Distinctions / Fellowships / Scholarships :

- ICAR National Talent Scholarship
- IInd Position in All India Post Graduate Students Research Convention in Soil Science held at Bihar Agricultural University, Sabour, Bhagalpur (Bihar)