जैविक तथा पारम्परिक खेती के तहत चावल-गेंहूँ-मूँग फसल प्रणाली से ग्रीनहाउस गैस उत्सर्जन

GREENHOUSE GAS EMISSION IN RICE-WHEAT-MUNGBEAN CROPPING SYSTEM UNDER ORGANIC AND CONVENTIONAL PRACTICES

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By

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This is to certify that the thesis entitled **"Greenhouse Gas Emission in Rice-Wheat-Mungbean Cropping System under Organic and Conventional Practices"** submitted to the Post-Graduate School, Indian Agricultural Research Institute, New Delhi in partial fulfillment of the requirements for the award of **Doctor of Philosophy** degree in **Environmental Sciences** embodies the result of a bonafide research work carried out by **Mr. Mahesh Kumar Malav, Roll No. 10445** under my guidance and supervision. No part of this thesis has been submitted for any other degree or diploma.

It is further certified that all the assistance and help availed during the course of investigation as well as all sources of information have been duly acknowledged by him.

Date: 31/01/21
Place: New Delhi

(Shiv Prasad)
Chairperson, Advisory Committee

DEDICATED

TO

Farming community who feed the nation

To my mother
A strong and gentle soul who taught me
patience and perseverance

To my father
Whose past memories and enthusiasm still
encourage me to believe in myself

To my wife and son
Whose friendship, love care, and humor gave me
strength and made me believe that "tough times
don`t last but tough people do."

To my brother and sisters
For supporting me all the way and for fulfilling my
life with little-little surprises

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Euripides (484 BC-406 BC) once told that, "The best and safest thing to keep a balance in your life, acknowledge the great powers around us and in us. If you can do that, and live that way, you are really a wise man." so it is essential to that I acknowledge the great powers, who paved the way on which I have walked so far.

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Dated: 31/01/21
Place: New Delhi

Mahesh

(Mahesh Kumar Malav)

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CHAPTER 1
INTRODUCTION

Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are the major Climate change is a crucial environmental issue and has broad implications on the food system, healthy sustainable development, and the future of the economy. Global warming caused by human-induced GHG emission represents significant scientific and political challenges of the 21st century. The ability to respond to the big task of regulating greenhouse gas (GHG) emission has links on the overall well-being of our entire country. IPCC, 2018 (SR15) special report highlights several climate change impacts that could be avoided by limiting global warming to 1.5°C compared to 2°C, or more. However, it will require unprecedented and collective climate action in all areas. The major challenge is to understand the biological mechanisms regulating carbon exchanges between the soil and atmosphere and how these exchanges respond to climate change through climate–ecosystem feedbacks are valuable (Hiemann and Reichstein, 2008; IPCC, 2018).

Today, the signs of global warming are throughout the world and are the most prominent environmental issue. It is caused by the enhanced concentration of greenhouse gases (GHGs) in the atmosphere (Pathak and Aggarwal, 2012). The GHGs, viz. carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), trap some of the outgoing radiation (infrared) emitted by the Earth's surface and radiate it back downward, thereby warming the atmosphere of the Earth. The addition of GHGs in the atmosphere and the consequent rise in Earth's temperature is termed as 'greenhouse effect.' According to FAOSTAT database, FAO, in 2016, the amount of atmospheric CH_4 reached a new high of about 1,853 ppb—about 60% comes from human activities like enteric fermentation in ruminant cattle, rice cultivation, and landfills. The burden of N_2O was 328.9 ppb in 2016-22% higher than in the pre-industrial era, primarily as a result of biomass burning and fertilizer use. From 1990 to 2010, global agricultural emissions increased by 8%. They are projected to increase by 15% above 2010 levels by 2030.

According to IPCC 2018 (SR15) special report, global warming anticipated rising to 1.5 °C above pre-industrial levels, with a likely range of 0.8°C to 1.2°C. Even

considering the complete implementation and contributions submitted by nations in the Paris Agreement, net emissions would rise compared to 2010, leading to a warming of around 3 °C by 2100. In contrast, restricting warming below or close to 1.5 °C would need to reduce net emissions by nearly 45% by 2030 and reach net zero by 2050. Even just for restricting global warming to below 2 °C, CO_2 emissions should decrease by 25% by 2030 and by 100% by 2075. Global warming is accelerating to various regional and global changes such as high temperature, heavy rainfall, floods, droughts, soil moisture, and rising sea levels.

Among various sources, agricultural soil is the major contributor to the greenhouse effect. Globally, agriculture contributes 54% of anthropogenic CH_4 and 58% of N_2O emissions. In soils, CH_4 is produced during microbial decomposition of organic matter under anaerobic conditions. Factors, including pH, Eh, temperature, and moisture content, influence methane fluxes. The use of nitrogenous fertilizers to soils is the leading source of N_2O emissions. The factors that influence N_2O emissions from soil are the agricultural practices (N fertilizer type, application rate, crops) and soil conditions (soil pH, texture, moisture, and organic C content).Agricultural production is also an emitter of CO_2 in the global food system. Soil management practices such as tillage trigger CO_2 emission through the biological decomposition of soil organic matter. Fuel-use for several agricultural works and burning of crop residues are the other sources of CO_2 emissions - an off-site source of CO_2 in the manufacturing of fertilizers and pesticides.

According to a summary of the Indian Network for Climate Change Assessment- 2011,the net GHGs emission from India was 1728 Mt of CO_2 equivalent. The leading sectors adding to this emission were energy (power), industries, agriculture operation, and unmanaged waste. With a cumulative emission of 334 Mt CO_2equivalents, the significant sources in the agricultural sector were livestock enteric fermentation (63.4%), rice cultivation (20.9%), soils (13.0%), manure (2.4%) and crop residues burning of (2.0%). The rice cultivation, soil, and field burning of crop residues, thus share 35.9% to the total emissions from agriculture. It is, therefore, pertinent to promote the technologies to reduce the emission of GHGs from agriculture(INCCA, 2010).

Excessive and indiscriminate use of synthetic agrochemicals in conventional agriculture is affecting not only the environment quality but also deterioration of soil

nutrient status, food chain, soil structure, micro-flora, soil organic matter content, and increase in soil salinization. Specifically, an Indian perspective, the area under rice-wheat cropping system shows that 0.5 % organic carbon content in the soil in the 1960s but, the current status is 0.2 % only (ICAR, 2011).Since the green revolution, the impact has been given mainly on furnishing macronutrients, especially N, P and K. The use of organic manure and micronutrient application has entirely ceased. The adverse effects of this biased fertilization are deterioration of soil physical, chemical, biological properties and emission of greenhouse gases as well as a diminishing return of decreasing dividends. The energy consumption in the production of fertilizers, as well as its application in the field, is resulted in the emission of greenhouse gasses (Stinner, 2015) compared to organic farming. That means one can say the production, transportation, and application of fertilizers merely increase carbon footprint in term of carbon dioxide equivalent basis (Väisänen*et al*., 2016).

In this context, organic agriculture offers much hope for the future of environmental sustainability and quality food production and helps in reducing greenhouse gas (GHG) emissions and adaption to climate change impacts. Promoting organic farming transition, subsequent certification, and conservation programs allow the countries throughout the world to offset the GHG emissions. However, ensuring the future environmental sustainability and quality food security in the shadow of climate change depends on the transition to more sustainable agricultural practices and policies. Organic farming is a trend since ancient time for growing most of the world's food holistically and naturally by using organic manure with the help of animaland human power (White, 1970). It stimulates and improves agro-ecosystem health byincreasing below-ground biodiversity, which assists in performing better nutrientcycling through soil biological activity. It emphasizes the use of mostly on-farm organic inputs with avoiding the use of synthetic chemicals such as fertilizers, pesticides, and hormones. Organic farming is a better way to makeagricultural production sustainable (Hazarika*et al*., 2013). According to the World of Organic Agriculture Report, 2018. India is home to 30% of the total organic producers in the world but accounts for just 2.59 % (1.5 million hectares) of the total organic cultivation area of 57.8 million hectares.

Shifting towards organic farming helps to increase soil organic carbon,reduce GHG emissions (Gattinger*et al*., 2012). It also improves water retention and nutrient uptake, sustaining yield response, thereby maintaining farm profitability, securing

biodiversity and resilience ofecosystem services (Crowder *et al*., 2010). Changes in both farming practices and food demand offer significant opportunities. On the supply side, crop management practices such as improved fertilizer management and conservation tillage offer the most significant reduction potential at relatively low costs. Organic agriculture also provides environmental benefits through the sequestration of atmospheric carbon in soil organic matter. Soil organic carbon stocks were 3.5 metric tonnes per hectare higher in organic than in non-organic farming systems. Organic farming systems sequestered up to 450 kg more atmospheric carbon per hectare and year through CO_2 bound into soil organic matter.

Nowadays, the demand for thegrowing of organic food has increased due to awareness about health andenvironmental problems arise from agriculture and a very much positive basis forrural income generation (Bhattacharyya and Chakraborty, 2005).In South Asia, the rice-wheat cropping system helps in contributing to about 80 % the total cereal production and provides food to more than 450 million people in India, Nepal, Bangladesh, and Pakistan (Ladha*et al*., 2003). The rice-wheatsystem supports more than 1 billion people, i.e., 15 % population of the world(Sah*et al*., 2014). The rice-wheat cropping system is followed on 10 M ha in India, out of13.5 M ha in the total area of Indo-Gangetic plains of South-Asia. This area has been under rice-wheat cultivation for more than 1000 years (Singh and Kaur, 2012)andsupporting the most population of our country by meeting their needs for food.

Rice-wheat is the dominant cropping pattern widely practiced throughout northern India. Practicing the rotations adding an inadequate and disproportionate amount of fertilizers have been creating system productivity stagnation, nutrient and water imbalance, soil organic matter depletion (Zia *et al.,* 1992). Conversely, the increasing demand for food necessitates further intensification of the crop production systems. The increase in cropping intensity or even sustaining the currently adopted cropping systems calls for the inclusion of grain legumes for improving the nutrition status of the people and maintaining soil health (Becker *et al.,* 1995; Norman *et al.,* 1984).Presently, the rice-wheat cropping system in India is facing many problems such as soil salinization due to use of excessive fertilizers, soil degradation (Bhandari *et al.,* 2002), declining water table (Humphreys *et al.,* 2010), yield stagnation (Busari*et al*., 2015), high nitrate content in groundwater (Bajwa, 1993), insect-pests outbreak, and multiple nutrient deficiencies.

The ameliorating effect of including legumes in cereal-based cropping systems has long been recognized, but because of low yield potentials and susceptibility to environmental stresses, legumes have generally declined in importance over time. Mungbean (*Vigna radiate* L.) is an essential crop for both human nutrition and enrichment of soil fertility (Norman *et al.,* 1984). In recent years, the cultivation of summer mungbean has been expanded considerably. Possibility of growing mungbean in the rice-wheat system also exists in the northern parts of the country. The expansion of mungbean cultivation in such areas depends mostly on its competitive ability with other crops (Hamid, 1996) and adaptability over a wide range of environmental conditions (Popalghat*et al.,* 2001).

GHG flux varies with the interactions among physical, chemical, and biological properties of soil and microclimate. Soil micro-organisms are involved in virtually all soil processes, mediating soil organic matter decomposition and nutrient cycling and are also involved in GHG dynamics between the soil and atmosphere.The main contributor to potential greenhouse gases, *i.e.,* CO_2, CH_4, and N_2O to the atmosphere is believed to be the terrestrial carbon pool. The rate of exchange between the terrestrial pool and the atmosphere is generally affected by various soil biological, physical, and chemical properties (Guo-yuan*et al*., 2006;Ihssen*et al*., 2003), including soil organic matter content, soil enzymes (Yuan *et al.,* 2006), soil micro-organisms (Xuexia*et al*., 2006) and management practices (Nkongolo *et al*., 2008). Relationships among soil physical, chemical properties, and greenhouse gas effluxes are documented by Agehara and Warncke, 2005; Jackson and Schlesinger, 2004; Fung *et al.*, 2005 and Gintin*get al*., 2003.Conrad, 1996 also reviewed the effects of soil chemical and physical properties as well as some interactions of soil enzymatic activities, soil organic matter content, soil water content, and soil biological properties.

These greenhouse gases are produced or consumed as a result of microbial activity in the soil, but the intensity of the fluxes between the soil and the environment depends massively on soil physical and chemical factors. Soil temperature and water content directly affect generation and consumption of greenhouse gases, through their effects on micro-organisms and plant root activity. Gas diffusivity, which depends on the air-filled pore space (and thus varies inversely with water content), controls the movement of the gases to and from the environment. It also influences soil aeration,

and thus indirectly controls the capacity of the soil to produce or consume CO_2, N_2O, and CH_4(Smith *et al.,* 2018).

The role of GHG in affecting temperature changes and subsequently, global warming is a highly discussed topic of current interest. Although considerable research has addressed these issues, we still do not fully understand the dynamics of GHG efflux to the atmosphere. The difficulty in understanding GHG efflux is most likely due to the high number and complexity of contributors of GHGs; the most complex of which is likely the soil-plant interface with the atmosphere. Within the soil matrix, soil organisms play an integral role due to their participation in organic matter decomposition (Xuexia*et al*., 2006). However, understanding GHG efflux dynamics between the soil and atmosphere is often challenging due to the natural spatial and temporal variability of soil properties (Yanai*et al*., 2003; Broos*et al*., 2007).

It is commonly known facts that soil micro-organisms regulate carbon, nitrogen, phosphorus, and sulfur cycles through organic matter decomposition, immobilization, and mineralization of these nutrients. These cycles are entirely controlled by enzymatic activities (Tate, 2002; Bandick and Dick, 1999). Therefore an understanding of the different soil enzymes involved in nutrient cycling processes is critical to understanding the processes themselves (Acosta-Martinez and Tabatabai, 2000). The β-glucosidaseenzyme is involved in the hydrolysis of cellobiose(Tabatabai, 1994). Dehydrogenase enzymes, which are essential in soil organic matter oxidation (Camina*et al*., 1998), are only found in living cells (Dick, 1994) and, therefore, provide a measure of the viable microbial population. Therefore, an understanding of the relationship between soil enzyme activity and GHG efflux could provide policymakers with useful information to assist in making meaningful recommendations to minimize GHG contributions.

From the literature, it is clear that greenhouse gases produced and released by soil micro-organisms are influenced by soil physical, chemical, and biological properties. However, the full extent of the role of micro-organisms in GHG efflux has not been explored, and interactions are not fully understood, and there exists a need for closer examination of the relationships among soil microbial properties, and greenhouse gas efflux mechanisms.Soil enzymes are often used as indicators of soil quality and microbial activity in soils. However, as far as we know, no previous attempt has been made to relate enzyme activity to greenhouse gas (GHG) efflux from organic

rice-wheat-mungbean cropping system. Keeping this in view, the present study was undertaken with the following objectives:

1. To quantify greenhouse gas emission from organic and conventional rice-wheat-mungbean cropping systems.
2. To study soil physico-chemical parameters in relation to GHG emission from organic and conventional agricultural practices.
3. To study soil microbial parameters in relation to GHG emission from organic and conventional agricultural practices.

CHAPTER 2
REVIEW OF LITERATURE

The review of the literature primarily focused on the various aspects related to the research carried out on greenhouse gas emission from organic and conventional farming. An effort has also been made to review the recent studies conducted under rice-wheat-mungbean cropping system. Various soil physico-chemical and biological parameters and their impact on greenhouse gas emissions under organic and conventional farming are also studied. A critical review of the literature in this specific investigation is presented under the following sub-headings.

2.1. Greenhouse gas effect and climate change

The consequence of climate change is the rapid warming of the Earth's climate caused by anthropogenic activities such as fossil fuels burning, deforestation, and farming. If left unchecked, it can pose an unprecedented threat to human civilization and the ecosystems on this planet. We know the climate is changing because it averaged out over more extended periods, the global mean temperature has been consistently increasing across land and sea. It is now about 0.85ºC above pre-industrial times. According to a special report of IPCC 2018 (SR15), global warming anticipated rising to 1.5°C above pre-industrial levels, with a likely range of 0.8°C to 1.2°C. Even considering the complete implementation and contributions submitted by nations, net emissions would rise compared to 2010, leading to a warming of around 3°C by 2100. In contrast, restricting warming below or close to 1.5°C would need to reduce net emissions by nearly 45% by 2030 and reach net zero by 2050. Even just for restricting global warming to below 2°C, carbon dioxide (CO_2), emissions should decrease by 25% by 2030 and by 100% by 2075.

The world has been experiencing frequent changes in climate, as a result of global warming, affecting millions of lives. Global warming is accelerating to various regional and global changes such as high temperature, heavy rainfall, floods, droughts, soil moisture, and rising sea levels. There has been much increase in the number of natural disasters worldwide (such as wildfires, droughts, floods) and the mass migration of species. The reason behind this is an enhanced greenhouse effect caused by changing the balance of certain gases in the Earth's atmosphere. These gases especially carbon

dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O)and water vapour, allowing sunlight to pass through the atmosphere, but then stop the heat from escaping back out into space (IPCC, 2014).

The Earth's atmosphere is made up of nitrogen (78.1%) and oxygen (20.94%). One-third of the solar radiation that intercepts the outer atmosphere is bounced back to space. The remaining two-thirds pass through the atmosphere and are absorbed by the Earth surface and by the atmosphere itself. The ground heats up and re-emits the energy as longwave radiation in the form of infrared rays. A significant amount of this energy is absorbed by the atmosphere and re-emitted to the Earth's surface. This process is known as the greenhouse effect (**Fig. 2.1**). Without the greenhouse effect, the Earth's surface temperature would be below the water freezing point and life, as we know, would not exist (Treut*et al.,* 2007). However, due to human activities, the constitution of gases,*i.e.,* CO_2, CH_4, and N_2O in the atmosphere is changing, increased concentration of these gases is trapping more heat and transmitting it back to the Earth. The rapid increase in *greenhouse gases* has created an *enhanced greenhouse effect,* contributing to global warming.

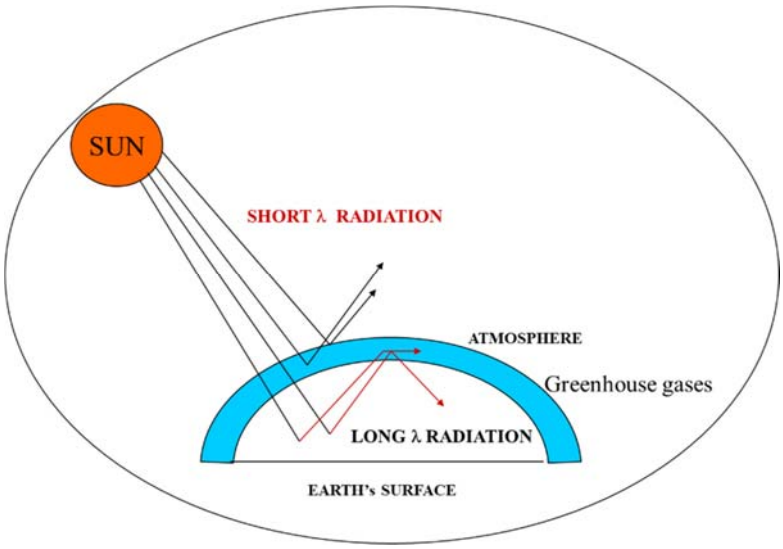

Fig. 2.1: The Earth's atmosphere and the greenhouse effect

2.2. Greenhouse gases

A greenhouse gas (GHG) is a gas that absorbs and emits radiant energy within the thermal infrared range (IPCC, 2008). The leading greenhouse gases in Earth's atmosphere are water vapour, CO_2, CH_4, N_2O, and ozone. Water vapour and CO_2 are

the most important GHG, but other gases such as CH_4, N_2O, ozone, halocarbons, and aerosol also increase the atmospheric temperature (Treut*et al.,* 2007). Although water vapour is the primary GHG in the atmosphere, it is little affected by human activities (Forster *et al.,* 2007), while they greatly influence CO_2, CH_4, and N_2O. Thus, these three GHGs are considered the most important, causing the greenhouse effect.

The ability of each GHG to absorbs the infrared radiation and re-emits it as heat, raising the atmosphere temperature, which is known as global warming potential (GWP). The larger the GWP, the more warming the gas causes. The GWP of each gas is assigned as a function of its lifetime in the atmosphere and rated about CO_2 since this is the most abundant GHG in the atmosphere (Snyder *et al.,* 2009). Therefore, consider a time horizon of 100 years, CH_4 has a lifetime of 12 years, and GWP of 21 and N_2O has a lifetime of 114 years and a GWP of 310 (Watson*et al*., 1996; Forster *et al.,* 2007). CO_2 has a GWP of 1 and serves as a baseline for other GWP values.

The concentration of GHGs in the atmosphere is continuously increasing since the industrial revolution. The atmospheric concentration of CO_2 was around 280 ppm, until 1750 (Industrial Revolution), and rose to 391 ppm, in 2011 (IPCC, 2014). That increase was primarily caused by fossil fuels burning, agriculture, industries, and deforestation. Emissions of CH_4 result from paddy fields, landfill sites, and ruminants cattle (Forster *et al.,* 2007; Denman *et al.,* 2007). The level of CH_4 in the atmosphere has reached from 400 ppb (parts per billion), during glacial periods to 700 ppb during interglacial periods, while present-day levels reach 1803 ppb (IPCC AR5, 2014).

The N_2O level in the atmosphere increased from 270 ppb, during the preindustrial period, up to 324 ppb, in 2011 (IPCC AR5, 2014). The primary sources of N_2O are the N-fertilizers application on soil, fossil fuel combustion, and some natural process that occur in terrestrial and aquatic ecosystems. The concentrations of the greenhouse gases CO_2, CH_4, and N_2O have all increased since 1750 due to human activities, exceeding the pre-industrial levels by about 40%, 150%, and 20%, respectively (IPCC AR5, 2014).

2.3. Contribution of GHGs from Agriculture

With a share of 14% in carbon-dioxide equivalents (CO_2-eq.), agriculture contributes substantially (**Fig. 2.2**) to global greenhouse gas (GHG) emissions (IPCC Report, 2018). The indirect emissions from agriculture-related activities such as

fertilizer production and land-use change, this share can be up to 30% (Smith et al., 2008). In 2005, the agriculture sector contributed 56% to the emissions of the anthropogenic non-CO_2 GHG, *i.e.,* N_2O and CH_4, with an annual growth of 0.9% (Smith et al., 2014). An estimated 38% of agriculture's direct emissions originated from soils, 15% from N_2O from manure on pasture and 12% from N_2O of synthetic fertilizers- the latter at an annual growth rate of 3.9% from 1961 to 2010. In comparison, rice cultivation contributes 11% to the sector's yearly emissions, mainly in the form of CH_4 (Smith *et al.,* 2014).

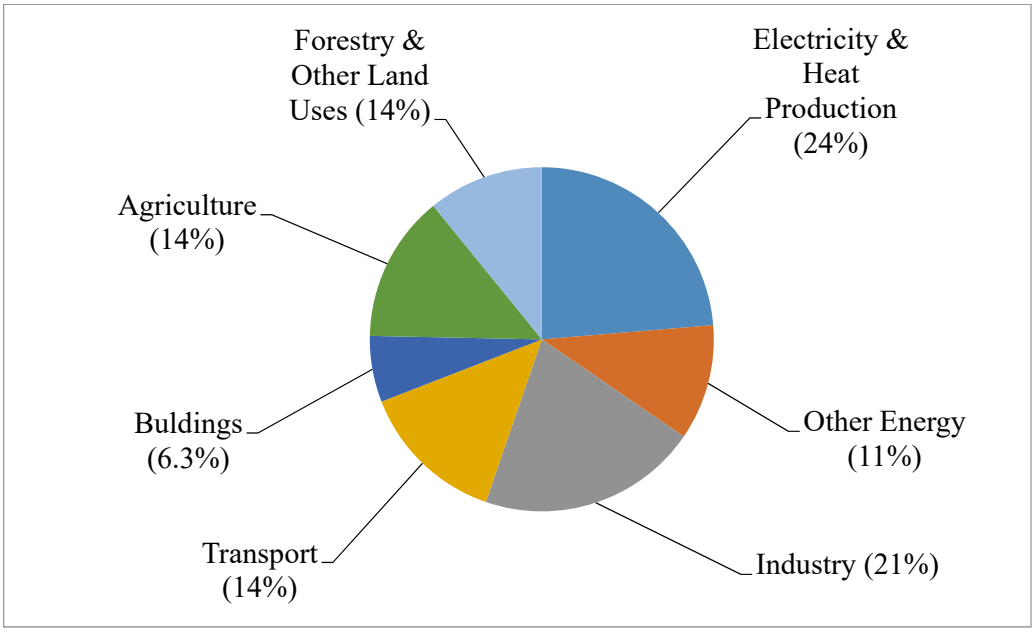

Fig. 2.2: Contribution by sectors in GHG emissions

Due to their high GWP, the reduction of N_2O and CH_4 emissions thus gives agriculture's mitigation potential regarding climate change high leverage in favour of limiting global warming (Ventereae*t al.,* 2012). Fostered by the Green Revolution and the availability of cheaper synthetic fertilizers from the 1950s onward, global grain production doubled to 2.5 billion tons between 1970 and 2010 with yield increase from 1600 to 3030 kg ha^{-1} (Smith *et al.,* 2014). However, this intensification was realized mainly through the enhancement in global fertilizer usage from 32 to 106 Mt yr^{-1} (+331%). Moreover, these achievements were accomplished at the cost of environmental damages, *i.e.,* biodiversity loss, soil erosion, and degradation, eutrophication covering algal blooms and oceanic dead zones, or adverse effects of pesticide on humans and wildlife. There is a well understanding that the challenges of

producing enough food and biomass sustainably, can not be materialized by modern intensive non-organic agricultural practices. Which is rely heavily on synthetic fertilizer input and pesticide application (Lorenz and Lal, 2016). Thus, agroecological approaches towards sustainability are fundamental for future food production.

2.4. Rice-wheat-mungbean cropping system

Rice–wheat (RW) cropping systems occupy 26 million ha of cultivated land in the Asian subtropics (Ladha*et al.,* 2003). In the Indo-Gangetic plain (IGP) of South Asia, the system occupies about 13.5 million ha of the most productive lands. In the RW system, the soil and water requirements of the two crops are drastically different. Rice seedlings are traditionally transplanted in puddled and submerged soils, while wheat requires a well-pulverized, aerated soil to attain its potential yield. The alluvial soil of the region has a sandy loam to loam texture with a high percolation rate requiring frequent irrigation when rice is grown. Water use by continuously-flooded rice is, therefore, often high due to substantial loss through seepage, percolation, and evaporation. Nitrogen losses from these soils under rice are also significant.

Further, the drying of the soil at the end of the rice crop and during wheat cropping makes the soil aerobic. Thus cycles of aerobic and anaerobic conditions operate in the soil, which considerably influences CH_4 and N_2O emissions (**Fig. 2.3**). Also, the RW system consumes a very high amount of N fertilizer, approximately 240 kg N ha^{-1} annually (Pathak *et al.,* 2002), which has a considerable impact on CH_4 and N_2O emissions.

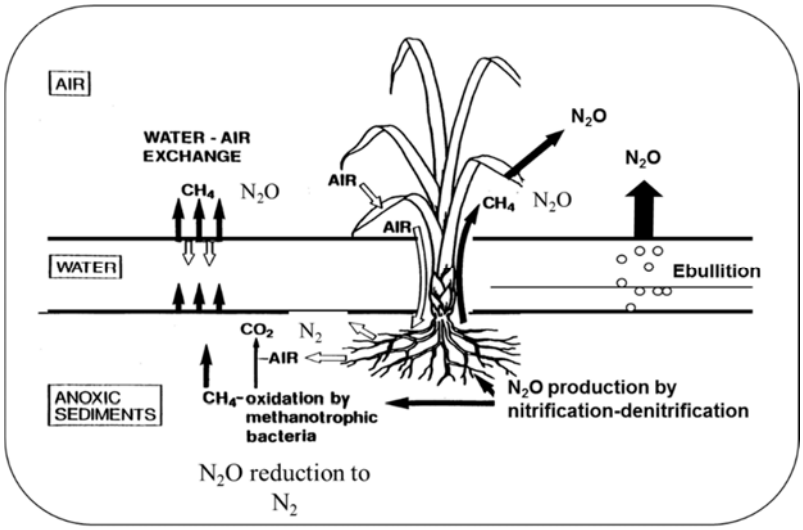

Fig. 2.3: GHG emission mechanism from rice fields

Rice–Wheat cropping systems (RWCS) are the primary source of food and income for millions of people in India. However, crop productivity is either stagnating (wheat) or declining (rice) despite the use of higher-yielding cultivars (Padre-Tirol and Ladha, 2006). That raises significant concerns over the long-term sustainability of current farming practices and poses a threat to future food security against a background of climate change. Key factors responsible for the deterioration in soil fertility and crop productivity include a decline in soil organic matter (SOM) due to reduced inputs of bio-resources and lack of an adequate rotation (Shibu*et al.,* 2010). The decline in the soil fertility, mainly due to the low organic carbon (C) levels in soil, seems to be the most significant factor for decreased sustainability of the system.

The practice of adopting a cereal–cereal cropping system on the same piece of land over the years has led to soil fertility deterioration, and questions are being raised about its sustainability (Prasad, 2005). However, the introduction of summer legumes, such as mung bean, in the RWCS after the harvest of wheat and before the transplanting of rice can increase the productivity of these crops, besides improving the carbon and nitrogen status of soil (Prasad, 2011). Legumes, such as mungbean, play a vital role in such cropping system by protecting the soil from erosion, enriching it with organic matter and nitrogen through nitrogen fixation by Rhizobium and by conserving precious natural resources like water in the soil. After picking matured pods of mungbean, the plant biomass (3-4 t ha^{-1} dry matter) can be used as crop residue that can be incorporated in the soil.

2.5. Organic vs. conventional farming

Two of the most pressing sustainability issues at present are the depletion of fossil energy resources and the emission of atmospheric greenhouse gases such as CO_2, CH_4, and N_2O to the atmosphere. Agriculture consumes fossil energy and hence contributes to the depletion of fossil energy resources as well as to the emission of GHGs. Agriculture is both the sink and the source of atmospheric GHGs. Atmospheric CO_2 is assimilated via agricultural crop production, part of which may be temporarily stored as organic matter in soils or used as a renewable energy source. Agriculture emits CO_2 by using fossil energy and through oxidation of soil organic matter. N_2O is emitted during storage and application of fertilizers and manures and CH_4 from paddy fields as well as from enteric fermentation in ruminant farm animals (Pathak *et al.,* 2002; Nemecek*et al.,* 2011).

Organic farming is often considered to contribute to reducing energy use and GHG emissions, both on a per unit area basis as well as on per unit product basis as compared to conventional agriculture. That has been supported by a relatively large number of studies (Nemecek*et al.,* 2011; Gomiero*et al.,* 2008; Thomason *et al.,* 2008 and Grönroos*et al.,* 2006). Energy use and GHG emissions per ha in organic farming are often considerably lower than in conventional farming, which can be attributed to lower input use per ha in organic farming. The potential of different crops for carbon sequestration under organic and conventional farming systems is shown in **Table 2.1**.

Table 2.1: The carbon sequestration potential of different crops under organic and conventional farming systems

Crops	**Organic**	**Conventional**	**Difference**
Cash crops			
Above-ground biomass	3.76	4.95	-1.18
Root biomass	1.44	0.89	0.55
Catch crops			
Above-ground biomass	0.55	0.22	0.33
Root biomass	0.22	0.09	0.13
Weeds			
Above-ground biomass	0.22	0.04	0.17
Root biomass	0.04	0.01	0.03
Sum	6.23	6.19	0.04
Energy input	0.15	0.29	-0.14
Total	6.08	5.91	0.18
Carbon-sequestration efficiency	**42.8**	**21.6**	**21.2**

Source: Haas and Köpke, 1994. *Manure is not included

2.6. Organic Farming

The word ‘Organic Farming' was first mentioned by "Lord Northbourne' in the book "Look to the Land" (Paull, 2014). Organic farming is the way of cultivating the crops using naturally occurring organic amendment (on-farm resources) without using antibiotics, genetically modified organism (GMO), sewage sludge, synthetic agro-chemicals viz., pesticides, fertilizers, phytohormones etc. (Varshney and Suresh, 2016)

that maintains the agro-ecological balance for sustaining the productivity of a farm. According to the International Federation of Organic Agriculture Movements (IFOAM), there are four basic principles in organic farming, i.e., the principle of health, fairness, ecology, and care, as shown in **Fig. 2.4**. These principles put in indispensable goals that include superior quality food production, fiber, and other farm products in an ecologically sustainable way to meet the needs of the present as well as the future generation.

Fig. 2.4: Basic principles in organic farming

In India, the government has carried out the National Programme for Organic Production (NPOP) for setting the standards for organic production, the advancement of organic farming, certification bodies, etc. (APEDA, 2016). According to the certification standard, organic food, as well as producers of organic products, has to follow the rules and regulations for acquiring organic certification. Farmers are ineffectual in marketing their products with organic labeling without organic certification. Organic certification and labeling facilitate easy identification and selling of organic products. The legislation set out the three levels of organic products, and those are labeled as ‘100% organic' (entirely organic), ‘95% organic' (organic) and ‘made with organic ingredients' (contain at least 70 % organic ingredients). Organically grown produce has the highest value in consumer markets in term of its quality and monetary return. Growing awareness of consumers towards organic products has assisted in the production of organic produce.

The organic form of carbon is the essential constituent in soil, and it plays a crucial role in various functions in soil (Clairotte*et al.,* 2016). Organic farming has an inherent potential to both reduce GHG emissions and to enhance carbon sequestration in the soil. It is a low-risk farming strategy with reduced input costs.Therefore, lower risks with partial or total crop failure in extreme weather conditions (Eyhorn, 2007). Williams et al., 2006, reported that on the application of Nitrogenous Fertilizer, the GHG emission factor was 7.607 kg CO_2-eq kg^{-1} N, while with the compost it was 4.4 kg CO_2-eq kg^{-1} N. Pathak et al., 2001, also reported that application of FYM and DCD reduced the emission of N_2O-N in rice.

Certified "organic" farming is one of the best options for combating greenhouse gas emission from agriculture. However, there are still knowledge-gaps regarding the effects of organic farming on soil carbon (C) and nitrogen (N) fluxes, and thus on N_2O and CH_4 emissions from the soil (Van Groenigen*et al.,* 2015). Organic fertilization strategies through farmyard manure, compost, and cropping of N-fixing legumes and catch crops influence soil C and N flux in complex processes. Investigating these processes needs long-term measurements, at best covering complete crop rotations.

2.7. Impact of organic farming on soil properties

Addition of organic matter in the soil is a well-known component of organic farming. Ideally, organic farming systems are designed to enhance soil properties to achieve multiple goals. Important goals include improvement of physical, chemical, and biological properties of soil so that it can support healthy plants growth and maximize crop yield. Organic farming maintained the plant nutrients in soil level to sustain crop productivity. It helps to manage the level of the production with adding and balancing the proportion of plant nutrients in the soil, although organic farming gives lower yield than conventional farming (Seufert*et al.,* 2012). Schrama*et al.,* 2018 found that closure of the yield gap between organic and conventional farming can be a matter of time and that organic farming may result in considerable spatial stability of soil properties and soil processes. The impact of critical physical properties of soil is discussed under the following sub-headings.

2.7.1. Impact on physico-chemical properties of soil

Soil physical properties are responsible for crop stand mainly. An equal proportion of clay, silt, and sand is ideal for crop cultivation. Hence, loamy soils are

better in this context. Instead of soil texture, soil structure is the crucial determinant factor for soil fertility and crop productivity, so it (soil structure) has special ecological significance (Nesic*et al.,* 2014). Organic matter plays a central role in influencing soil physical properties. Papadopoulos *et al.,*2014, found thatby comparing the soil physical quality of paired fields representative of organic and conventionally managed soils, organic farming can substantially improve soil structural conditions, organic matter levels, aggregate stability, and porosity.

2.7.1.1.Soil pH

Soil pH is the measure of the acidity or alkalinity of the soil. pH is defined as the negative logarithm (base10) of the activity of hydronium ions (H^+ or more precisely, H_3O^+aq) in a solution. Soil pH is considered an essential variable in soils as it affects many chemical processes. It affects explicitly plant nutrient availability by controlling the chemical forms of the different nutrients and influencing the chemical reactions they undergo.Whalen *et al.,* 2000 observed that compounds other than carbonates and bicarbonates, such as organic acids with carboxyl and phenolic hydroxyl groups have an essential role in buffering soil acidity and decreasing the pH of underlying soils amended with manure. The pH of the soil slightly reduced with the addition of organic manures (FYM, poultry manure, and press-mud) alone or in combination with N or NP fertilizer for ten years over the initial value that might be attributed to the formation of organic acids during decomposition of organic matter. A slight decrease in soil pH with the addition of FYM has also been reported by Laxminarayana and Patiram (2005).

2.7.1.2.Soil electrical conductivity

Electrical conductivity (EC) is the capability of a material to transmit (conduct) an electrical current and is commonly expressed in units of mS/m. Soil EC measurements may also be expressed in units of decisions per meter (dS/m), which is equal to the reading in mS/m divided by 100. Eghball, 2002reported that increasing manure rate also increased the soil EC with the application of P and N-based manure on a clay loam textured soil. Similar findings were also reported by Eigenberg*et al.,* (2002). An increase in the EC of the soil was observed by Antil and Singh, 2007, with the continuous application of organic manures for 10 years. However, an increase in soil EC with the constant use of NP fertilizers over the initial value was marginal. There was a significant increase in EC of the soil with the combined application of organic

manures plus NP fertilizers over-application of NP fertilizers alone, similar to the finding of Balaguraviah*et al.,* 2005. The proportionate increase in EC was more with the addition of FYM than poultry manure and press mud, which might be due to the supply of a higher quantity of salts through FYM compared to press mud and poultry manure.

2.7.1.3.Soil bulk density and porosity

Bulk density (BD) is the weight of oven-dry soil per unit bulk volume, including air space. Bulk density varies with the mineral composition of the soil solids, with how the solid particles pack together, as well as organic carbon content. Replacement of any of the solid components with a component of different density effect a change in bulk density. Likewise, the introduction of a substance into the soil that can alter the arrangement of the solid particles to effect a change in the amount of air space change bulk density.

BD is the dynamic property of the soil. Soils with high BD, shows the ill effect on the growth, whereas, BD of the soil is less in values, signifies the favorable growth of the plant. Interestingly, soil pore spaces are responsible for controlling the increase or decrease in BD (Das, 2011). Even, the proportion of organic matter present in soil negatively affects the bulk density of the soil. The treatment with compost plots had a maximum number of total pore spaces and fallen off the value of BD compared with control plots, but, NPK with control was on par (Xin*et al.,* 2016). Similarly, Guo*et al.,* 2016 observed that plots with cattle manure compost had marked negative correlation with soil bulk density.

Ademir*et al.,* 2009 reported that Soil bulk density and porosity were lower and higher, respectively, in the organic management than in the conventional management and native vegetation areas after three years of organic and conventional farming. At the end of the 3rd year, the average of soil bulk density was 1.31, 1.42, and 1.52 g cm^{-3} in the organic, native vegetation and conventional farming, respectively.

Contrasting to SOC content, the soil bulk density decreased significantly, following organic practices. The lower bulk density observed in the organic system is due to the permanent addition of compost that contributes to increasing organic matter input, decreasing soil bulk density (Valpasso*et al.,* 2001). The results concerning soil bulk density and total porosity indicated that the increase of soil porosity was

accomplished by a decrease in soil bulk density, as reported by Werner, 1997 in organic systems.

2.7.1.4.Water-filled pore space

Water-filled pore space (WFPS) is the ratio of volumetric soil water content to total soil porosity. Soil WFPS is determined simply from its bulk density and moisture content because particle and water densities are stable at ~2.6 and 1 kg/l, respectively. Application of organic fertilizers increases total porosity of the soil; therefore, decreases Water Filled Pore Space to some extent (Carter *et al.,* 2004).

2.7.1.5.Soil Nitrogen

Soil fertility is associated intrinsically to soil organic matter (SOM) because it is essential in maintaining good soil physical conditions especially soil structure, aeration, and water holding capacity, which contribute to soil fertility, and it is a crucial nutrient reserve. Organic matter also holds most of the soil reserve of N and large proportions of other nutrients such as phosphorus and sulfur (Shepherd, 2002). Typical ranges for SOM are from as little as 1.5% (of dry soil weight) in sandy soils under arable farming to as much as 10% in clay soils under permanent pasture. At the upper end of this range, that can extend to between 5 and 15 t organic N ha^{-1} in the top 15 cm (Briggs *et al.,* 2005).

Soil microbial biomass is a labile source of macronutrients like Carbon, Nitrogen, Sulphur, and Phosphorous. Organic matter is added in the soil help to boost growth and activity of soil organisms. C/N ratio and plant composition affect its mineralization by the soil microbes. A lustrous green plant part if add to the soil, it incorporates more amount of organic nitrogen, and due to narrower C/N ratio, microbes are easy to utilize and mineralize it. In this context, green manuring is more efficient (Castro and Whalen, 2016). Along with the nitrogen, in the practice of organic farming, improve the content of P, K, and other micronutrients. Marinari*et al.,* 2006 reported that NO_3^--N, NH_4^+-N, and P content was more in quantity in organically managed soil compared to the conventional one when measured at 5-20 cm and 25-30 cm depth.

Application of organic manure prepared from sawdust mixed livestock waste gave the better results of content of macronutrients (N, P, K, Ca and Mg) and micronutrients (Cu, Mn, and Zn) in the soil and the increase in dry matter of plant had shown higher amount of N, P, K, Cu and Zn accumulation (Wong *et al.,* 1999). Wang

et al., 2016 have been found that the soil treated with sheep manure compost was more enriched in total nitrogen as well as available K, Zn, Fe, and Mn quantity, but available phosphorous concentration unaffected, and available copper was reduced. Ali *et al.,* 2012 laid out a long term experiment in which they had used FYM compost + inorganic NPK fertilizers was able to raise soil organic carbon, total nitrogen as well as sulfur and ammoniacal nitrogen.

2.7.1.6.Soil organic carbon

Soil organic carbon (SOC) is a measurable component of soil organic matter. SOC makes up just 2–10% of most soil's mass and has a vital role in the physical, chemical, and biological function of soils. Organic matter contributes to nutrient retention and turnover, soil structure, moisture retention and availability, degradation of pollutants, carbon sequestration, and soil resilience.Terrestrial carbon sequestration reverses the loss of soil organic carbon resulting from intensive agricultural practices (Jackson and Schlesinger, 2004; IPCC, 2007).

Soil organic matter (SOM) acts as a reservoir for large amounts of carbon (Purakayastha*et al.,* 2008). Thus factors that affect the dynamics of SOM are of significant concern (Kemmitt*et al.,* 2008). Soil organic matter is integral to the development and maintenance of soil properties (Yin and Cai, 2006); and is known to influence soil fertility, soil chemical properties, soil water content (Rawls *et al.,* 2003), plant growth, soil microorganisms, greenhouse gas emissions, and nutrient cycling (Bastviked*et al.,* 2007). Soil organic matter also influences soil temperature, microbial activity, and the ability of the soil to sequester carbon and act as a sink for environmental contaminants (Fung *et al.,* 2005).

The literature on carbon sequestration in soils is extensive. However, SOC responds slowly to changes in the management of agriculture (Ludwig *et al.,* 2011). Most SOC changes need many years to be detectable by present analytical methods (Rasmussen *et al.,* 1998), and therefore, long-term experiments are required. Nevertheless, numbers of studies have been performed, and a few reviews have been published recently (Gonzalez-Sanchez *et al.*,2012;Govaerts*et al.*,(2009). Gonzalez-Sanchez *et al.,* 2012 concluded from a meta-analysis of data of 29 publications that some forms of conservation agriculture (*i.e.,* no-tillage and implementing cover crops) can have positive effects on soil organic carbon. Govaerts*et al.,* 2009 also reviewed

three aspects of conservation agriculture: reduction in tillage, retention of crop residues, and use of crop rotations.

Kim *et al.,* 2014 found that the use of compost decreased CH_4 emission as a contrast to manure by 50%. The agricultural practice of biogas spent slurry + urea reduced the dried CH_4 emission as compared to FYM + Urea from paddy soil (Debnath*et al.,* 1996).Soil Service Final publishable report; 2012 reviewed the soil organic matter (SOM) content, which is closely linked to SOC. Conventional farming included management regimes with mineral fertilizer and pesticide application, whereas organic fields included management types with organic manure and no pesticides. Söderström*et al.,* 2014 had studied observation onthe period of 1945–2009.They found that 29 studies were meeting their screening criteria for meta-analysis and indicated a positive impact of organic fertilizers on SOM content.

2.7.2. Effect on biological properties of soil

The soil is a habitat for more than $1/4^{th}$ of the entire living species present on the earth. A teaspoon of soil is composed of thousand species, millions of microbes, and their interlinking mechanisms. Soil biota is divided into three major groups based on their functional behavior *viz.,* biological regulators, chemical engineers, and ecosystem engineers. First, the biological regulators control the population of other soil organisms by way of browsing, parasitism, competition, predation, etc. An important role is accomplished by chemical engineers to transform the complicated soil organic matter into the mineralized form and releases the nutrients for recycling again. Other reconstructive ways followed by the ecosystem engineers for maintaining the soil structure, aggregation, porosity, and soil particle movement (Turbé*et al.,* 2010).

2.7.2.1.Soil microorganisms

Soil micro-organisms play a very significant role in nutrient cycling (Creamer *et al.,* 2016), organic matter decomposition (Riggs and Hobbie, 2016), degradation of organic pollutants (Kästner and Miltner, 2016), etc. On the constructive way, the organic farming helps in enhancing and maintaining the below-ground (Bender *et al.,* 2016) as well as above-ground biodiversity in contrast to the conventional farming system (Tuck *et al.,* 2014). Organically managed field condition provided a more suitable habitat for soil micro-biota by narrow down their evenness besides build up the richness (species) in comparison to the conventionally regulated field with synthetic fertilizers. The use of FYM in the conventionally managed plot had fertilized with

synthetic NPK fertilization resulted in providing more suitable conditions for slow-growing oligotrophic soil organisms, generated more dispersion, and became greater in species evenness as well.

Microbial/biological processes mediate the efflux of CO_2 (MacDonald *et al.,* 1995; Paul and Kimble, 1995), N_2O (Cao *et al.,* 2006) and CH_4 (Paul and Kimble, 1995). With microbial processes contributing over 70% of N_2O emitted to the atmosphere (Conrad, 1996) it is, therefore, essential to understanding how anthropogenic activities impact soil microbial population and greenhouse gas efflux and subsequently global climate changes. It is common knowledge that soil microorganisms regulate carbon, nitrogen, phosphorus, and sulfur cycles through organic matter decomposition, immobilization, and mineralization of these nutrients. These cycles are almost entirely controlled by enzymatic activity (Tate, 2002). Therefore an understanding of the different soil enzymes involved in nutrient cycling processes is critical to understand the processes themselves (Acosta-Martinez and Tabatabai, 2000). For example, amino acid arylamidase catalyzes the hydrolysis of an N-terminal amino acid from acrylamides (Acosta-Martinez and Tabatabi, 2002). While β-glucosidase is involved in the hydrolysis of cellobiose (Tabatabai, 1994), Dehydrogenase enzyme important in soil organic matter oxidation is only found in living cells (Wolińska and Stępniewska, 2012); therefore, provide a measure of the viable microbial population.

2.7.2.2.Soil enzymatic activities

An enzyme is a biocatalyst which speeds up a reaction rate and slowing down activation energy without its involvement in the reaction or process. Soil enzymes have often been used as indicators of soil quality and health because of the critical roles in regulating carbon, nitrogen, and other nutrient cycles through organic matter decomposition, and carbon and nitrogen immobilization and mineralization (Tate, 2002). Over the last 50 years enzyme activities have been used to monitor soil response to management practices, heavy metal pollution (Lorenz and Kandeler, 2006; Belen-Hinojosa et al., 2004), chemicals used in pest and disease control (Rahmansyah et al., 2009) and to assess soil functional diversity. Despite considerable research on soil enzyme activity, few attempts (Pant, 2009; Qin *et al.,* 2010; Wingate *et al.,* 2009) have demonstrated the use of enzyme activity as a tool for assessing microbial contributions to GHG efflux. Soil enzymes are the indicator of soil health; some necessary soil enzymes are given in **Table 2.2.**

Table 2.2:Important soil enzymes act as an indicator of soil health

Soil enzymes	Indicator	References
Dehydrogenase	Electron transport system (ETS) activity and C-cycling	Wolińska and Stępniewska, 2002
β- Glucosidase	Hydrolysis of maltose and cellobiose and C-cycling	Ekenler and Tabatabai (2004)
Phenol Oxidase	Degradation of recalcitrant aromatic compounds like lignin	Floch et al., 2007; Sinsabaugh, 2010
N-acetyl glucosaminidase	Conversion of chitin to amino sugars, which are major sources of mineralizable N in soils	Ekenler and Tabatabai (2004)
Phosphatase	Release of inorganic phosphate (PO_4^{3-}) and P cycling	Tabatabai .and Bremner,1969

Soil enzymes are the indicator of biological activity in the soil. It is an intracellular enzyme and having a positive correlation with microbial activity in soil (Bello *et al.,* 2013). That is involved in respiration as it oxidizes organic matter by donating protons along with electrons to acceptors (Das and Varma, 2011). It releases two protons which are transferred to either NAD^+ (Nicotinamide adenine dinucleotide) or $NADP^+$ (Nicotinamide adenine dinucleotide phosphate) and reduce those (Kumar *et al.,* 2013). Dehydrogenase activity in soil affects any interruption caused by trace elements, pesticides, and management practices (McCarthy *et al.,* 1994; Pitchel and Hayes, 1990).

Dehydrogenase activitywas higher in surface soil than sub-surface soil, as the surface soil having more amount of organic matter content (Kumar *et al.,* 2013). The biochar amended high SOM (Soil Organic Matter) soil had resulted in 1.3 and 1.6 times higher response for dehydrogenase activity and MBC (Microbial Biomass Carbon), respectively while comparing with soil having low SOM (Amelo*et al.,* 2015). Włodarczyk*et al.,* 2002, reported that soil dehydrogenase activity increased curvilinearly with organic matter content and decreased curvilinearly with redox potential (Eh).

(i). α and β- Glucosidase

Naturally, due to the wide variety of glycosidic bonds, there is a wide diversity of enzymes that are known as glucosidases (Daroit, 2007). Thus, the general name

glucosidases have been used to describe a group of enzymes that catalyze the hydrolysis of various glycosides (Kim and Ma, 2018). This diversity of enzymes is due to the different nature of their substrates and also the different evolutionary solution to the problem of constructing active sites capable of hydrolyzing glycosidic bonds (Daroit, 2007). Therefore, glucosidases usually are named according to the material/substrate that they hydrolyze. For instance, the α-glucosidase catalyzes the hydrolysis of α-D-glucopyranosides and β-glucosidase (BG) hydrolyzes maltose and cellobiose (EivaziTabatabai, 1990). The changes in management and soil use, such as deforestation or conventional agriculture, can lead to significant reductions in the soil organic matter content (Miralles*et al.,* 2012). BG activity in the soil is sensitive to a variety of management and various soil types and textures. Thus, in soils which are degraded and have a low amount of organic material, there are less simple sugars for the microbial population due to the BG activity reduction (Stott *et al.,* 2010).

The β-glucosidase enzyme is widely distributed in nature and is related to the carbon cycle, acting in the cleavage of cellobiose into glucose molecules. Because of its sensitivity, this enzyme is considered a soil quality indicator and is directly related to the quantity and quality of soil organic matter. About land use and management, BG activity tends to be higher in soil with high content for easily decomposable organic matter that is, in preserved soils and also in soils under crop rotation and direct planting. Furthermore, the addition of the soil organic residues such as biosolids, manure, urban sludge, and poultry litter, also increase the activity of this enzyme in the soil. However, in soils with the addition of organic material with a high C:N ratio and high amounts of lignified roots there is less BG activity and therefore slow organic matter decomposition (Meyer *et al.,* 2015). Several studies have shown that β-glucosidase activity was higher in fertilization treatments with compost, vermicompost, municipal solid waste compost, and straw mulch, than in those without compost as well as those with synthetic fertilizer and herbicide (Crecchio*et al.,* 2004; Meyer *et al.,* 2015). In general, β-glucosidase activity is closely related to soil organic matter, biological activity, and C cycling.

(ii). Phenol oxidases

Phenol oxidases (POs) are a group of soil extracellular oxidoreductase enzymes, which are involved in oxidative processes related to nutrient cycling. This class of enzymes has multiple functions at both the organism and ecosystem level and can

trigger either positive or negative feedback loops between soil organisms and soil organic matter. One of the main, and most studied, groups of enzymes involved in oxidative processes are phenol oxidases (POs) (Stursova and Sinsabaugh, 2008), which are extracellular oxidoreductase enzymes. They are released into the environment by excretion for cellular lysis. They can oxidize phenolic compounds and degrade lignin and humic substances, permitting the release of C and other nutrients (Piotrowska-Dlugosz, 2014; Sinsabaugh, 2010).

It is responsible for the oxidation of recalcitrant aromatic compounds, for instance, lignin, into readily available compounds consuming oxygen as the ultimate electron acceptor (Cullen and Kersten, 1996). Some soil microbes take advantage of extracellular phenol oxidases for the chemical decomposition of lignin and humus for getting carbon, energy, and other nutrients (Sinsabaugh, 2010). The low phenol oxidase activity results in the accumulation of soluble phenolic compounds, thereby the activity of the hydrolytic enzyme is hampered, which assist in sequestration of carbon in soil (Sinsabaugh, 2010). Martina Mazzon*et al.,* 2018 observed that the activity of specific phenol oxidase was lower in the compost treatment, although the differences were not statistically significant.

(iii). N-acetyl glucosaminidase (NAG) and Leucin amino peptidase (LAP)

N-acetyl glucosaminidase plays a vital role in both Carbon and Nitrogen cycling in soil. Riah*et al.,* 2013 reported that highest activity of NAG was recorded in biowaste compost plots (1.41) as compared to the control plots whereas highest β-glucosidase activity was observed in municipal solid waste compost and FYM applied plots. Their study revealed that the most sensitive enzymes reflecting soil functioning under organic amendment were β-glucosidase, N-acetyl-glucosaminidase (NAG), urease, and alkaline phosphatase.

Allison and Jastrow (2006) observed that the β-glucosidase and NAG enzymes in organic matter fractions have the significant potential to degrade plant-rich materials. Whereas Ceninі*et al.,* 2016 investigation provides evidence that fertilized soils showed significantly higher BG activities and lower NAG and LAP activities. This result also agrees with the results of other researchers, which showed that increased inorganic N availability has effects on the activity of N-acquiring enzymes (Stursova*et al.,* 2006).

2.7.2.3.Microbial biomass carbon

Microbial biomass is one of the most labile of the pools comprising organic matter. An increase in MBC is likely to better represent changes in the nutrient-supplying capacity of organic matter than an increase in total organic matter (Gunapalaand Scow, 1998). MBC, which represents about 1–4% of total soil organic C, is a more sensitive indicator of changing soil conditions than direct analysis of the organic C content. Leita*et al.,* 1999 reported lower MBC in the control and mineral fertilized soils (163–226 mg g^{-1} soil) then the soils amended with both FYM and increasing doses of compost. In Rice-Wheat-Mungbean cropping system, Singh *et al.,* 2015 reported the highest Organic Carbon and Microbial Biomass Carbon (range from 62.2 to 102.5 µg g^{-1} soil) was in the plots receiving a combination of vermicompost, crop residue, and bio-fertilizer.

2.7.2.4.Basal respiration and metabolic quotient

Soil respiration was significantly enhanced by the input of crop residue to plots receiving FYM and vermi-compost, whereas Metabolic Quotient (qCO_2) was the highest in plots receiving a combination of FYM, Crop Residue, and Bio-fertilizer. The metabolic quotient (qCO_2) evaluates the efficiency of soil microbial biomass in using the organic C compounds (Anderson andDomsch, 1989). Application of CR in combination with FYM, VC, and biofertilizer resulted in high qCO_2 values. That shows that those soils which receive inputs of easily degradable C account for the high qCO_2 values mainly due to more available C present in crop residue.

A high microbial quotient generally implies a ready supply of fresh organic residues (Anderson and Domsch, 1989). The higher qCO_2 values in these treatments could reflect an increase in the ratio of active: dormant components of the microbial biomass. Crop Residue supplies carbon as an energy source for micro-organisms and increases the microbial activity (Rousk and Baath 2007; Smith *et al.,* 1993). Addition of the bio-fertilizer to the plots receiving FYM + CR caused a significant decline in the Basal Respiration activity both in RWCS and RWMCS (Singh *et al.,* 2015).

2.8. Effect of organic farming on GHGs emission

Carbon, nitrogen, oxygen, and hydrogen are critical elements of life on Earth as the significant components of the atmosphere, soil air, and soil organic matter (Paul and Kimble, 1995). The processes that maintain the balance of carbon and nitrogen between

the atmosphere and soil are the carbon and nitrogen cycles, respectively (Keeling, 1997; Paul and Kimble, 1995). Carbon and nitrogen enter the atmosphere in the forms of CO_2, CH_4, and N_2O, which are by-products of coal, natural gases, and petroleum combustion. Additional contributions of CO_2 and N_2O to the atmosphere are made through industrial and agricultural processes (Keeling, 1997) with changes in land use affecting the nutrient cycles and the exchange rates of gases between the soil and the atmosphere (Glatzel*et al.,* 2004; Subbarao*et al.,* 2006).

The continued worldwide concern with increases in greenhouse gases and their effect on global climate change and the environment require a better understanding of the processes that govern greenhouse gas efflux (Fang and Moncrieff, 2000). Carbon dioxide (Zhou and Shangguan, 2006; Heinemann *et al.,* 2006; Xuexia*et al.,* 2006), nitrous oxide (McLain and Martens, 2005; Guo-yuan*et al.,* 2006) and methane (Keeling, 1997) are the gases significant concern. Carbon-dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are the primary greenhouse gases (GHGs), and their increment in per unit volume of air contributing to the global rise in temperature leads to positive radiative forcing. Agricultural activities give rise to an increase in the percentage of these GHGs (Robertson *et al.,* 2000). Globally, the agriculture sector is a significant contributor to greenhouse gas emissions, which is increasing at the rate of 1% per annum.

Agriculture is the chief contributor of CO_2, CH_4, and N_2O. Mainly, puddle rice emits more methane which contributes to around 24 % (*i.e.,* 3.37 Mt) out of total agriculture CH_4 emission, whereas, the application of nitrogenous fertilizers are responsible for 0.14 Mt N_2O from wheat, rice and other crops (Bhatia *et al.,* 2013). The conventional rice-wheat cropping system (RWCS) of Indo-Gangetic Plain (IGP) is the chief source of CH_4 emission and due to which more global warming potential (GWP) (Gupta *et al.,* 2016). Changes in management practices are relevant to minimize greenhouse gas (GHGs) emission. In the perspective of conventional farming, CO_2, or CO_2-eq evolution is much higher than organic farming. Because of the manufacturing of synthetic fertilizers evolve CO_2 or CO_2-eq from possible sources of fuels used in the fertilizer manufacturing industries.

Similarly, N_2O emission is also more from conventional farming.Interestingly, application of N fertilizes like ammonium sulfate reduces CH_4 emission but promotes

denitrification as N_2O loss. Applications of ammonium-based fertilizers or urea are induced methane consumption or oxidation by methanotrophs present in rice root rhizosphere (Bodelier, 2011). Therefore, CH_4 and N_2O emissions are affected by fertilizer applications (Cai*et al.,* 1997).

2.8.1. Carbon dioxide

*Carbon*dioxide is added to the troposphere through burning fossil fuels (coal, natural gas, and oil), solid waste, trees, biomass, and also as a result of specific chemical reactions (*e.g.,* industrial process). CO_2 is removed or sequestered from the air when plants absorb it as part of the biological carbon cycle. The impact of organic farming on CO_2 emissions is low (as discourage the activities of synthetic fertilizer production and their transportation up to field).

2.8.2. Methane

Methane (CH_4) is emitted during transportin and burning of coal, natural gas, and oil. CH_4 emissions also producedfrom livestock and other agricultural practices (paddy cultivation) and by the decay of organic waste in municipal solid waste and landfills. Plant-mediated CH_4 release from rice paddies accounts for about 60-90% of the total CH_4 emissions (Wassmann and Aulakh, 2000). CH_4 is an end product of anaerobic decomposition and produce by the reduction of CO_2 at highly reduced conditions, *i.e.,* 200 to -280 mV (Patrick and Reddy, 1978). Therefore, significant factors govern on CH_4 emissions are flooded conditions (highly reduced state) and carbon inputs.

Short duration or intermittently flooded conditions with proper drainage less favour the CH_4 emissions. Fertilizer application, rate, and types strongly affect the CH4 flux in the soil. Urea application increases the CH_4 emission due to a decline in redox potential and to increase soil pH, which accelerates the methanogens (Wang *et al.,* 1993). If more organic carbon adds to the soil through sources are promoted to be more CH_4 emissions, but depends upon reduction potential of the soil. Whereas, the impact of organic farming on CO_2 emissions is low (as discourage the activities of synthetic fertilizer production and their transportation up to field), but CH_4 emission could be more depends on a system of crop management (whether upland or flooded) with carbon inputs like in flooded rice.

2.8.3. Nitrous oxide

Nitrous oxide (N_2O) is emitted from agricultural and industrial activities, combustion of fossil fuels and solid waste, as well as during wastewatertreatment. N_2O plays a significant role in global warming and the depletion of stratospheric ozone (Forster *et al.,* 2007). Agricultural soils have been identified as a significant anthropogenic source of N_2O entering the atmosphere; globally releasing approximately 1.7–4.8 Tg N_2O-N yr^{-1} (IPCC, 2007). Nitrous oxide is emitted from the soil during the processes of nitrification and denitrification. Nitrification is the biological oxidation of ammonium (NH_4^+) to nitrate (NO_3^-) via nitrite intermediate, and nitrous oxide is a byproduct formed during this conversion, following ammonium fertilizer or ammonia forming fertilizer addition in aerobic soil. In soils, N_2O can be produced from nitrification under aerobic conditions and denitrification (the reduction of NO_3^- to N_2O and N_2) under moderately reducing conditions, i.e., the conditions under which denitrification partly, completely stops at the level of N_2O (Skiba*et al.,* 1993).

In contrast to conventional farming, application of FYM or green manure in organic farming induces methane emission, but not affects the N_2O emission (Linquist*et al.,* 2012). The applications of sulfate-based fertilizers are contributing to the reduction of CH_4 emissions. The use of ammonium sulfate and sulfate fertilizers reduced the CH_4 emission by 40 % and 28 % (208 kg S ha^{-1}), respectively, but enhanced N_2O emission in a flooded rice field (Linquist*et al.,* 2012). Similarly, N_2O emissions were also lower in organic farming (0.65±0.64 kg N ha^{-1} $year^{-1}$), whereas, conventional farming did more N_2O emission (0.95 ± 0.77 kg N ha^{-1} $year^{-1}$) (Marie *et al.,* 2015).

The overall conclude that conventional cropping systems significant emitters of N_2O and CO_2, but less impact on CH_4 emission as organic farming does. However, the adverse effect of conventional farming is more on the environment in organic farming. It is mainly because of more emission from fertilizers and agrochemicals application in conventional farming. Which also affecting soil biodiversity, deplete carbon stock, and adding harmful pesticide residue in food grains. However, organic farming is a natural emitter of GHGs with a positive effect on the environment. It also enhances biological activities, carbon-sequestration, and improvises physical condition of the soil.

2.9. Effect of soil physico-chemical properties on GHGs emission

The GHGs- CO_2, CH_4, and N_2O are the main contributors to radiative forcing in the atmosphere (Lal*et al.,* 2008 and Van Zwieten*et al.,* 2010. Besides various anthropogenic activities (fossil fuel combustion, cement production, industrial procedures), agronomic practices (drainage of wetlands, plowing, land-use conversion), paddy fields, fertilizers, livestock and wetlands are significant sources of CH_4 and N_2O (Yao *et al.,* 2012; Minamikawa*et al.,* 2011; Gogoi*et al.,* 2012).

Emission of GHGs from soils also depends on various soil physical and chemical properties. Related emission flux rates largely depend on soil water content (humidity), soil temperature, nutrient availability, and pH-value (Ludwig *et al.,* 2011). Soil pH is one of the most critical factors that affect N_2O production and consumption processes in soil (Van Zwieten., 2010). Microbial activity is influenced by soil pH (Dalal and Allen, 2008). Therefore, management practices such as liming influence soil emissions; additional carbonate can be released as CO_2 (Snyder *et al.,* 2009). Acidic soil conditions lead to lower soil emissions. The optimal pH-value for methanogenesis (CH_4 production) lies between pH 4 and 7 (Dalal and Allen, 2008). CO_2 emissions were observed to be highest at neutral pH-values (Cuhel*et al.,* 2010). N_2O emissions decrease only under acidic soil conditions. Nitrification increases with higher pH-values since the equilibrium between NH_3 and NO_3^- shifts to ammonia (Nugroho*et al.,* 2007). Soil, up to a large extent, alters the rates of microbial carbon turnover and thus can regulate CO_2 emissions. Lianfeng Wang, 2010 concluded that CO_2 emission increased positively with soil pH (R^2 =0.98, P<0.01).

Accumulation of soluble salts resulting from N-fertilizer also affects microbial production of N_2O and CO_2 in soils. Adviento-Borba*et al.,* 2006 conducted a study to determine the effects of electrical conductivity (EC) and water content on N_2O and CO_2emission in 5 soils under intensive cropping. Salt mixtures were supplemented to achieve an initial in situ soil EC of 0.5, 1.0, 1.5 and 2.0 dSm^{-1}. Themean CO_2emission decreased with increasing EC at both soil water contents, indicating overall reduction in microbial respiration with increasing EC. Average cumulative N_2O production at 60% WFPS decreased from 2.0 mg N_2O-N m^{-2} at an initial EC of 0.5 dS m^{-1} to 0.86 mg N_2O-N m^{-2} at 2.0 dSm^{-1}.

The primary source of N_2O from agriculture is the application of N-fertilizers in soil. Although de-nitrification is responsible for most of the N_2O produced in the soil, nitrification can also produce N_2O when O_2 is limited. Increasing the soil organic C content can also increase the N_2O production (Brentrup*et al.,* 2000) but not as significant as the application of N-fertilizers. However, the effect of organic C depends on the degree of anaerobic conditions created by microbial metabolism (Stevens & Laughlin, 1998). Skinner *et al.,* 2019 observed a 40.2% reduction of N_2O emissions per hectare for organic compared to non-organic systems. When compared to inorganic N fertilizers, farmyard manure (FYM) increased CH_4 emissions by 26% in flooded rice system (Linquista*et al.,* 2012). Increasing soil N content generally leads to higher soil respiration and higher net ecosystem exchange (NEE), if carbon is not limiting (Niu*et al.,* 2010; Peng*et al.,* 2011). NH^{4+} fertilizers caused higher N_2O emissions under saturated conditions (Tenuta and Beauchamp, 2003).

McGill *et al.,* 1981 proposed that soluble organic C in the soil is an immediate source of C for soil microorganisms, which in turn emit CO_2. Alvarez *et al.,* 2001 found that increase of CO_2 emission from the soil represented 21% of C applied through sludge. Curtin, 1998 observed that incorporation of straw increased CO_2 flux from 0.3 to 1.3 kg CO_2 ha^{-1} d^{-1}. Soil water content in water-filled pore space is another variable that affects the rate of respiration (Xu and Qi, 2001). The release of CO_2 by aerobic-respiration is a non-linear function of temperature over a wide range of soil water contents but then becomes a function of water content as the soil dries out. Lowering the water table in organic soils through drainage increases the release of soil carbon as CO_2 in some but not all environments, and reduces the quantity of CH_4 emitted to the atmosphere.

Aerated soils are a sink for atmospheric $CH_4$by microbial oxidation. The control of the oxidation rate is gas diffusivity, and the temperature response is small. Emission of N_2O increases markedly with increasing temperature, and this is attributed to increases in the anaerobic volume fraction, brought about by a raised respiratory sink for O_2. Increases in water-filled pore space also result in increased anaerobic volume; again, the outcome is an exponential increase in N_2O emission (Smith *et al.,* 2014). In another experiment, Carbon dioxide production from the soil for the 0 to 75 mm sampling depth, for both fertilized and non-fertilized soils, was highly correlated with % WFP ($r = 0.892$, $p < 0.001$). The percentage of the soil pore space filled with water

appears well correlated with aerobic microbial activity as estimated by CO_2 or N_2O production (Linn *et al.,* 1984).

2.10. Effect of soil biological properties on GHGs emission

The influence of soil physical and chemical factors has already been reported in several studies (Cuhel*et al.,* 2010; Linquista*et al.,* 2012). Thus new factors that have a relationship with GHG emission are of the utmost importance to try to understand the dynamics of the gases in the soil. The carbon of microbial biomass and the basal respiration are the most used attributes in studies on biological indicators of soil. Higher basal respiration rate means the release of nutrients into the soil and in long term loss of organic carbon to the atmosphere. Metabolic quotient (qCO_2) calculates the release of CO_2 per unit biomass for a certain period this related to CO_2 and CH_4 emissions (Anderson and Domsch, 1993).

Higher CO_2 production in the soils was probably due to the higher soil SOC and MBC contents; the CO_2 production from soils showed a positive correlation with soil MBC (Kong *et al.,* 2013). That was consistent with the findings of Iqbal *et al.,*2010, where a significant positive correlation between soil CO_2 flux and MBC was also observed. The release of CO_2 is due to the action of microorganisms in the process of decomposition of organic matter. These organisms are extensively used as indicators of soil quality as they argue positively to changes in soil management in the short term (Galdos*et al.,* 2009) since physical and chemical attributes are not always appropriate to explain the variations that occur in the soil from the actions of its use handling.

Nigel Hoilett, 2011 reported positive correlations among GHG and nutrient cycling enzymes and suggested that substrate availability affected GHG efflux since mineralizing enzymes are integral in the release of nutrients from organic matter. However, significant, although weak, correlation between the activities of β-glucosidase (r -0.20; $p<0.01$), dehydrogenase (r -0.39; $p<0.001$), and arylamidase (r -0.22; $p<0.01$) and GHG efflux indicates that enzymes may provide useful information on the role of soil microorganisms in GHG efflux.

Włodarczyk*et al.,* 2002, reported that soil dehydrogenase activity increased curvilinearly with organic matter content and decreased curvilinearly with redox potential (Eh). Generation of CO_2 and N_2O under flooded conditions was shown to be significantly related to dehydrogenase activity. The final cumulative CO_2 production

increased linearly with soil organic matter content and curvilinearly with dehydrogenase activity and decreased linearly with redox potential. The final cumulative N_2O production decreased linearly with Eh and increased curvilinearly with pH and dehydrogenase activity but linearly with organic matter content. Cristina Muñoz *et al.,* 2019 also reported that CO_2 emissions have a positive Pearson correlation coefficient (r-value) with total N (0.59) and urease activity (0.59). N_2O emissions have a positive correlation with total N (0.72), microbial biomass (0.49), β-glucosidase (0.52) and urease (0.73) but a negative correlation with soil pH (−0.57). Besides, CH_4 emissions present a positive r value with soil pH (0.50) but a negative correlation with β-glucosidase activity (−0.43).

CHAPTER 3
MATERIAL AND METHODS

The study was undertaken to quantify greenhouse gas (GHG) emission from organic vs. conventional rice-wheat-mungbean (R-W-M) cropping systems. The effect of organic vs. conventional cropping systems on soil physico-chemical and microbial parameters with GHG emission under R-W-M) cropping systems was also studied. This chapter focus on materials and methods employed during research work and described in detailed under the following sub-headings:

3.1. Experimental site

The field experiment was conducted in the prime block 14-C of the research farm of the ICAR-Indian Agricultural Research Institute, New Delhi, India, during 2015-16 and 2016-17. The site is situated at 28.4° N and77.1° E at an elevation of 228.6 m above mean sea level (Arabian Sea). IARI-Delhi research farm has a semi-arid and sub-tropical climate with hot and dry summers and cold winters. It falls under the Trans-Gangetic Plains, a critical agro-climate zone of India. The summer months (May and June) are the hottest temperature with the maximum and ranged from 41 to 48°C, while January is coldest with the minimum temperature ranging between 3 and 7°C. The temperature rises gradually through February to March and reaches a maximum during June, then drops slightly with the arrival of south-west monsoon rain. The mean rainfall of Delhi is 650 mm which is mostly received during July–September with occasional rain during winter. The soil of the experimental field is a sandy clay loam (typical Ustochrept) in texture, having 52.06% sand, 22.54% silt and 25.40% clay (pH 8.18, organic matter 1.25%). The physiochemical properties of the experimental field are given in **Table 3.1**.

3.2. Experimental design

The field experiment investigation was laid out in a Randomized Plot Design with three replications. No chemical pesticide/disease/weed control agent was supplied in the field. Hence this study was carried out totally under organic farming conditions. The seven types of treatments were selected for the field study. These treatments were managed since 2003 for both rice and wheat crop(**Table 3.2**).

Table 3.1 Physiochemical properties of the experimental field

Mechanical Composition	
Sand (%)	52.06
Silt (%)	22.54
Clay (%)	25.40
Textural Class	Sandy Clay Loam
Chemical Composition and Physical Properties	
pH (1:2.5 Soil-water ratio)	8.16
Electrical Conductivity (ds m^{-1})	0.79
Organic Carbon (g kg^{-1} soil)	5.20
Total Kjeldahl N (mg kg^{-1} soil)	580
0.5 M $NaHCO_3$ extractable P (mg kg^{-1} soil)	8.42
Neutral 1 N NH_4OAC extractable K (mg kg^{-1} soil)	187
Bulk Density (Mg m^{-3})	1.50
Field Capacity at 1/3 atmospheric tension (%)	24.57

Table 3.2 Cropping history of the experimental field

Year	**Kharif**	**Rabi**	**Summer**	**Remarks**
2001-02	Rice	Wheat	--	Conventional Farming
2002-03	Rice	Wheat	--	
2003-04	Rice (organic)	Wheat (organic)	--	Transitional Period
2004-05	Rice (organic)	Wheat (organic)	--	
2005-06	Rice (organic)	Wheat (organic)	Mung bean (organic)	
2006-07	Rice (organic)	Wheat (organic)	Mung bean (organic)	Organic Farming
2007-08	Rice (organic)	Wheat (organic)	Mung bean (organic)	
2008-09	Rice (organic)	Wheat (organic)	Mung bean (organic)	
2009-10	Rice (organic)	Wheat (organic)	Mung bean (organic)	
2010-11	Rice (organic)	Wheat (organic)	Mung bean (organic)	
2011-12	Rice (organic)	Wheat (organic)	Mung bean (organic)	
2012-13	Rice (organic)	Wheat (organic)	Mung bean (organic)	
2013-14	Rice (organic)	Wheat (organic)	Mung bean (organic)	
2014-15	Rice (organic)	Wheat (organic)	Mung bean (organic)	
2015-16	Rice (organic)	Wheat (organic)	Mung bean (organic)	
2016-17	Rice (organic)	Wheat (organic)	Mung bean (organic)	

3.2.1. Treatment details

Treatments consisted of eight combinations of one cropping system, namely rice-wheat–mungbean: (T1) FYM + CR + B; (T2) VC+CR+B (T3) FYM + CR; (T4) VC; (T5) FYM; (T6) VC+CR; (T7) Recommended dose of fertilizers and (T8) a non-amended control (**Table 3.3**). These treatments were applied to all the crops, i.e., rice, wheat, and mung bean, during the period 2015-16 and 2016-17. The cropping history of the experimental field and treatment details are summarized in **Table 3.3**. The specific biofertilizers were applied to the wheat (Azotobacterial and cellulolytic culture), rice (BGA and Cellulolytic culture), and mung bean (rhizobium culture) crops. For analytical the study, soil samples were collected at the rice-wheat–mungbean harvest of both the years.

FYM (Farm Yard Manure) - equivalent to 60 kg N ha^{-1}

VC (Vermicompost) – equal to 60 kg N ha^{-1}

CR (Crop Residue) – incorporation of the residue of the previous crop in succeeding crop

B (Biofertilizer) – Crop Specific:Rice(BGA, and Cellulolytic culture);Wheat (Azotobacter and Cellulolytic culture);and Mungbean (Rhizobium culture)

Experimental design: RBD, Plot size: 6.4 m x 7.6 m

Varieties:DBW-17 (Wheat),

Pusa Basmati 1121 (Rice),

Pusa Vishal (Mung bean)

Table 3.3 Number of treatments and Treatment details

Sr. No.	Treatments	Source of Nutrients
T1	CONTROL	No fertilizer or manure is applied
T2	CONVENTIONAL	The recommended dose of N, P, K through synthetic fertilizers (120:60:40)
T3	FYM	Through FYM
T4	VC	Through Vermicompost
T5	FYM + CR	Through FYM and Crop Residue
T6	VC+CR	Through Vermicompost and Crop Residue
T7	FYM + CR + B	Through FYM, Crop Residue and Biofertilizers in addition
T8	VC+CR+B	Through Vermicompost, Crop Residue and Biofertilizers in addition

3.3. Laboratory analysis

3.3.1. Soil sample collection and processing

Soil samples were drawn from 0-15 cm and 15-30 cm depth of soil from each plot separately with the help of core sampler. These soil samples were dried in the shade and passed through 2 mm sieve. Sieved soil samples used for further physico-chemical propertiesanalysis. An additional set of moist soil sample of 0-15 cm depth was stored in the refrigerator for soil microbial and enzymatic study. The third set of undisturbed soil samples, as well as disturbed soil samples (collected with the help of core sampler), were reserved for soil physical analysis. Soil samples were collected after wheat harvesting because we considered the soil samples have represented an output of the whole cropping system.

3.4. Soil physico-chemical properties

Summary of the physico-chemical properties of the soil samples used for analysis is given in the **Table 3.4**.The procedures for the measurement of physico-chemical parameters are shown in**Plate 3.1**:

Table 3.4 Analysis of Soil physico-chemical properties

Sr. No.	Parameters	Methods
1.	Electrical conductivity	EC meter
2.	pH	Potentiometry (Piper,1966)
3.	NO_3^- N	Steam distillation with MgO and Devardra alloy
4.	NH_4^+ - N	Steam distillation with Indophenols blue
5.	Total Nitrogen	Kjeldahl method
6.	Bulk density	Core Sampler Method (Dastane, 1967)
7.	Organic carbon (Kg/ha)	Walkley& Black's wet oxidation method (Jackson, 1973)
8.	Water-filled pore space (%)	Hutchinson and Mosier, 1981.

Plate 3.1: Measurement of physico-chemical parameters

3.4.1. pH and EC

Five grams of air-dried soil was stirred with 25 ml distilled water for half an hour and pH (1:5 Soil: water suspension) was determined using glass electrode in combination with calomel electrode on pH meter (Piper, 1966). The electrical conductivity of 1:5 soil: water supernatant solution was measured by conductivity meter after keeping soil suspension overnight (Jackson, 1967).

3.4.2. Ammonium (NH_4^+-N)

NH_4-N was extracted with Sodium Chloride (NaCl) solution and determined calorimetrically by the Nessler method. Take fresh soil samples and determine moisture content gravimetrically. Add acidified NaCl solution and filter with Whatman No. 42 into a Buchner funnel. Add sodium tartrate and gum acacia as a protective colloid. Then Nessler reagent was mixed, and the intensity of the orange color was measured at 410 nm.

3.4.3. Nitrate (NO_3^--N)

NO_3^--N in the soil extract can be determined calorimetrically or by reducing with the help of Devarda's alloy followed by distillation. Clear soil extract is obtained by using $CuSO_4$, Ca $(OH)_2$ or $MgCO_3$, and the interference of chloride ions is prevented by adding silver sulfate to the $CuSO_4$ solution. The colorimetric method is based on the nitration of phenol disulphonic acid in fuming sulphuric acid. The colorless product (in acid) behaves like a nitrophenolic type indicator and turns yellow when neutralized with NH4OH due to the formation of ammonium nitrophenoldisulphonic acid. Measure the intensity of the yellow color at 470 nm in a spectrophotometer.

3.4.4. Total Nitrogen

The estimated total Nitrogen was done by Kjeldahl method following wet digestion, for which 0.5 g dried soil was digested with sulphuric acid and hydrogen peroxide according to the method of Wolf (1982). For this purpose, the dried soil (0.5 g) was placed in digestion tubes, 2 mL of conc. H_2SO_4 was added and incubated overnight at room temperature. Then 1 mL of H_2O_2 (35%) AR grade extra pure was poured down through the sides of the digestion tubes and was rotated. Tubes were ported in a digestion block and heated up to 350°C until fumes were produced and proceeded to heat for another 30 min, digestion tubes were removed from the block and cooled. Then 1 mL of H_2O_2 was slowly added, and tubes were placed back into the digestion block until fumes were produced for 20 min. Again, digestion tubes were removed. Above step was repeated until the cooled matter became colorless. The volume of extracts was made up to 50 mL with distilled water. Then it was filtered and used for the determination of total nitrogen.

Total nitrogen was determined by the Kjeldahl method. 10 mL of aliquot was taken in Kjeldahl flask. Then it was placed on the Kjeldahl ammonium distillation unit, 10 mL of 40 % sodium hydroxide solution was added, and the flask was immediately connected to the distillation apparatus. 10 mL of 2 % boric acid solution was taken with a few drops of mixed indicator (bromocresol green methylene red) in 100 mL conical flask. When the distillate was approximately 40-50 mL, the conical flask was removed, and distillation was turned off. The distillates were cooled for a few minutes and then titrated with 0.01 N standard sulphuric acid up to pink endpoint. A blank was run for the complete procedure (Jackson, 1962).

3.4.4. Bulk density

Soil samples were collected from 0-15 cm soil depth before sowing and after harvest of the crop in each replicate with the help of core sampler for assessing bulk density (BD). BD was determined by keeping the soil samples under oven at 105°C for 48 hours and expressed in g/cc (Dastane, 1967).

$$\text{Bulk density (g/cc)} = \frac{\text{Weight of oven-dry soil}}{\text{Volume of wet soil}}$$

3.4.5. Water Filled Pore Space

Water-filled pore space (WFPS) is the ratio of volumetric soil water content to total soil porosity. A soil's WFPS is determined simply from its bulk density and moisture content because particle and water densities are stable at ~2.6 and 1 kg/l respectively. Water-filled pore space was analyzed by firmly established methodologies *described* by Hutchinson and Mosier, (1981). WFPS was calculated from the equation:

$$WFPS = (SWC^* BD) / \{(1- (BD/PD)\}$$

Where,

SWC is the soil water content (g g^{-1}), BD is the bulk density (Mg m^{-3}), and PD is the particle density (2.65 Mg m^{-3}).

3.4.6. Soil Organic Carbon

0.5 g soil samples having passed 0.2 mm non-ferrous sieve was placed in a 500 ml conical flask. Next, precisely 10 ml of 1 N $K_2Cr_2O_7$ solution was pipetted onto the soil and mixed with swirling the flask. Then 100 ml of concentrated H_2SO_4 was added and mixed by gentle rotation for 1 minute to assure complete contact of the reagent with the soil and allowed to stand 20-30 minutes. A standardized blank was also run in the same way. The solution was diluted to 200 ml with water, and 10 ml 85% H_3PO_4, 0.2 g NaF, and few drops of diphenylamine indicator were added. The solution was back titrated with FAS (Ferrous Ammonium Sulphate) until the colour of the mixture turns brilliant green. The following equation calculated the results: -

$$\% \text{ Organic Matter} = 10[1(S-B)] \text{ X } 0.67$$

Where,S = sample titration; B = blank titration

3.5. Microbiological analysis

Summary of the microbial properties of the soil *samples used* for analysis is given in the following **Table 3.5**.Representative moist soil samples were collected at the harvesting of crops for microbial properties analysis by supplying irrigation to the field.

Table 3.5 Analysis of Soil microbiological properties

Sr. No.	Properties	Methods
1.	Dehydrogenase	Spectrophotometric method by Klein *et al.,* 1971
2.	Microbial biomass carbon	Fumigation extraction method by Jenkinson and Powelson, 1976)
3.	β- Glucosidase	MUB based fluorometric method
4.	α-Glucosidase	MUB based fluorometric method
5.	Phenol Oxidase	MUB based fluorometric method
6.	N-acetyl glucosaminidase	MUB based fluorometric method
7.	Phosphatase	MUB based fluorometric method
8.	Basal respiration	Alkali trap method
9.	Metabolic quotient	qCO_2 = (Basal respiration/MBC) * 1000

After reaching to field capacity, samples were collected manually from each treatment plots at 0-15 cm depth of soil using a tube auger. Wet soil samples were kept in the polythene bags and stored in the refrigerator at -20°C and utilized within two days for all microbial and enzymatic study.Soil microbial propertiesanalysis was carried out by thoroughly mixing moist samples in triplicate, and the results were displayed on a dry weight basis.

3.5.1. Dehydrogenase Enzyme

Soil Dehydrogenase activity was measure using Spectrophotometric method described by Klein *et al.,* 1971. Biological activity of a soil is a function of the number of organisms present in soil coupled with their physiological efficiencies. The rate respiration can be used as an index of biological activity of soil as it reflects the physiological efficiency of the organisms. Monitoring of dehydrogenases, which are respiratory enzymes and an integral part of all soil organisms, give a measure of biological activity of soil at a given time.

For determination of dehydrogenase activity, 1 g air-dried soil sample was taken in a 15 mL air-tight screw-capped tube. Then 0.2 ml of 3% TTC solution was added in each of the tubes to saturate the soil. After that, 0.5 ml of 1% glucose solution was added in each tube. Smoothly tap the bottom of the test tube to drive out all trapped oxygen, and thus a water seal was formed above the soil. Ensure that no air bubbles were formed and tubes were incubated at 28±0.5 °C for 24 hours. After incubation 10 ml methanol was added and shaken vigorously and allowed to stand for 6 hours. Clear pink coloured supernatant was withdrawn. Then readings were recorded with a spectrophotometer at a wavelength of 485 nm (blue filter). The amount of Triphenylformazan formed from the standard curve drawn in the range of 10 to 90 µg TPF ml^{-1} was extrapolated and results were expressed as µg TPF $h^{-1}g^{-1}$ soil.

3.5.2. Basal Respiration and Metabolic Quotient

The soil respiration (SR) was measured by the alkali entrapment method (Stotzky, 1965) and the metabolic quotient was computed as respiratory activity in relation to microbial biomass (Anderson &Domsch, 1993). The qCO_2, i.e., the respiration to biomass ratio, was calculated from:

$$qCO_2 = \text{Basal respiration} \times 1000/\text{Microbial Biomass Carbon}$$

The method involves absorption of CO_2 evolved during a given period of time in a known volume and strength of alkali (NaOH). When CO_2 is absorbed in NaOH, it is converted to Na_2CO_3. The excess of NaOH is titrated against standard HCl. Before titration with HCl, a few drops of saturated $BaCl_2$ solution is added to the NaOH solution to precipitate the Na_2CO_3 as $BaCO_3$. Otherwise, CO_3^{-2} in Na_2CO_3 consumeHCl and underestimate the CO_2 evolved(Insam&Haselwandter, 1989).

Take 40g moist soil in a 50 ml capacity beaker and keep the beaker inside the glass jar. Take 5 ml of 0.5N NaOH in a scintillation vial and place it inside the glass jar just beside the beaker. Add 2 to 3 ml of water in the floor of the jar and close the lid to make it airtight. Also, keep one blank without the soil. Keep the jar in the incubator and takeout the jar from the incubator at different specific time intervals. Transfer the 0.5N NaOH solution from the vial to a conical flask. Give several pieces of washing of the vials to ensure complete transfer. Add a few drops of saturated $BaCl_2$ solution and few drops of phenolphthalein indicator. Titrate with standard 0.5N HCl slowly until the pink color disappears. Approach the endpoint with caution and record the exact amount of

acid required. The following formula is applied to determine the amount of CO_2 released from the sample during the incubation period:

$$mg\ CO_2 = (B-V) * (N*E)$$

where,

B= Volume (ml) of the standard blank HCl needed to titrate the trap solution from the empty jar (blank) to the endpoint

V= Volume (ml)of the standard acid needed to titrate the trap solution from the sample jars to the endpoints

N= Normality of HCl

E= Equivalent weight of C in CO_2

1 ml 0.1 M consumed NaOH was equivalent to 2.2 mg CO_2.

The metabolic quotient (qCO_2) was calculated as the ratio of respiration (mg CO_2-C $g^{-1}h^{-1}$) to MBC.

3.5.3. Microbial Biomass Carbon

Soil MBC was determined by the fumigation-extraction method described by Jenkinson and Powelson (1976), and MBN was measured using a procedure explained by Brookes *et al.,* (1987).20g of soil samples were taken and put the soil for fumigation with chloroform to kill all the organisms in the soil for three days. Non-fumigated samples were added with 50ml of 0.5M $K_2SO_4$and 10 ml aliquot collected in 500 ml flasks. Subsequently, 2ml $K_2Cr_2O_7$ and 10 ml concentrated H_2SO_4 was added and left for half an hour. Then orthophosphoric acid and 250 ml distilled water was added and titrated with 0.01N Ferrous Ammonium Sulphate. The same procedure was followed for fumigated samples, and calculation was done by the following formula:

MBC (µg per g of soil) = [{(EC (f)*vol. of solution in extracted soil (ml))/dry weight of sample (g)} - EC (nf)* {vol. of solution in extracted soil (ml)/dry weight of sample (g)}]/K_{EC}

Where,

EC (f)= Organic carbon extracted from fumigated sample µg g-1 soil on oven dry weight basis.

EC (nf)= Organic carbon extracted from non-fumigated sample µg g-1 soil on oven dry weight basis.

K_{EC}= Efficiency of MBC = 0.25

3.5.4. A fluorimetric method for measuring the soil enzymes activity

Microorganisms, mainly bacteria, and fungi produceextracellular enzymes. They are key agents involved in many biogeochemical processes. They are necessary to facilitate terrestrial ecosystem nutrient cycling. They have been studied for decades to understand decomposition and nutrient cycling better. More recently, enzyme activity has been examined in relation to ecosystem responses to global climate change.Fluorescence is when a molecule transmits light of one wavelength after absorbing light of a different wave-length. Fluorometric-assays use a difference in the fluorescence of substrate from product to estimate the enzyme reaction. The basic concept of the fluorescence enzyme assay is that synthetic substrate-bound with a fluorescent dye is added to soil samples.

Enzyme activity is estimated as the fluorescent dye is released from the substrate by an enzyme-catalyzed reaction; whereas higher fluorescence indicates more substrate degradation compared to lower fluorescence. Two commonly used synthetic fluorescent indicators are 4-methylumbelliferone (MUB) and 7-amino-4-methyl coumarin (MUC).These assays usually are much more sensitive than spectrophotometric assays. However, they can suffer from interference caused by impurities and the instability of many fluorescent compounds when exposed to light.*Summary* of thefluorometric-assays to estimate the soil enzyme reactionis given in the following **Table 3.6**. Enzymatic analysis by Tecan infinite m200 microplate reader is shown in **Plate 3.2.**

Table 3.6. Fluorometric-assays to estimate the soil enzyme reaction

Enzyme Assayed	**Substrate**
β-Glucosidase (BG)	4-MUB- β-D-glucopyranoside
Leucineaminopeptidase (LAP)	L-leucine-7-amido-4-methyl coumarin hydrochloride
Phosphatase (PHOS)	4-MUB phosphate
β-Xylosidase (XYL)	4-MUB- β-D-xylopyranoside
N-acetyl- β-Glucosaminidase (NAG)	4-MUB-N-acetyl- β-D-glucosaminide

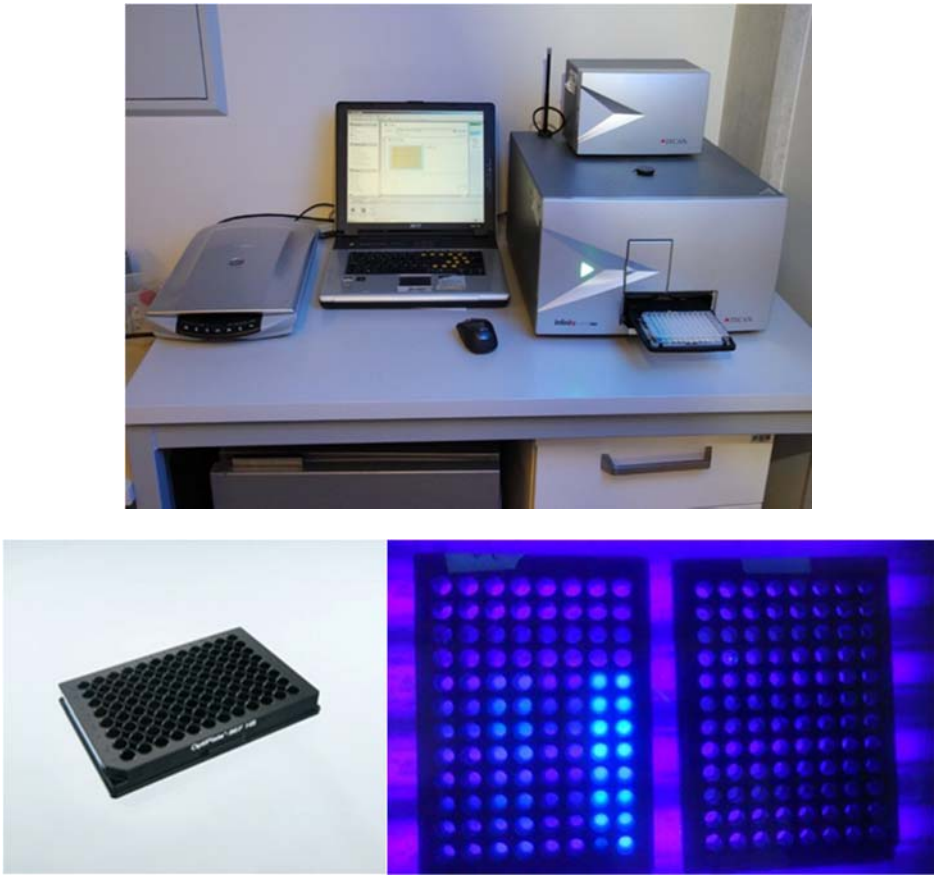

Plate 3.2: Enzymatic analysis by Tecan infinite m200 microplate reader

3.5.4.1. Stock solution and standard preparation (1 mM)

Dissolve 17.6 mg of MUB in 100 ml distilled water. Dissolve 17.5 mg of MUC in 100 ml distilled water. Dilute the standard stock solution to create a standard curve. Start with a 1:10 dilution of the stock solution to create a 100µM solution. Make all further dilutions of 50, 25, 10, 5, 2.5 µM from 100 µM. Because of background autofluorescence, a standard curve must be prepared for each sample.

3.5.4.2. Buffer preparation

50 mM, Tris Buffer, dissolve 6.057g Tris Base in 900ml distilled water and maintain pH to 8.2 with concentrated HCl. The buffer should be made fresh but can be refrigerated at 4°C for a week.

3.5.4.3. Assay Set-Up

Prepare standard plates by pipetting 200 µl of appropriate standards into correct wells of MUB or MUC standard plates. Prepare soil slurries by weighing 2.75g of moist

field soil into a blender. Be sure to measure moisture content because enzyme activity is typically presented on a g^{-1} soil dry weight basis. Then add 91ml of 50 mM buffer and mix for 1 minute. Pipette 800 µl of soil slurry into wells for enzyme activity measurement and standard curves preparation. Pipette 200µl of appropriate 200 µM substrate into correct assay wells and record the time of substrate addition.

3.5.4.4. Incubation and Analysis

Seal the plates with plate mats and place them in an incubator for 1.5 hours at 35°C. When incubation is complete, centrifuge plates for 3 minutes at 1500 rpm. Transfer 250µl aliquot from each well into corresponding well in a flat-bottomed black 96-well plate and add 5 µl of 0.5 N NaOH to each sample to adjust the final pH to 10. Measure the fluorescence in Tecan Infinite M200 microplate reader using the following parameters:

Excitation wavelength (nm)= 365 nm and Emission wavelength= 450 nm

3.6. Greenhouse gas emission (GHG) study

3.6.1. Quantification of GHS emission from rice, wheat and mungbean fields

Collection of gas samples were carried out for CO_2, CH_4, and N_2O by the closed chamber technique (Hutchinson and Mosier, 1981). Chambers of 15 cm x 15 cm x 50 cm (length x width x height) were made of 4 mm thick acrylic sheets (**Plate 3.3a**). An aluminum channel was placed in the field with each chamber. The channels were inserted at 10 cm depth in the soil and filled with water to make the system airtight. One 3-way stopcock (Eastern Medikit Ltd. India) was fitted at the top of the chamber to collect gas samples. The chamber was thoroughly flushed several times with a 50 ml syringe to homogenize the inside air. Gas collection by closed chamber technique in wheat, rice and mungbean are shown by **Plate 3.3b, 3.3c and 3.3d,** respectively.Gas samples were drawn with 50 ml syringe with the help of a hypodermic needle (24 gauges) at 0, 30 & 60 minutes and syringes were made an airtight with a 3-way stopcock. Headspace volume inside the box was recorded, which was used to calculate the flux of N_2O, CO_2, and CH_4. The concentration of these gases in the gas samples were measured using a gas chromatograph fitted with appropriate detectors (**Plate 3.4).**

The concentration of CH_4 and N_2O were detected by using a flame ionization detector (FID) and electron capture detector (ECD), respectively. Whereas the concentration of CO_2 was measured using FID fitted with methanizer. Total CO_2, CH_4,

and N_2O emission were estimated in the entire crop growth period by successive linear interpolation of average emission of these gases on sampling days. Hypothesize that emission of these gases followed a linear trend during the periods when no sample was taken (Pathak *et al*., 2003; Bhatia *et al*., 2005 and Gupta *et al*., 2016).

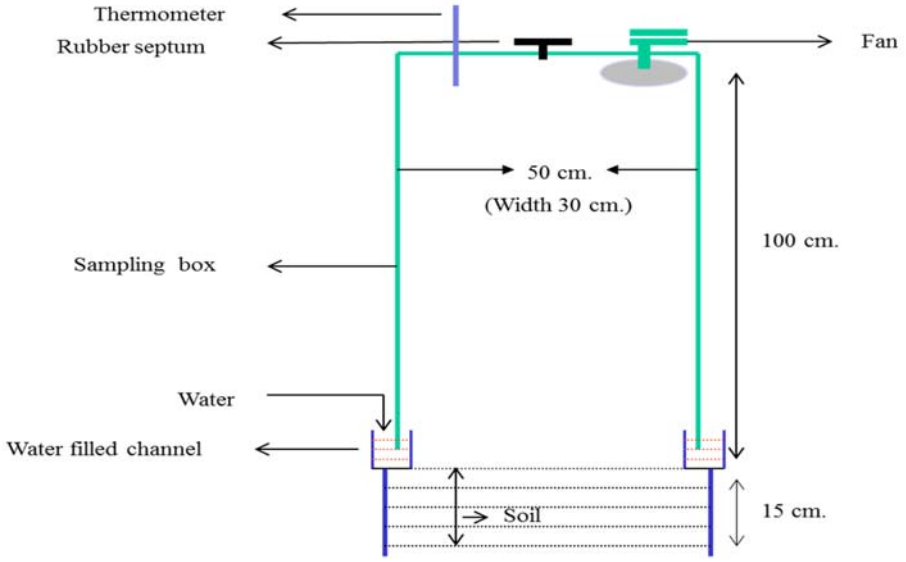

Plate 3.3a: Dimentions of the gas collection chamber

Plate 3.3b: Gas collection by closed chamber technique in wheat

Plate 3.3c: Gas collection by closed chamber technique in rice

Plate 3.3d: Gas collection by closed chamber technique in mungbean

Plate 3.4: Measurement of GHG flux by Gas Chromatography

3.6.2. Calculation of GHG (CH_4, N_2O, and CO_2 flux) in the gas samples

Cross-sectional area of the chamber = A m^2

Headspace = H m

Volume of headspace = AHm^3 = 1000 x AH l

Concentration given GHG at 0 time = Co ppmv

Concentration given GHG after time t = C_t ppmv

Change in concentration in time t = (C_t -C_o) ppmv

= (C_t -C_o) µl l^{-1}

Volume of given GHG evolved in time t = (C_t -C_o) µl l^{-1} x 1000 AH L

= (C_t -C_o) x AH ml

When t is in hours, then flux = (C_t -C_o) x AH)/(A x t) ml m^{-2} h^{-1}

= Y µl m^{-2} h^{-1}

Now 22.4ml of CH_4 is 'M' mg at STP (M = molecular weight of given GHG)

So, Y µl of N_2O is (44 x Y/22.4) µg at STP

Therefore, Flux = Y x 44/22.4 µg $m^{-2}h^{-1}$

Hence, N_2O Flux = [(C_t-C_o)/t] x H x 44/22.4 µg $m^{-2}h^{-1}$

CH_4 Flux = [(C_t-C_o)/t] x H x 16/22.4 µg m^{-2} h^{-1}

CO_2 Flux = [(C_t-C_o)/t] x H x 44/22.4 µg m^{-2} h^{-1}

Flux of GHGs in mg ha^{-1} d^{-1}

Flux of N_2O (mg ha^{-1} d^{-1}) = [(Ct – Co)/t] × H × 44/22.4 × 10000 × 24

Flux of CH_4 (mg ha^{-1} d^{-1}) = [(Ct – Co)/t] × H × 16/22.4 × 10000 × 24

Flux of CO_2 = [(Ct – Co)/t] × H × 44/22.4 × 10000 × 24 mg ha^{-1} d^{-1}

3.6.3. Calculation of Global warming potential (GWP)

Global warming potential (GWP) is an index used to compare the effectiveness of each greenhouse gas in trapping heat in atmosphere relative to a standard gas, by convention, CO_2. The GWP for CH_4 (based on a 100-year time horizon) is 21, while that for N_2O is 310 when the GWP value for CO_2 is taken as 1. The global warming

potential (kg CO_2 equivalent ha^{-1})) was calculated using the following equation (Watson et al., 1996).

$$GWP\ (kg\ ha^{-1}\ CO_2\ eq.) = CH_4\ (kg\ ha^{-1}) * 21 + N_2O\ (kg\ ha^{-1}) * 310 + CO_2\ (kg\ ha^{-1})$$

3.7. Statistical analysis

A two-factor analysis of variance (ANOVA) was conducted to determine the effects of nutrient management/organic amendments, cropping systems, and their interactions on soil biological and biochemical properties. Data analysis for all soil parameters was performed using the SAS software. For statistical analysis of data, the least significant difference (LSD at $p = 0.05$) was used to determine whether means differed significantly.

CHAPTER 4
RESULTS

The present study, field experiments were carried out with the objectives (i) to quantify greenhouse gas emission from organic vs. conventional rice-wheat-mungbean (R-W-M) cropping systems (ii) to study soil physico-chemical parameters in relation to GHG emission from organic and conventional agricultural practices and iii) to study soil microbial parameters with regard to GHG emission from organic vs. conventional rice-wheat-mungbean (R-W-M) cropping systems. The results obtained during research work, described in detailed under the following sub-headings:

4.1. Impact of organic amendment on GHG emissions from Rice

4.1.1. CH_4 emission fromRice

Organic and conventional plots had shown noticeable variations in average greenhouse gas emission during both the years. Organic plots treated with FYM+CR+BF (34.56 kg/ha) and VC+CR+B (32.82 kg/ha) were recorded highest in methane (CH_4) emission **(Table 4.1)** while it was relatively lower in organic treatments such as FYM+CR (28.24 kg/ha) and VC (28.69 kg/ha) than other organic plots. Though, the initial CH_4 emissions from these plots were comparable with FYM+CR+B and VC+CR+B applied plots **(Fig.4.1 and 4.2).**

Table 4.1Seasonal variability of CH_4 emission under organic and conventional plots

Treatments	Seasonal cumulative CH_4emission (kg/ha)		
	2015-16	2016-17	Pooled mean
CONTROL	10.51±0.46	11.93±0.80	11.22
CONVENTIONAL	25.37±0.64	25.80±1.61	25.58
FYM	29.40±1.62	31.83±2.10	30.62
VC	27.48±2.49	29.91±2.63	28.69
FYM+CR	28.19±2.45	28.29±1.36	28.24
VC+CR	31.41±0.94	31.85±2.06	31.63
FYM+CR+B	34.28±2.66	34.84±1.45	34.56
VC+CR+B	32.10±2.59	33.53±1.52	32.82

CH_4 emission from non-amended control (11.22 kg/ha) and Conventional (25.58 kg/ha) plots were less as compared to all organic plots. Methane emission from all the plots increased gradually after transplanting, attains peaks about 40 days after transplanting (DAT), and then decreased until harvesting **(Fig.4.1 and 4.2).**

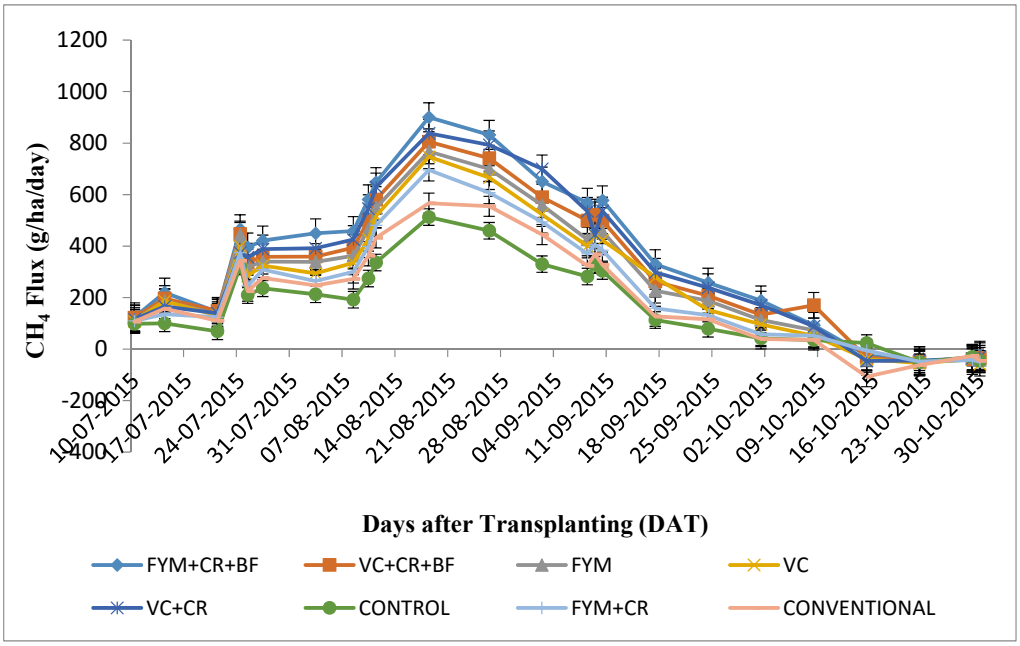

Fig. 4.1 Temporal variability of CH_4 emission under organic and conventional plots during 2015-16

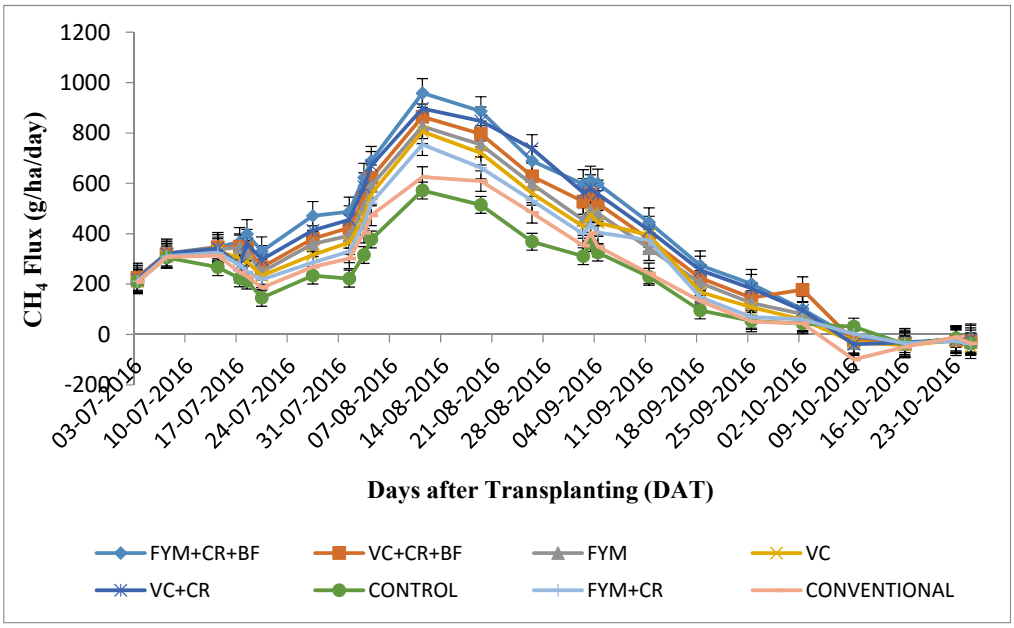

Fig. 4.2 Temporal variability of CH_4 emission under organic and conventional plots during 2016-17

Temporal pattern and magnitude of CH_4 fluxes during rice significantly differed among the treatments. However, high fluxes of CH_4 were observed during tillering to reproductive stages in all the treatments. The cumulative CH_4 emission under rice treatments varied from 10.51 to 34.28 kg CH_4 ha^{-1} and 11.93 to 34.84 kg CH_4 ha^{-1} in first and second years respectively **(Table 4.1).**

4.1.2. N_2O emission from Rice

Average N_2O emission was highest from Conventional Plot (1.79 kg/ha) followed by VC+CR+B (0.58 kg/ha), FYM+CR+B (0.57 kg/ha), FYM (0.51 kg/ha), FYM+CR (0.45 kg/ha) and then VC (0.38 kg/ha) during both years (**Table 4.2**). N_2O emission from Conventional plot was about 3.09 to 7.46 times higher than organic treatments during the study. Peaks of emission were observed in Conventional Plot following fertilizer and irrigation application (**Fig. 4.3 and 4.4**).

In the organic plots, N_2O emissions were comparatively higher during the latter crop growth period. The N_2O flux from Control Plot (0.21 kg/ha) was lowest among all the treatments. N_2O emission was highest from conventionally managed plots and even higher after 1^{st} and 2^{nd} dose of synthetic nitrogen (N) application through fertilizer. Among organic treatments, VC+CR+B applied plots were high in emitting N_2O followed by FYM+CR+B, FYM and FYM+CR.

N_2O flux from the treatments showed more or less similar temporal trends with appearance of a peak after 3-4 days of urea applications during both the years, however, the magnitude of flux differed (**Fig. 4.3 and 4.4**). Application of urea in crop fields led to increased NH_4^+-N substrate supply to microorganism for nitrification and denitrification process. N_2O peak was observed after three days of each dose of urea application in the present study. The Lowest N_2O emission flux was observed in control treatment compared to the other treatments throughout the cropping seasons. It might be due to lower availability of nitrogenous substrate for nitrification and denitrification process. The cumulative emission of N_2O from different treatments varied from 0.20 to 1.77 kg ha^{-1} in the first year and from 0.22 to 1.81 kg ha^{-1} in the second year (**Table 4.2**). The cumulative N_2O emission from different combinations were in the order of Control < VC+CR < VC < FYM+CR < FYM < FYM+CR+B< VC+CR+B <Conventional.

Table 4.2 Seasonal variability of N_2O emission under organic and conventional plots

Treatments	Seasonal cumulative N_2O emission (kg ha^{-1})		
	2015-16	2016-17	Pooled mean
CONTROL	0.20±0.10	0.22±0.04	0.21
CONVENTIONAL	1.77±0.07	1.81±0.12	1.79
FYM	0.49±0.08	0.53±0.09	0.51
VC	0.35±0.08	0.41±0.07	0.38
FYM+CR	0.44±0.07	0.46±0.10	0.45
VC+CR	0.22±0.05	0.26±0.06	0.24
FYM+CR+B	0.54±0.06	0.60±0.05	0.57
VC+CR+B	0.56±0.13	0.61±0.11	0.59

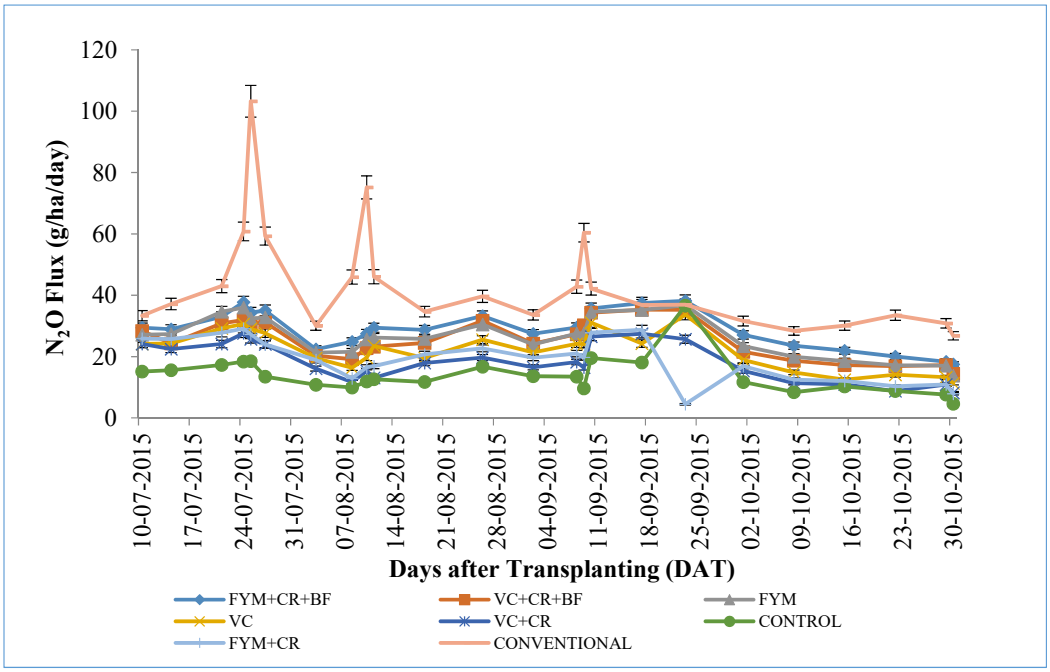

Fig. 4.3 Temporal variability of N_2O emission under organic and conventional plots during 2015-16

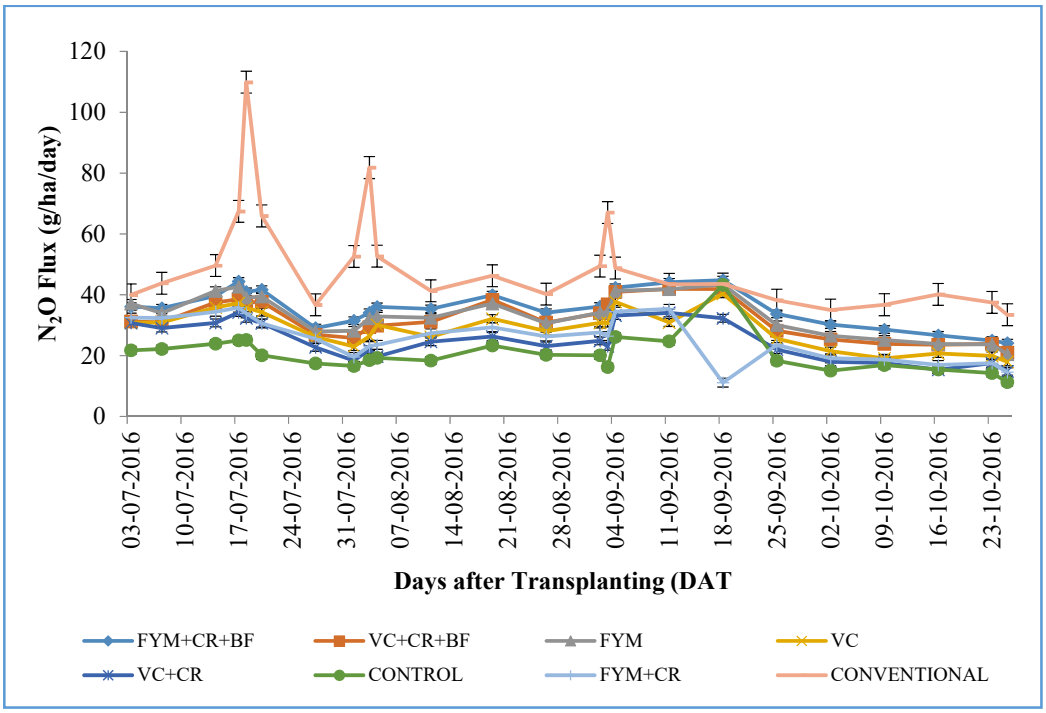

Fig. 4.4 Temporal variability of N_2O emission under organic and conventional plots during 2016-17

4.1.3. CO_2 emission from Rice

CO_2 flux also exhibited temporal variability throughout the cropping period. Maximum CO_2 flux was observed in FYM+CR+B (706.03 kg/ha) treated plots and VC+CR+B (710.81 kg/ha) treated plots followed by other organic plots (VC+CR- 655.65 kg/ha, FYM+CR- 635.62 kg/ha, FYM- 534.53 kg/ha and VC- 477.24 kg/ha). It was minimum from non-amended Control (249.40 kg/ha), while emission from Conventional Plot (545.02 kg/ha) was significantly lower as compared to Organic Plots (**Table 4.3**). Different organic treatment combinations led to 23.29% increase in CO_2 flux over the conventional system. CO_2 fluxes were lower during initial stage then it increased and reached maximum value between 45-60 DAT and then decreased again.

All the treatments were lower in CO_2 flux after sowing of the rice crop. However, during latter crop growth stage, particularly vegetative growth the CO_2 emission flux increased significantly and reached at its maximum value during 55-65 DAT (**Fig. 4.5 and 4.6**). The cumulative CO_2 emission from different combinations were in the order of Control < VC < FYM < Conventional < FYM+CR < VC+CR < VC+CR+B < FYM+CR+B.

Table 4.3 Seasonal variability of CO_2 emission under organic and conventional plots

Treatments	Seasonal cumulative CO_2emission (kg ha^{-1})		
	2015-16	2016-17	Pooled mean
CONTROL	233.58±12.94	265.23±14.06	249.40
CONVENTIONAL	538.23±50.55	550.27±20.51	545.02
FYM	535.47±16.97	533.58±16.30	534.53
VC	469.74±15.31	484.74±19.91	477.24
FYM+CR	639.02±62.45	632.23±41.09	635.62
VC+CR	650.77±22.39	660.52±20.81	655.65
FYM+CR+B	702.23±33.53	710.58±14.11	706.03
VC+CR+B	710.55±26.23	710.44±37.86	710.51

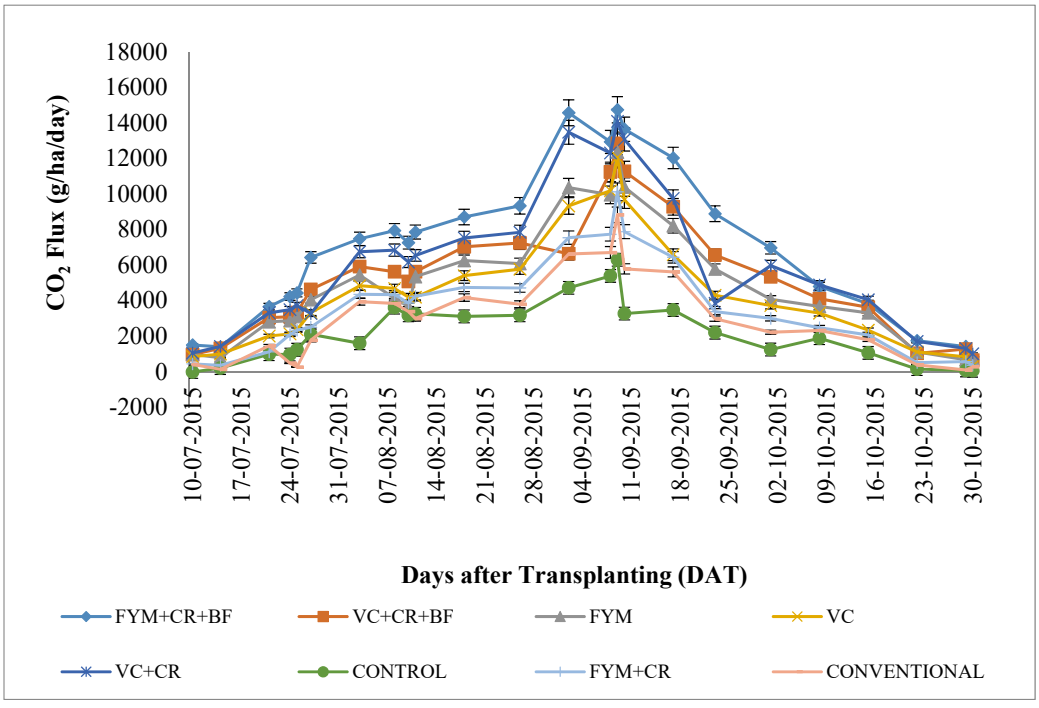

Fig. 4.5 Temporal variability of CO_2 emission under organic and conventional plots during 2015-16

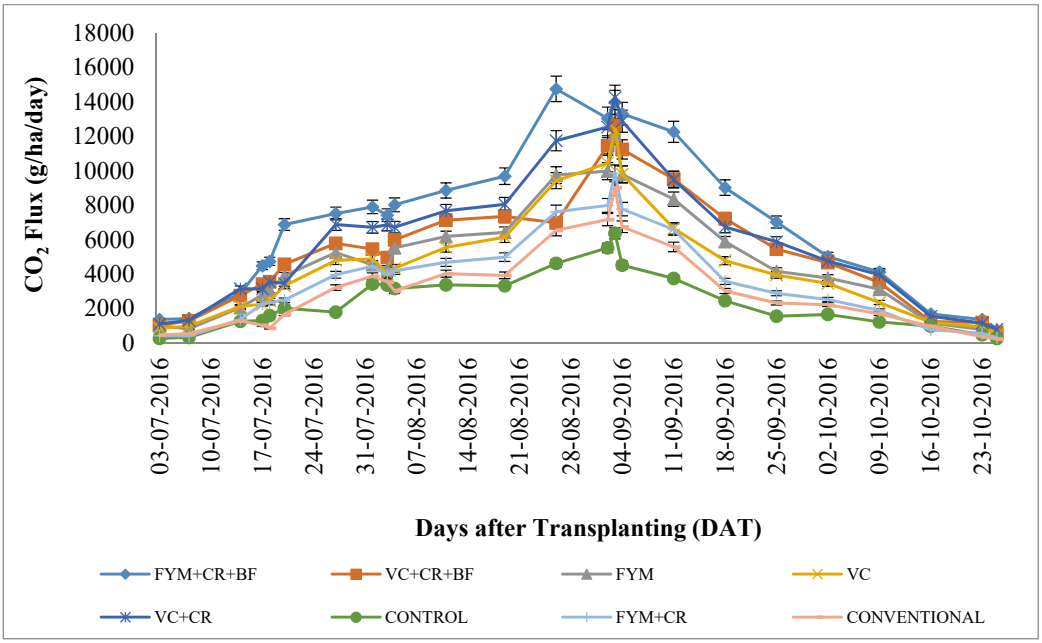

Fig. 4.6 Temporal variability of CO_2 emission under organic and conventional plots during 2016-17

4.2. Impact of organic amendment on GHG emissions from Wheat

4.2.1 CH_4 emission from Wheat

Occurrence of aerobic condition in soil, during most part of the crop growth leads to almost zero or somewhat negative net emission of CH_4 under wheat cropping season with no definite patterns observed among the various organic and conventional treatments (**Fig. 4.7 and 4.8**).The cumulative CH_4 emission under various treatments varied from -1.69 to -2.37 kg CH_4 ha^{-1} and -1.14 to -1.89 kg CH_4 ha^{-1} in first and second years respectively (**Table 4.4**).

Table 4.4 Seasonal variability of CH_4 under organic and conventional plots

Treatments	Seasonal cumulative CH_4emission (kg ha^{-1})		
	2015-16	2016-17	Pooled mean
CONTROL	-1.85±0.10	-1.14±0.12	-1.49
CONVENTIONAL	-1.83±0.11	-1.26±0.07	-1.55
FYM	-2.37±0.49	-1.67±0.22	-2.02
VC	-1.77±0.12	-1.85±0.18	-1.81
FYM+CR	-1.81±0.13	-1.24±0.07	-1.53
VC+CR	-1.69±0.15	-1.21±0.12	-1.45
FYM+CR+B	-1.91±0.02	-1.89±0.08	-1.90
VC+CR+B	-1.72±0.13	-1.85±0.14	-1.78

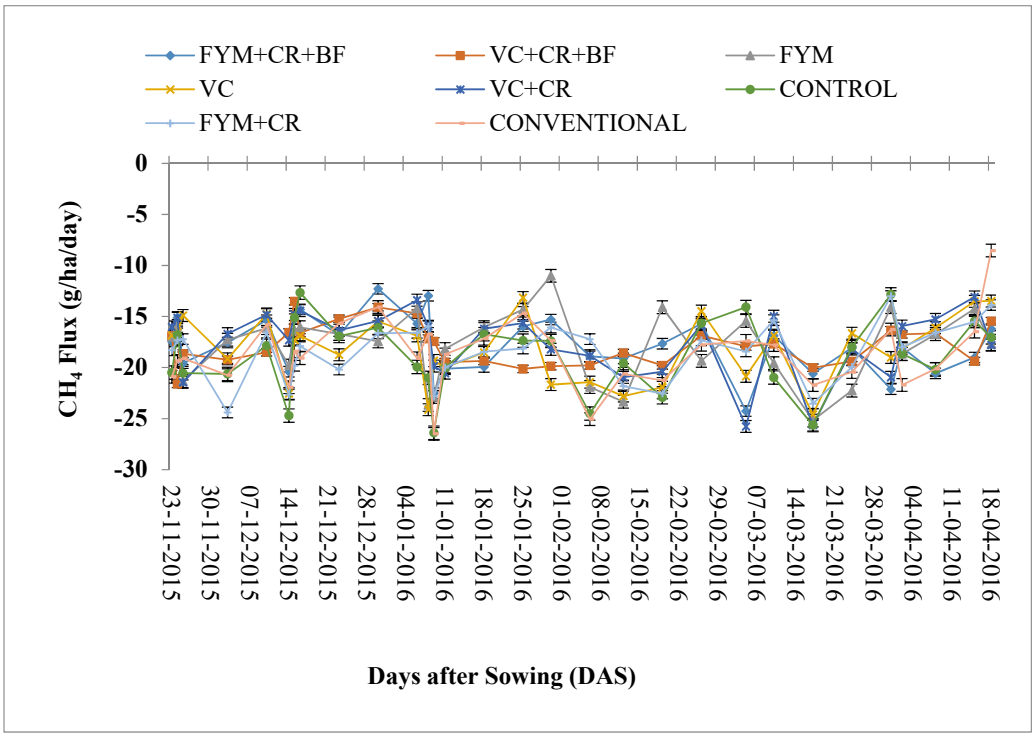

Fig. 4.7 Temporal variability of CH_4 emission under organic and conventional plots during 2015-16

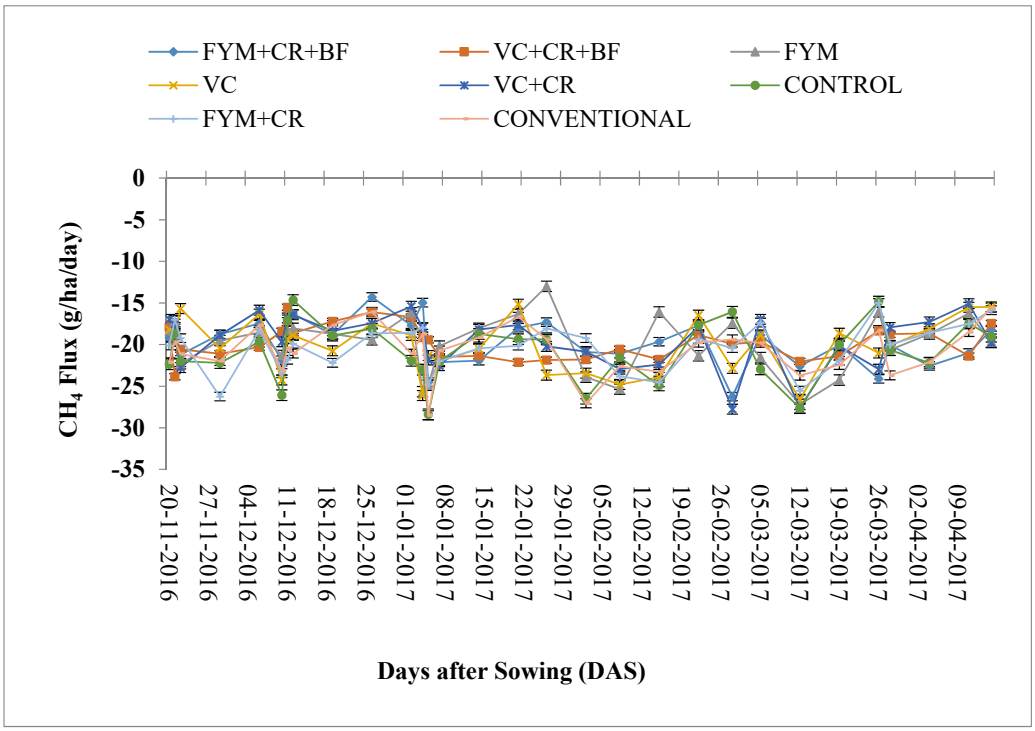

Fig. 4.8 Temporal variability of CH_4 emission under organic and conventional plots during 2016-17

4.2.2 N_2O emission from Wheat

During wheat crop also, the average N_2O emission was highest from Conventional Plot (1.80 kg/ha) followed by FYM+CR+B (0.59 kg/ha) VC+CR+B (0.55 kg/ha), FYM (0.48 kg/ha), FYM+CR (0.44 kg/ha), VC (0.35 kg/ha) and VC+CR (0.23 kg/ha) during both years (**Table 4.5**). N_2O emission from conventional plot was about 3.05 to 7.82 times higher than organic treatments during the study. Peaks of emission were observed in Conventional Plot following fertilizer and irrigation application (**Fig. 4.9 and 4.10**).

The N_2O flux from Control Plot (0.18 kg/ha) was lowest among all the treatments. N_2O emission was highest from conventionally managed plots and even higher after 1st and 2nd dose of synthetic nitrogen (N) application through fertilizer. N_2O flux from the treatments showed more or less similar temporal trends with appearance of a peak after 3-4 days of urea applications during both the years, however, the magnitude of flux differed (**Fig. 4.9 and 4.10**).

The cumulative emission of N_2O from different treatments varied from 0.17 to 1.76 kg ha^{-1} in the first year and from 0.19 to 1.84 kg ha^{-1} in the second year (**Table 4.5**). The cumulative N_2O emission from different combinations were in the order of Control < VC+CR < VC < FYM+CR < FYM < FYM+CR+B < VC+CR+B < Conventional.

Table 4.5 Seasonal variability of N_2O emission under organic and conventional plots

Treatments	Seasonal cumulative N_2O emission (kg ha^{-1})		
	2015-16	2016-17	Pooled mean
CONTROL	0.17±0.04	0.19±0.04	0.18
CONVENTIONAL	1.76±0.12	1.84±0.14	1.80
FYM	0.46±0.04	0.49±0.11	0.48
VC	0.33±0.04	0.37±0.13	0.35
FYM+CR	0.42±0.11	0.46±0.07	0.44
VC+CR	0.24±0.10	0.21±0.06	0.23
FYM+CR+B	0.55±0.07	0.54±0.11	0.55
VC+CR+B	0.58±0.16	0.60±0.13	0.59

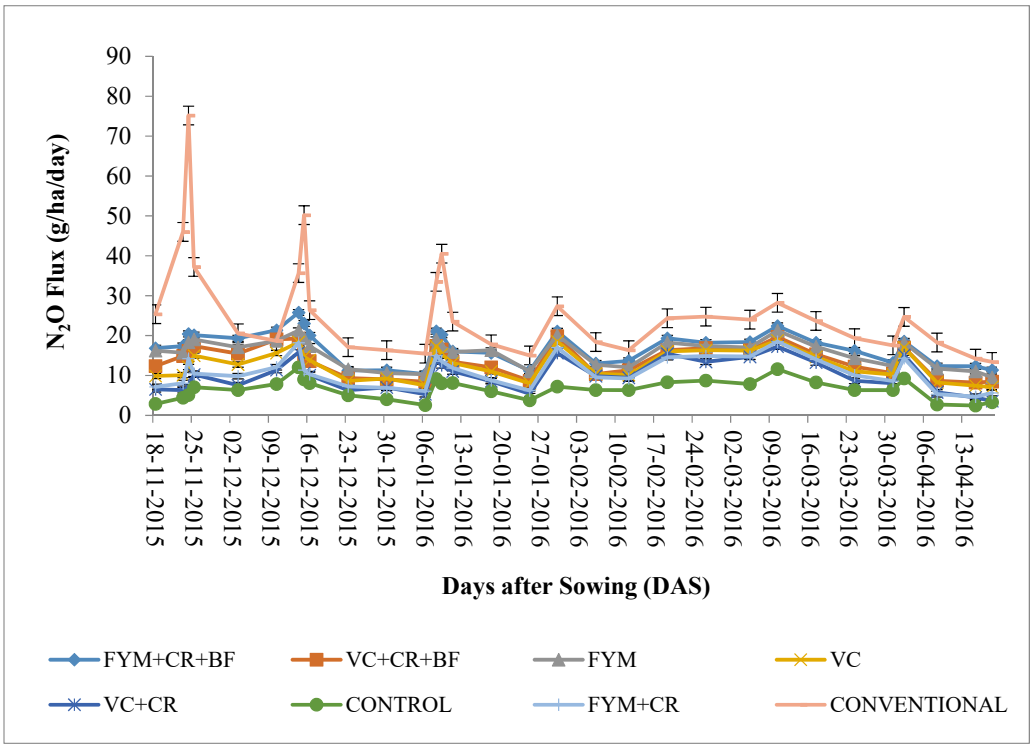

Fig. 4.9 Temporal variability of N_2O emission under organic and conventional plots during 2015-16

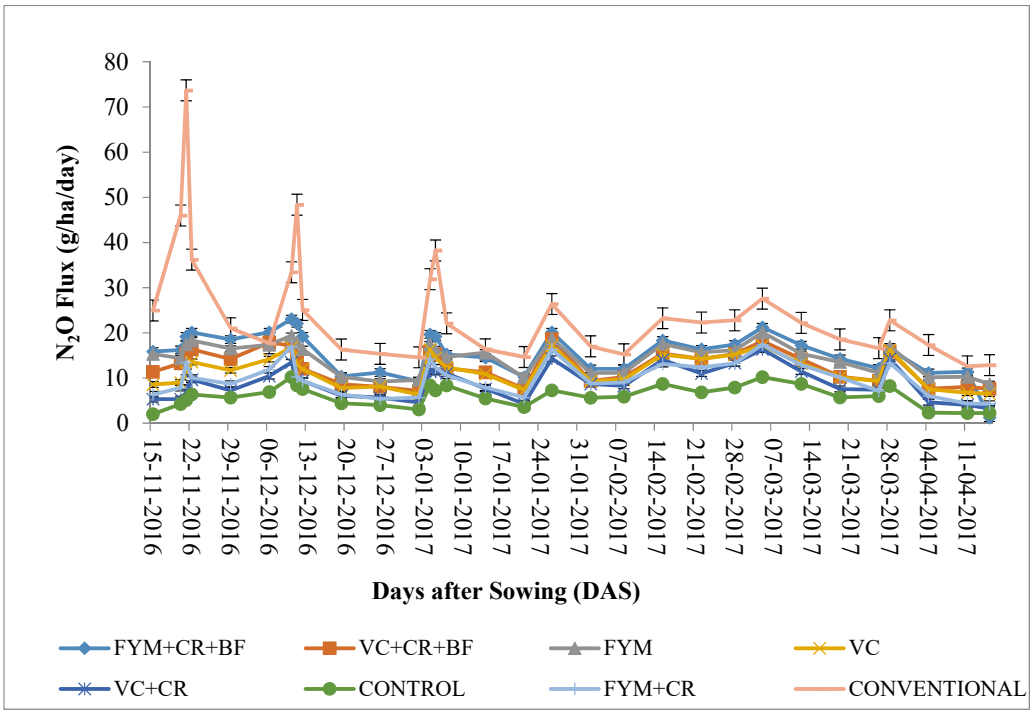

Fig. 4.10 Temporal variability of N_2O emission under organic and conventional plots during 2016-17

4.2.3 CO_2 emission from Wheat

During wheat, maximum CO_2 flux was observed in VC+CR (1057.06 kg/ha) and FYM+CR+B (968.46 kg/ha) treated plots followed by VC+CR+B-885.49 kg/ha, FYM+CR- 952.94 kg/ha, FYM- 900.76 kg/ha and VC- 815.69 kg/ha). It was minimum from non-amended Control (488.39 kg/ha) and emission from Conventional Plot (847.15 kg/ha) was significantly lower as compared to most of Organic Plots (**Table 4.6**). The cumulative CO_2 emissions were higher from wheat than rice crop.

Table 4.6 Seasonal variability of CO_2 from organic and conventional plots

Treatments	Seasonal cumulative CO_2emission (kg ha^{-1})		
	2015-16	2016-17	Pooled mean
CONTROL	504.62±24.15	472.15±27.78	488.39
CONVENTIONAL	845.79±23.62	848.51±32.56	847.15
FYM	918.11±29.13	883.42±26.46	900.76
VC	833.03±25.99	798.34±18.10	815.69
FYM+CR	953.33±37.27	952.55±25.52	952.94
VC+CR	1074.40±58.17	1039.71±44.70	1057.06
FYM+CR+B	977.8±48.56	959.11±19.07	968.46
VC+CR+B	881.95±55.48	889.02±19.27	885.49

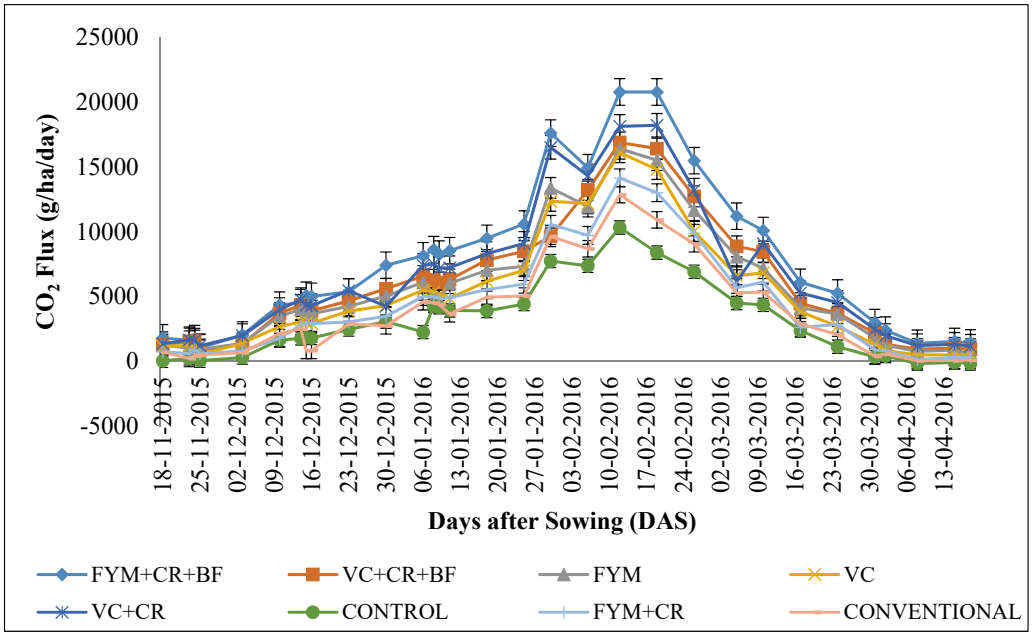

Fig. 4.11 Temporal variability of CO_2 emission under organic and conventional plots during 2015-16

CO_2 flux exhibited temporal variability throughout the cropping period. All the treatments were lower in CO_2 flux after sowing of the wheat crop. However, during latter crop growth stage, particularly vegetative growth the CO_2 emission flux increased significantly (**Fig. 4.11 and 4.12**). The cumulative CO_2 emission from different combinations were in the order of Control <Conventional <VC<FYM<FYM+CR <VC+CR+B < VC+CR< FYM+CR+B.

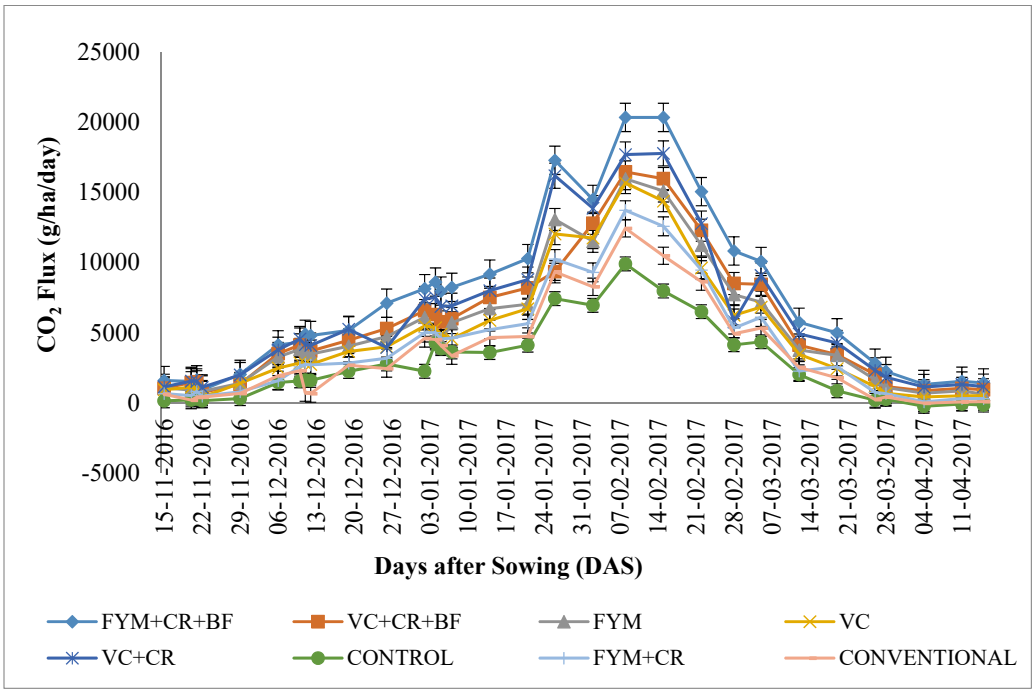

Fig. 4.12 Temporal variability of CO_2 emission under organic and conventional plots during 2016-17

4.3. Impact of organic amendment on GHG emissionsfrom Mungbean

4.3.1. CH_4 emission from Mungbean

Like wheat, in mungbean also, occurrence of aerobic condition in soil during most part of the crop growth leads to almost zero or somewhat negative net emission of CH_4 with no definite patterns observed among the various organic and conventional treatments (**Fig. 4.13 and 4.14**).

The cumulative CH_4 emission under various treatments varied from -0.97 to -1.11 kg CH_4 ha^{-1} and -1.07 to -1.22 kg CH_4 ha^{-1} in first and second years respectively (**Table 4.7**).

Table 4.7 Seasonal variability of CH_4emission from organic and conventional plots

Treatments	Seasonal cumulative CH_4 emission (kg/ha)		
	2015-16	2016-17	Pooled mean
CONTROL	-1.10±0.10	-1.20±0.18	-1.15
CONVENTIONAL	-1.08±0.15	-1.18±0.11	-1.13
FYM	-1.03±0.10	-1.14±0.21	-1.09
VC	-1.03±0.12	-1.13±0.19	-1.08
FYM+CR	-1.11±0.11	-1.22±0.12	-1.17
VC+CR	-0.97±0.06	-1.07±0.10	-1.02
FYM+CR+B	-0.98±0.08	-1.08±0.16	-1.03
VC+CR+B	-0.99±0.11	-1.10±0.11	-1.05

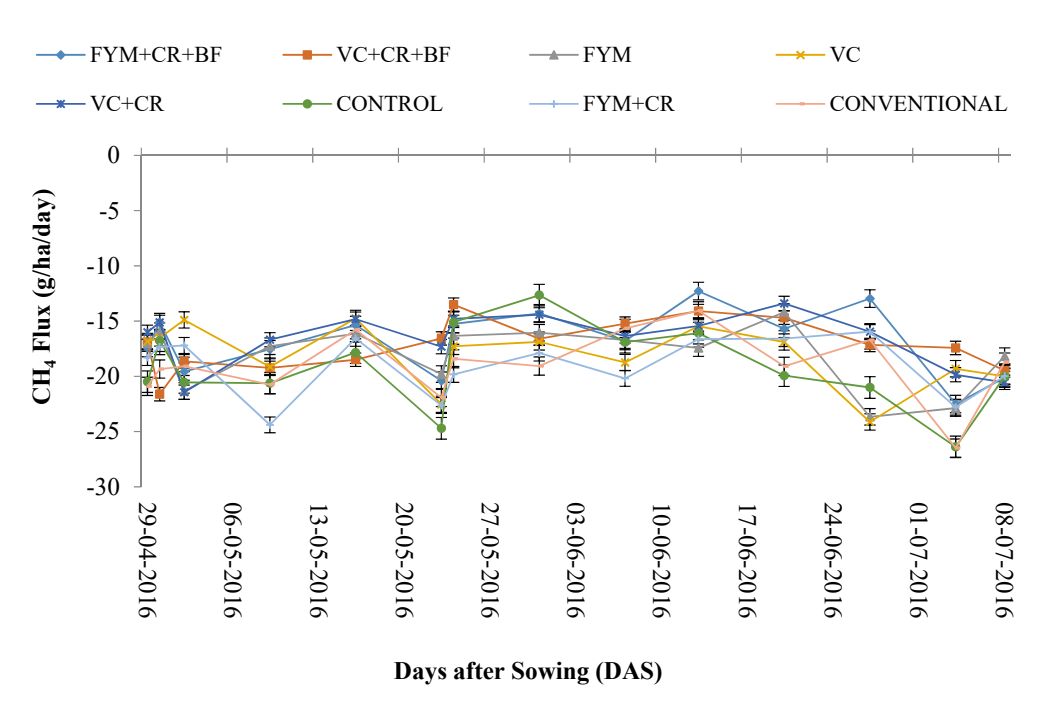

Fig. 4.13 Temporal variability of CH_4 emission under organic and conventional plots during 2015-16

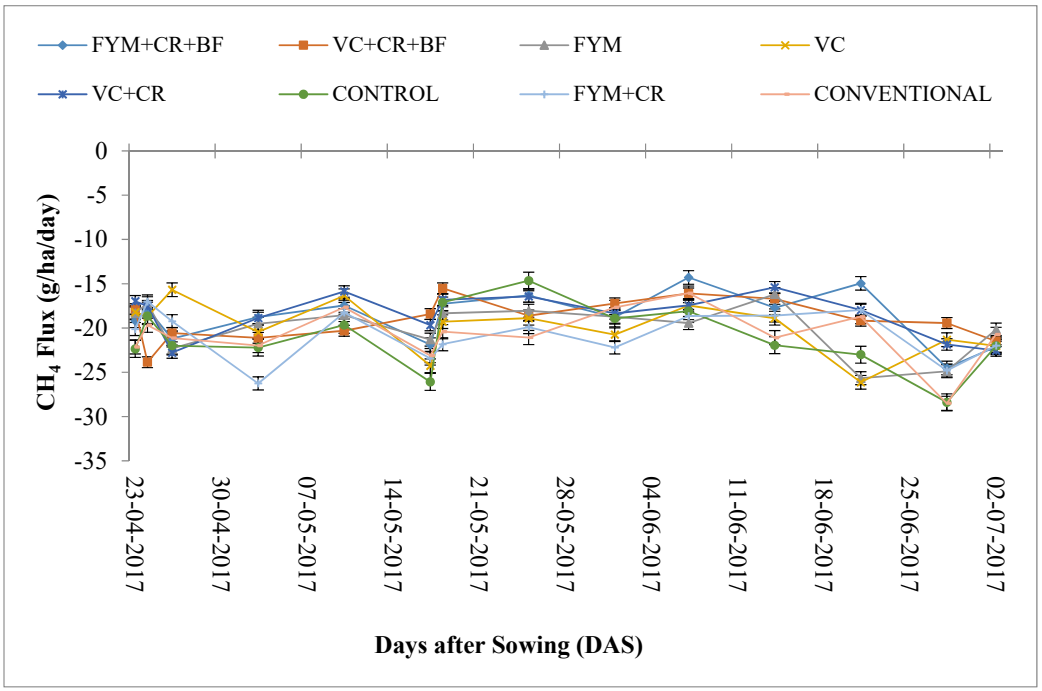

Fig. 4.14 Temporal variability of CH_4 emission under organic and conventional plots during 2016-17

4.3.2. N_2O emission from Mungbean

In mungbean also, the nitrous oxide emission followed the similar trend as Conventional Plot (1.65 kg/ha) contributed maximum flux followed by VC+CR+B (0.62 kg/ha), FYM (0.58 kg/ha), FYM+CR+B (0.51 kg/ha), VC+CR (0.49 kg/ha), FYM+CR (0.45 kg/ha) and VC (0.41 kg/ha) (**Table 4.8**). N_2O fluxes were increased from all treatments after consecutive irrigations. Moreover, in the conventional plot, the application of synthetic NPK fertilizer in split doses had shown higher N_2O fluxes (**Fig.4.15 and 4.16).** N_2O emission from VC+CR+B and FYM applied plots were higher than other organic plots throughout the cropping season. N_2O emission from conventional plot was about 2.66 to 4.07 times higher than organic treatments during the study.

The N_2O flux from Control Plot (0.15 kg/ha) was lowest among all the treatments. N_2O emission was highest from conventionally managed plots and even higher after 1st and 2nd dose of synthetic nitrogen (N) application through fertilizer. N_2O flux from the treatments showed more or less similar temporal trends with appearance of a peak after 3-4 days of urea applications during both the years, however, the magnitude of flux differed (**Fig. 4.15 and 4.16**).

The cumulative emission of N_2O from different treatments varied from 0.13 to 1.67 kg ha^{-1} in the first year and from 0.17 to 1.63 kg ha^{-1} in the second year (**Table 4.8**). The cumulative N_2O emission from different combinations were in the order of Control < VC < FYM+CR < VC+CR < FYM+CR+B < FYM < VC+CR+B < Conventional.

Table 4.8 Seasonal variability of N_2Oemission from organic and conventional plots

Treatments	Seasonal cumulative N_2O emission (kg/ha)		
	2015-16	2016-17	Pooled mean
CONTROL	0.13±0.06	0.17±0.06	0.15
CONVENTIONAL	1.67±0.14	1.63±0.11	1.65
FYM	0.57±0.15	0.59±0.08	0.58
VC	0.39±0.10	0.42±0.10	0.41
FYM+CR	0.45±0.06	0.44±0.10	0.45
VC+CR	0.48±0.08	0.50±0.06	0.49
FYM+CR+B	0.53±0.07	0.49±0.14	0.51
VC+CR+B	0.62±0.14	0.61±0.12	0.62

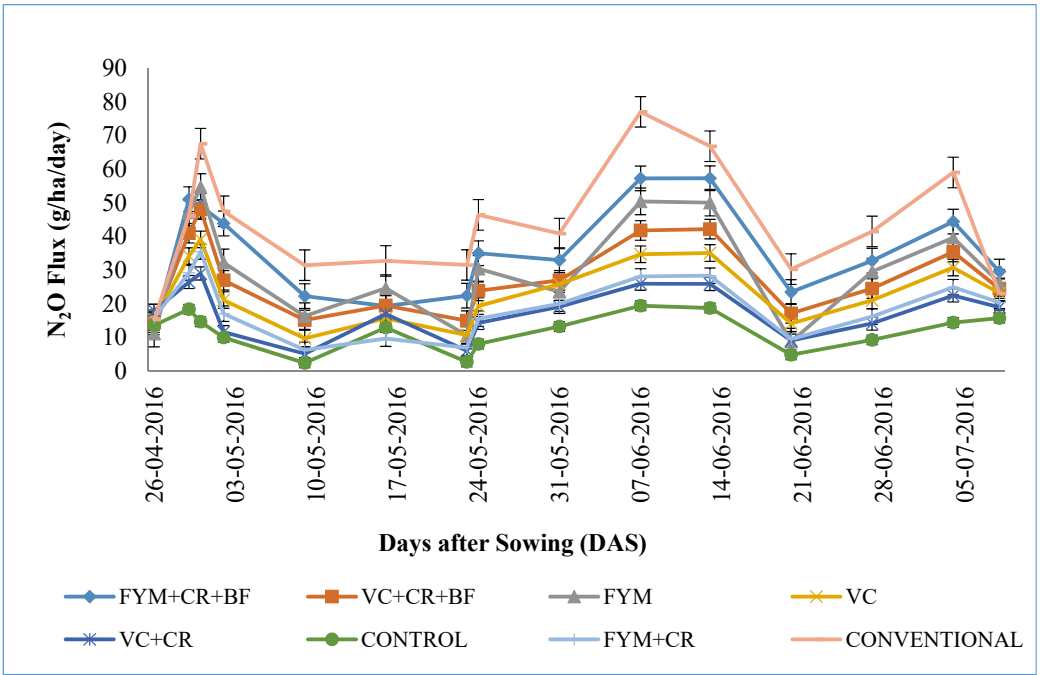

Fig. 4.15 Temporal variability of N_2Oemission under organic and conventional plots during 2015-16

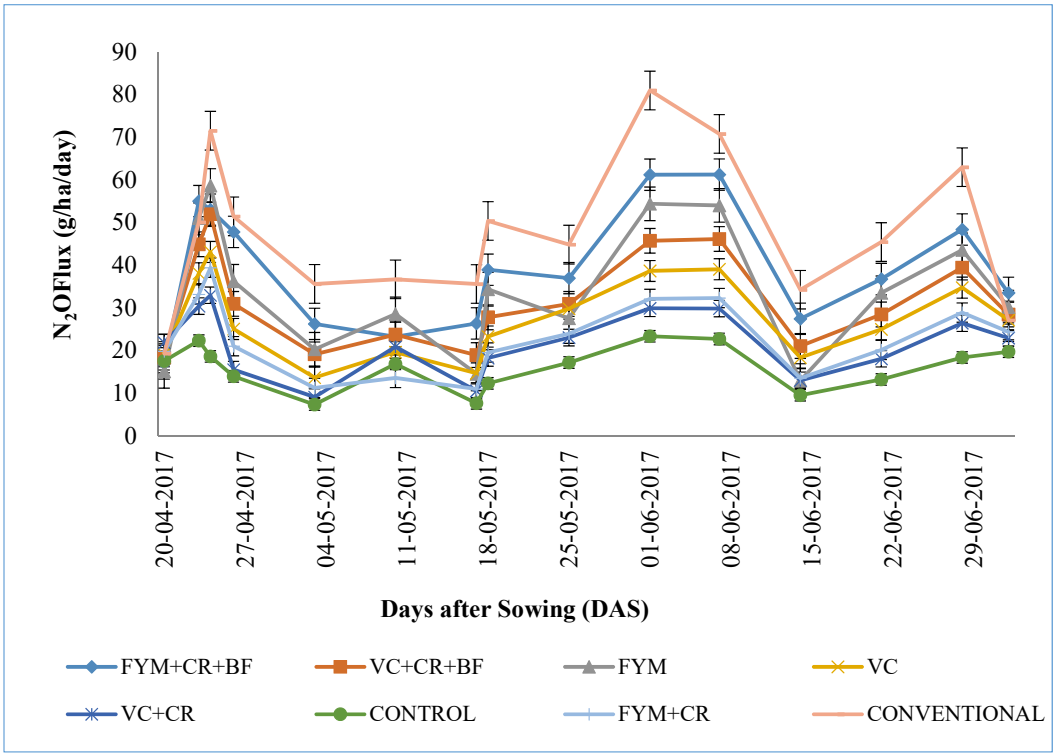

Fig. 4.16 Temporal variability of N_2Oemission under organic and conventional plots during 2016-17

4.3.3. CO_2 emission from Mungbean

Organically amended plots were foremost in contributing to CO_2 flux during both years of study. During mungbean season, highest contribution in average CO_2 flux was made by FYM+CR+B (1101.7 kg/ha) applied plot followed by VC+CR (1055.14 kg/ha), FYM (1018.6 kg/ha), VC+CR+B (985.8 kg/ha), VC (857.0 kg/ha) and FYM+CR (783.1 kg/ha) treated plots (**Table 4.9**). The flux was lowest from non-amended Control (485.05 kg/ha) and Conventional Plot (818.09 kg/ha) and was significantly lower as compared to most of the organic plots.

The peak of CO_2 flux was observed at the flowering stage of the crop (**Fig. 4.17 and 4.18**). The cumulative CO_2 emissions from mungbean were higher than wheat and rice crop.The cumulative CO_2 emission from different combinations were in the order of Control < FYM+CR < Conventional < VC < VC+CR+B < FYM < VC+CR < FYM+CR+B.

Table 4.9 Seasonal variability of CO_2emission from organic and conventional plots

Treatments	Seasonal cumulative CO_2 emission (kg/ha)		
	2015-16	2016-17	Pooled mean
CONTROL	459.21±19.31	510.88±16.92	485.05
CONVENTIONAL	811.12±37.14	825.05±16.29	818.09
FYM	1016.60±18.63	1020.54±25.45	1018.57
VC	855.09±51.77	859.03±53.17	857.06
FYM+CR	793.41±11.37	772.76±28.04	783.08
VC+CR	1069.31±34.41	1040.97±80.46	1055.14
FYM+CR+B	1109.08±62.89	1094.31±30.49	1101.69
VC+CR+B	984.51±40.94	987.14±40.88	985.83

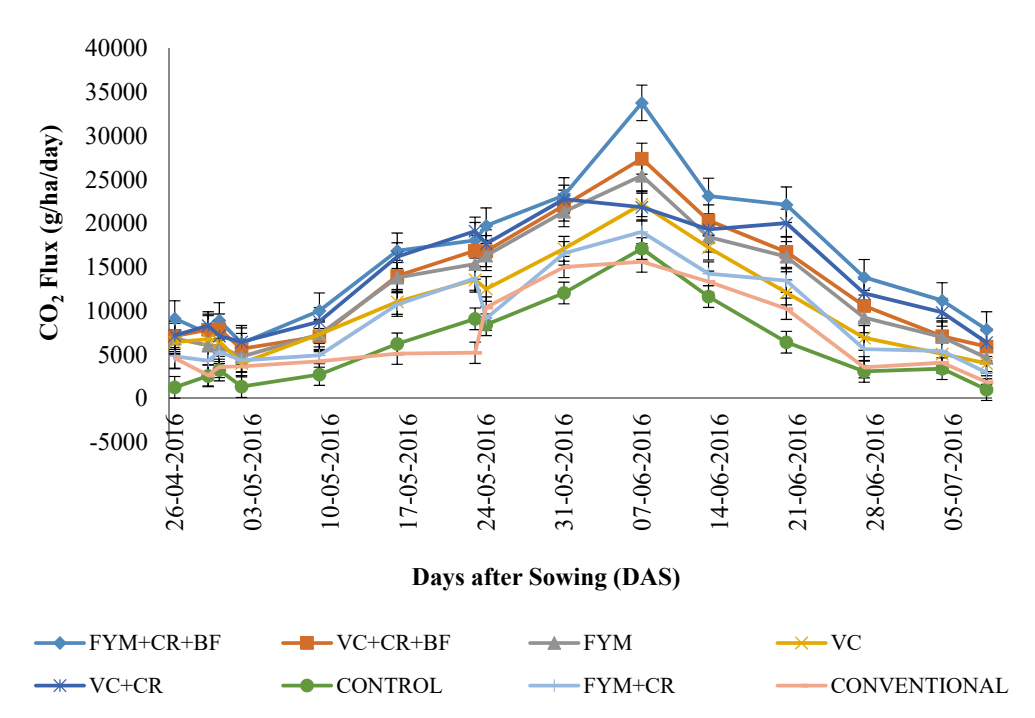

Fig. 4.17 Temporal variability of CO_2 emission under organic and conventional plots during 2015-16

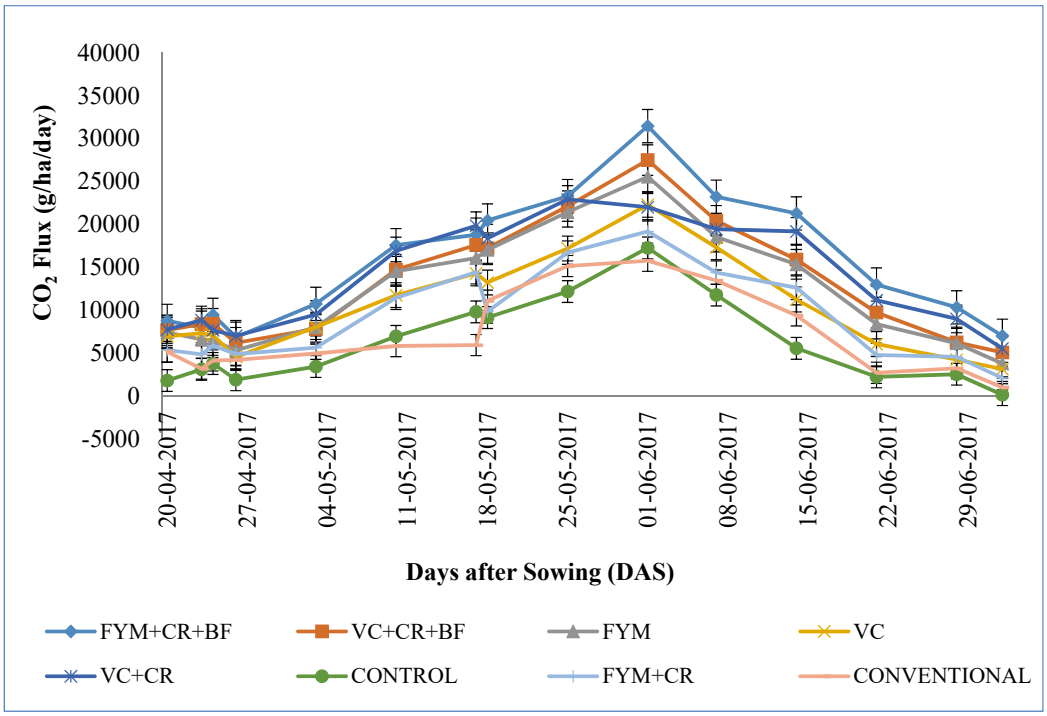

Fig. 4.18 Temporal variability of CO_2 emission under organic and conventional plots during 2016-17

4.4. Global Warming Potential

Net Global Warming Potential was calculated by adding the GWPs of all three greenhouse gases. GWP of organic and conventional treatments was depended on flux of CH_4, CO_2 and N_2O throughout the cropping season.

4.4.1 Rice

The GWP (CH_4+N_2O+CO_2) of various treatments varied from 516.29 to 1619.70 kg CO_2 eq. ha^{-1} and 583.96 to 1653.17 kg CO_2 eq. ha^{-1} in the first and second years of rice cropping, respectively (**Table 4.10**). From the results it was evident that net global warming potential of conventional treatment was significantly higher as compared to the organic treatments. Lowest GWP was observed in unfertilized control.

Different organic treatment combinations led to about 1.73 to 26.84 % reduction in GWP over the conventional system while 66.39 % reduction was observed in control. The order of GWP among the different combination of treatments was as follows: Control < VC< FYM < FYM+CR < VC+CR < VC+CR+B < FYM+CR+B <Conventional during both the years (**Table 4.10**).

Table 4.10 Net Global Warming Potential under organic and conventional amended plots during years 2015-16 and 2016-17

Treatments	GWP (kg CO_2 eq. ha^{-1})		
	2015-16	2016-17	Pooled mean
CONTROL	516.29±22.09	583.96±40.38	550.13
CONVENTIONAL	1619.70±36.44	1653.17±55.06	1636.44
FYM	1304.77±68.14	1366.31±87.20	1335.54
VC	1155.32±45.81	1239.95±50.95	1197.64
FYM+CR	1367.41±94.69	1368.92±97.64	1368.17
VC+CR	1378.58±52.58	1409.97±53.43	1394.28
FYM+CR+B	1589.51±35.80	1628.22±31.14	1608.87
VC+CR+B	1558.25±87.14	1603.67±99.63	1580.96

4.4.2 Wheat

The GWP (CH_4+N_2O+CO_2) of various treatments varied from 518.47 to 1352.96 kg CO_2 eq. ha^{-1} and 507.11 to 1392.45 kg CO_2 eq. ha^{-1} in the first and second years of wheat cropping respectively (**Table 4.11**). From the results it was evident that net global warming potential of conventional treatment was significantly higher as compared to the organic treatments. Lowest GWP was observed in unfertilized control.

Table 4.11 Net Global Warming Potential under organic and conventional amended plots during years 2015-16 and 2016-17

Treatments	GWP (kg CO_2 eq. ha^{-1})		
	2015-16	2016-17	Pooled mean
CONTROL	518.47±36.08	507.11±37.25	512.79
CONVENTIONAL	1352.96±56.11	1392.45±71.54	1372.71
FYM	1010.94±49.30	1000.25±59.46	1005.60
VC	898.16±39.04	874.19±48.12	886.18
FYM+CR	1045.52±51.15	1069.11±35.86	1057.32
VC+CR	1113.31±89.47	1079.40±50.19	1096.36
FYM+CR+B	1108.19±27.13	1086.82±21.01	1097.51
VC+CR+B	1025.63±24.95	1036.17±58.66	1030.90

Different organic treatment combinations led to about 20.04 to 35.44 % reduction in GWP over the conventional system while 62.64 % reduction was observed in control. The order of GWP among the different combination of treatments was as follows: Control < VC < FYM < FYM +CR < VC+CR+B < VC+CR < FYM+CR+B < Conventional (**Table 4.11**).

4.4.3 Mungbean

The GWP (CH_4+N_2O+CO_2) of various treatments in mungbean varied from 476.41 to 1306.14 kg CO_2 eq. ha^{-1} and 538.38 to 1305.57 kg CO_2 eq. ha^{-1} in the first and second years respectively (**Table 4.12**). Similar to rice and wheat, the net global warming potential of conventional treatment was significantly higher as compared to the organic treatments. Lowest GWP was observed inunfertilized control.

Different organic treatment combinations led to about 9.2 to 31.3 % reduction in GWP over the conventional system. The order of GWP among the different combination of treatments was as follows: Control < FYM+CR < VC < FYM< VC+CR < VC+CR+B < FYM+CR+B < Conventional (**Table 4.12**).

Table 4.12 Net Global Warming Potential under organic and conventional amended plots during years 2015-16 and 2016-17

Treatments	GWP (kg CO_2 eq. ha^{-1})		
	2015-16	2016-17	Pooled mean
CONTROL	476.41±17.81	538.38±12.36	507.40
CONVENTIONAL	1306.14±57.79	1305.57±32.61	1305.86
FYM	1171.67±63.47	1179.50±17.49	1175.59
VC	954.36±46.86	965.50±46.15	959.93
FYM+CR	909.60±15.85	883.54±4.85	896.57
VC+CR	1197.74±60.19	1173.50±72.91	1185.62
FYM+CR+B	1252.80±43.80	1223.53±64.67	1238.17
VC+CR+B	1155.92±63.43	1153.14±79.51	1154.53

4.5. Impact of organic amendment on soil physico-chemical properties

Soil samples were analyzed at sowing and flowering stages of rice, wheat, and mungbean to assess the effects of long-term organic and conventional rice-wheat-mungbean cropping system on soil physico-chemical parameters.

4.5.1. Soil pH

Soil pH value for rice, wheat, and mungbean for both the year (2016 and 2017) under conventional, and the organically treated plotsare given in Annexure 2a, 2b, and 2c. Soil pH in rice (2015-16) ranged from 7.95 to 8.24, while in 2016-17, it varied from 8.75 to 9.05 (Annexure-2a). In wheat (2015-16), it was ranged from 7.74 to 8.15, while in 2016-17, it ranged from 8.4 to 9.0 (Annexure-2b). In mungbean (2015-16), it was varied from 8.25 to 8.78, while in 2016-17, it ranged from 8.30 to 8.72 (Annexure-3c). The polled value of pH for both the year is presented in **Table 4.13.**

Table 4.13: Pooled data of soil pH in R-W-M- cropping system

Treatments	Rice	Wheat	Mungbean
FYM+CR+B	8.29±0.55^{d}	8.53±0.57^{c}	8.48±0.54^{d}
VC+CR+B	8.42±0.56^{b}	8.45±0.56^{d}	8.56±0.47^{b}
FYM	8.29±0.54^{d}	8.51±0.57^{d}	8.50±0.5^{d}
VC	7.99±0.53^{f}	8.52±0.54^{d}	8.27±0.65^{e}
VC+CR	8.13±0.51^{e}	8.48±0.51^{d}	8.38±0.62^{de}
CONTROL	8.41±0.56^{c}	8.57±0.57^{b}	8.55±0.48^{c}
FYM+CR	8.28±0.52^{d}	8.36±0.56^{e}	8.46±0.48^{d}
CONVENTIONAL	8.56±0.57^{a}	8.65±0.58^{a}	8.75±0.49^{a}
Mean	8.51	8.30	8.49
LSD (*p = 0.05*)	0.031	0.029	0.032

The results showed that the soil pH values were significantly higher in the conventional system than the organic farming system (**Fig. 4.19**). The value for pH within the crop grown under both systems ranged from 7.99±0.53to 8.75±0.49. On average lower pH values recorded during wheat (8.30) as compared to rice (8.51) and mungbean (8.49) crops (**Table 4.13**). Soil pH value in rice found significantly higher in conventional treatment (8.56±0.57) followed by VC+CR+B (8.42±0.56), control (8.41±0.56), and it was lowest in VC (7.99±0.53).

In wheat, it was found higher in conventional treatment (8.65±0.58) followed by Control (8.57±0.57), FYM+CR+B (8.53±0.57) and it were lowest in FYM+CR (8.36±0.56). In mungbean found higher in conventional treatment (8.75±0.49) followed by VC+CR+B (8.56±0.47), Control (8.55±0.48), and it was lowest in

VC(8.27±0.65)(**Table 4.13**). The soil pH was decreased slightly, with the addition of organic manure. However, among organic plots, soil pH does not vary significantly.

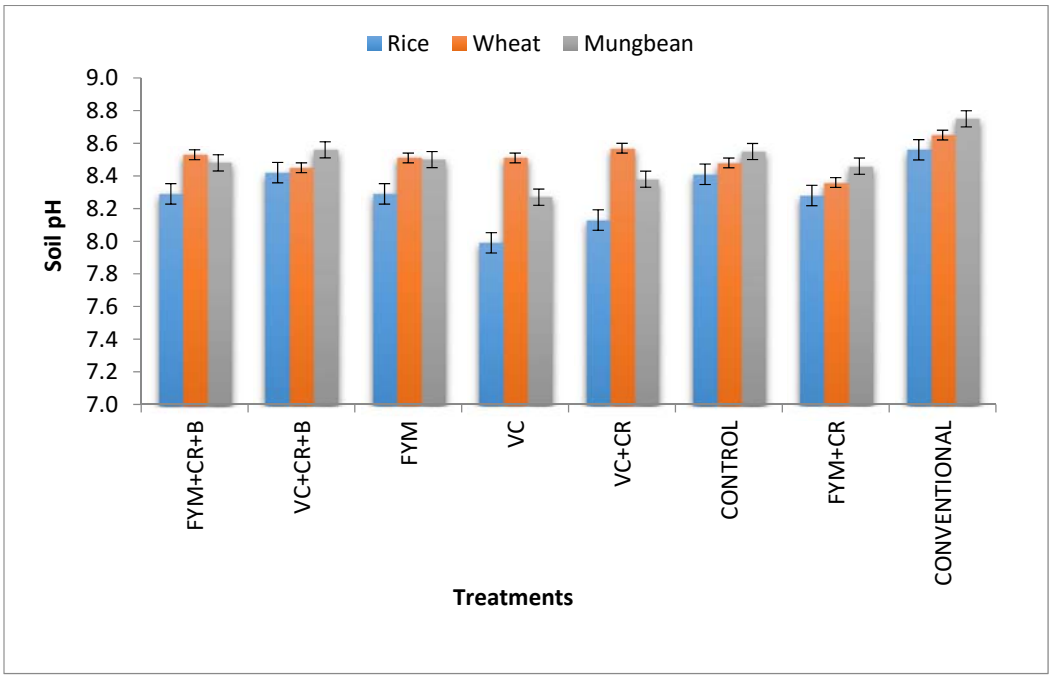

Fig 4.19: Pooled data of soil pH in R-W-M- cropping system

4.5.2. Soil Electrical Conductivity

Soil electrical conductivity (EC) values for rice, wheat, and mungbean for both the year (2016 and 2017) under conventional, and the organically treated plots are given in Annexure 2a, 2b, and 2c.Soil EC in rice (2015-16) ranged from 102.8 to 200.6 µmho/cm, while in 2016-17, it ranged from 119.8 to 217.4 µmho/cm (Annexure-2a). In wheat (2015-16) it ranged from 101.0 to 196.1 µmho/cm, while in 2016-17, it ranged from 117.8 to 212.5 µmho/cm (Annexure-2b). In mungbean (2015-16), it was ranged from 99.8 to 201.8 µmho/cm, while in 2016-17, it ranged from 116.6 to 218.7 µmho/cm (Annexure-3c).The polled value of EC for both the year is presented in **Table 4.14**.The results showed that the soil EC values were higher in the organic farming system than the conventional system (**Fig.4.20**). The value for EC within the crop grown under both systems ranged from 99.8±6.9to 217.4±14.5 µmho/cm- the lower EC values recorded during mungbean as compared to wheat and rice crops (**Table 4.14**).

Table 4.14. Pooled data of Soil EC in R-W-M- cropping system

Treatments	Rice	Wheat	Mungbean
FYM+CR+B	208.6±11.9[a]	204.3±11.6[a]	210.2±11.9[a]
VC+CR+B	204.6±11.6[a]	193.1±10.9[b]	188.4±10.7[bc]
FYM	181.5±10.3[b]	178.3±10.1[c]	167.0±9.5[d]
VC	208.9±11.8[a]	195.4±11.1[b]	196.3±11.6[b]
VC+CR	151.7±8.6[d]	122.5±6.9[e]	131.4±7.5[g]
CONTROL	111.3±12.0[e]	109.3±11.9[f]	108.1±11.8[h]
FYM+CR	167.1±9.5[c]	156.9±8.9[d]	155.6±8.8[e]
CONVENTIONAL	156.1±14.5[d]	154.3±14.4[d]	146.6±14.0[f]
Mean	173.7	164.2	162.9
LSD (*p = 0.05*)	11.3	10.0	11.9

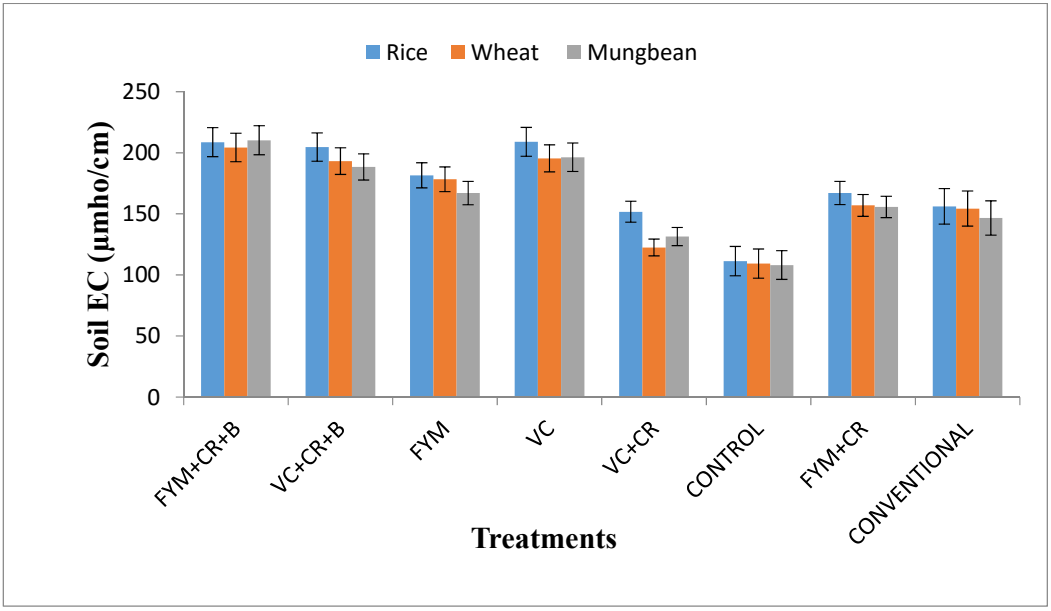

Fig. 4.20: Pooled data of Soil EC in R-W-M- cropping system

Soil EC value in rice was found significantly higher in organic treatments with maximum being inVC (208.9±11.8µmho/cm) and FYM+CR+B (208.6±11.9µmho/cm) followed by VC+CR+B (204.6±11.6µmho/cm), FYM (181.5±10.3µmho/cm), FYM+CR (167.1±9.5µmho/cm) and VC+CR (151.7±8.6µmho/cm), and it was lowest in Conventional (156.1±14.5 µmho/cm) and Control (111.3±12.0µmho/cm) plots. In wheat, it was found significantly higher in FYM+CR+B (204.3±11.6 µmho/cm) as compared to conventional (154.3±14.4µmho/cm) and control (109.3±11.9µmho/cm),

and among organic treatments, it was lowest in VC+CR (122.5±6.9 µmho/cm). In mungbean also, it was found higher in FYM+CR+B (210.2±11.9 µmho/cm) followed by other organic treatments, and it was lowest in control (108.1±11.8 µmho/cm). The soil ECincreased with the addition of organic manure (**Table 4.14**).

4.5.3. Soil Organic Carbon

Soil organic carbon (SOC) values for rice, wheat, and mungbean for both the year (2016 and 2017) under conventional, and the organically treated plots are given in Annexure 2a, 2b, and 2c. Organic carbon in rice (2015-16) ranged from 0.51 to 0.77%, while in 2016-17, it ranged from 0.55 to 0.84 % (Annexure-2a).In wheat (2015-16) it ranged from 0.53 to 0.77 %, while in 2016-17 it ranged from 0.57 to 0.84 % (Annexure-2b). In mungbean (2015-16) it was ranged from 0.52 to 0.86, % while in 2016-17, it ranged from 0.55 to 0.88% (Annexure-3c). The polled value of SOC for both the year is presented in **Table 4.15.**

Table 4.15: Pooled data of SOC in R-W-M- cropping system

Treatments	Rice	Wheat	Mungbean
FYM+CR+B	0.83±0.05^{a}	0.81±0.05^{a}	0.84±0.05^{a}
VC+CR+B	0.72±0.04^{b}	0.76±0.04^{b}	0.75±0.04^{b}
FYM	0.65±0.04^{bc}	0.68±0.04^{bc}	0.70±0.04^{bc}
VC	0.62±0.04^{bc}	0.66±0.04^{bc}	0.62±0.03^{d}
VC+CR	0.72±0.04^{b}	0.71±0.04^{bc}	0.67±0.04^{d}
CONTROL	0.54±0.03^{e}	0.59±0.03^{d}	0.55±0.03^{e}
FYM+CR	0.64±0.04^{d}	0.66±0.04^{d}	0.57±0.03^{e}
CONVENTIONAL	0.53±0.03^{e}	0.55±0.03^{e}	0.59±0.03^{e}
Mean	0.65	0.68	0.66
LSD (*p = 0.05*)	0.0474	0.0434	0.0341

The value for SOC within the crop grown under both systems ranged from 0.53±0.03 to 0.84±0.05%. The higher SOC values recorded during wheat as compared to mungbean and rice crops (**Table 4.15**). Soil OC value in rice found significantly higher in FYM+CR+B treatment (0.83±0.05%) followed by VC+CR+B (0.72±0.04%), VC+CR (0.72±0.04%), and It was lowest in conventional treatment (0.53±0.03 %). In wheat, it was found higher in FYM+CR+B treatment (0.81±0.05%) followed by

VC+CR+B (0.76±0.04 %), VC+CR (0.71±0.04 %), and it was lowest in conventional treatment (0.55±0.03%). Soil OC value in mungbean was also higher in FYM+CR+B treatment (0.84±0.05%) followed by VC+CR+B (0.75±0.04%), FYM (0.70±0.04%), and it was lowest in control (0.55±0.03 %).The soil SOC was increased with the addition of organic manure **(Fig. 4.21)**.

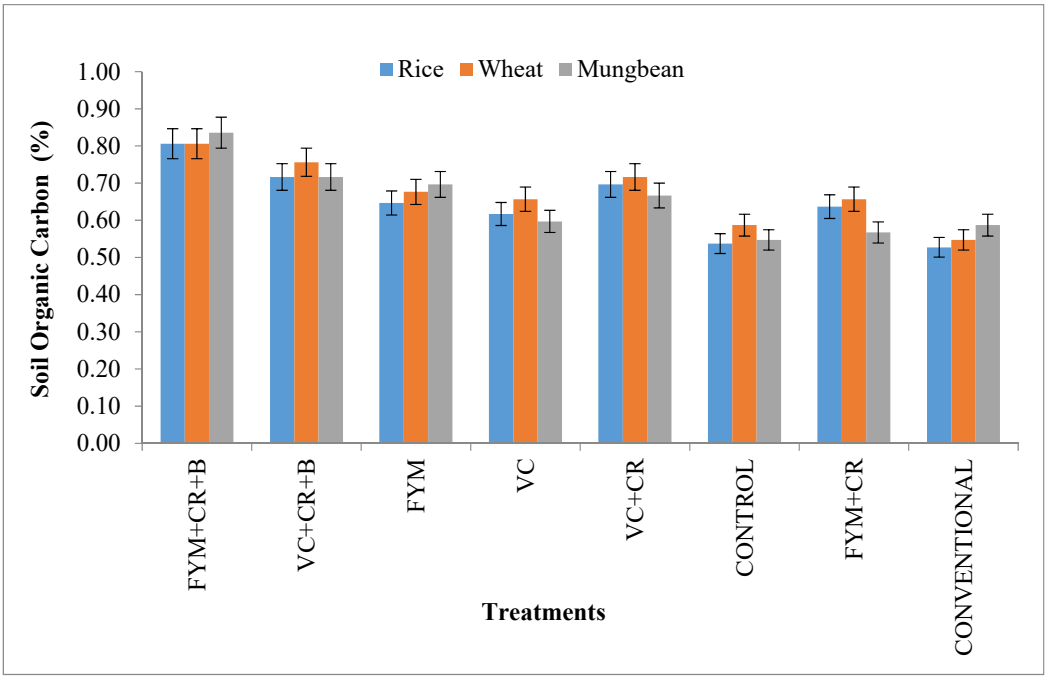

Fig. 4.21: Pooled data of SOC in R-W-M- cropping system

4.5.4. Soil Bulk Density

Bulk density (BD)values for rice, wheat, and mungbean for both the year (2016 and 2017) under conventional and the organically treated plots are given in Annexure 2a, 2b, and 2c. Bulk Density in rice *(*2015-16) ranged from 1.34 to 1.43 g/cc, while in 2016-17, it ranged from 1.46 to 1.55 g/cc (Annexure-2a). In wheat (2015-16), it was varied from 1.35 to 1.44 g/cc, while in 2016-17, it ranged from 1.46 to 1.56 g/cc (Annexure-2b). In mungbean (2015-16), it ranged from 1.34 to 1.46 g/cc, while in 2016-17, it ranged from 1.46 to 1.58 g/cc (Annexure-3c).The polled value of soil BD for both the year is presented in **Table 4.16.**

Soil Bulk Density value in rice was found significantly higher in conventional treatment (1.502±0.08 g/cc) followed by control (1.498±0.08 g/cc), FYM+CR (1.440±0.07 g/cc), and it was lowest in FYM+CR+B (1.408±0.08 g/cc). In wheat, it was found higher in conventional treatment (1.510±0.07 g/cc) followed by control

(1.496±0.05 g/cc), FYM+CR (1.448±0.08 g/cc), and lowest in FYM+CR+B (1.413±0.08 g/cc). In mungbean, it was also higher in conventional treatment (1.53±0.09 g/cc) followed by control (1.488±0.08 g/cc), FYM (1.44±0.08 g/cc), and lowest in FYM+CR+B (1.406±0.07 g/cc).Among all organic plots, the value of bulk density was almost similar, with no significant differences (**Fig. 4.22**).

Table 4.16:Pooled data of Soil Bulk Density in R-W-M- cropping system

Treatments	Rice	Wheat	Mungbean
FYM+CR+B	1.408±0.08^{d}	1.413±0.08^{d}	1.406±0.07^{d}
VC+CR+B	1.412±0.07^{d}	1.414±0.06^{d}	1.418±0.06^{d}
FYM	1.438±0.08^{c}	1.441±0.05^{c}	1.44±0.08^{c}
VC	1.420±0.06^{c}	1.419±0.08^{d}	1.417±0.07^{d}
VC+CR	1.440±0.07^{c}	1.444±0.09^{c}	1.419±0.07^{d}
CONTROL	1.498±0.08^{b}	1.496±0.05^{b}	1.488±0.08^{b}
FYM+CR	1.440±0.07^{c}	1.448±0.08^{c}	1.42±0.08^{d}
CONVENTIONAL	1.502±0.08^{a}	1.510±0.07^{a}	1.53±0.09^{a}
Mean	1.445	1.448	1.442
LSD (*p = 0.05*)	0.0081	0.0074	0.0096

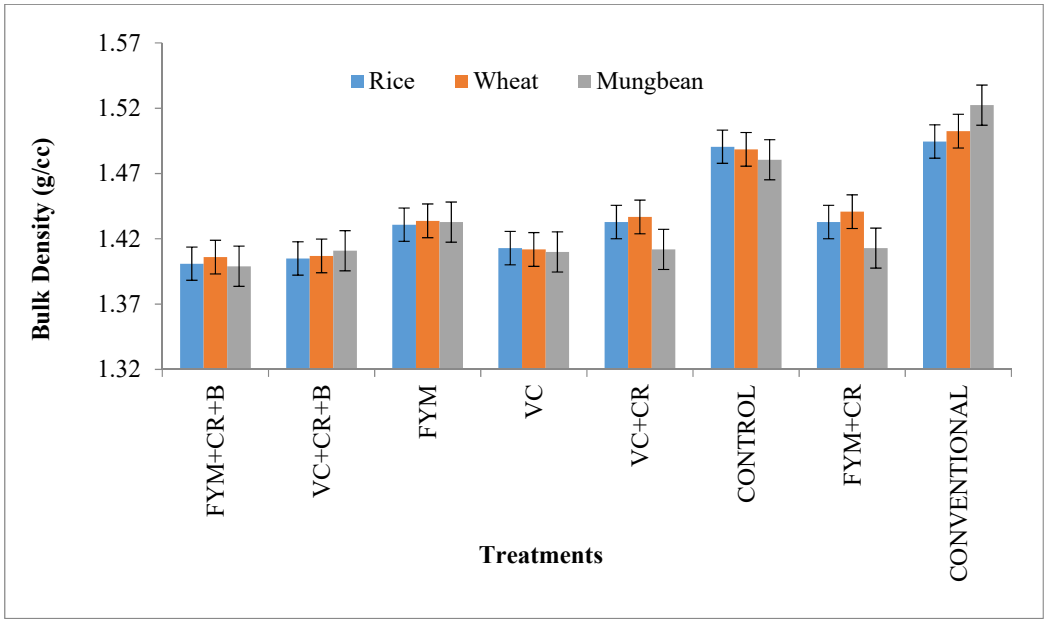

Fig. 4.22: Pooled data of Soil Bulk Density in R-W-M- cropping system

4.5.5. Water Filled Pore Space (WFPS)

Water Filled Pore Space (WFPS) values for rice, wheat, and mungbean for both the year (2016 and 2017) under conventional and the organically treated plots are given in Annexure 2a, 2b, and 2c. WFPS in rice *(*2015-16) ranged from 44.5 to 72.6%, while in 2016-17, it ranged from 44.6 to 73.3% (Annexure-2a). In wheat *(*2015-16), it ranged from 47.9 to 65.9 %, while in 2016-17, it ranged from 45.7 to 70.2% (Annexure-2b). In mungbean *(*2015-16), it ranged from 51.4 to 72.5% while in 2016-17, it ranged from 50.1 to 72.1% (Annexure-2c).The polled value of Water Filled Pore Space (WFPS) for both the year is presented in **Table 4.17.**

Table 4.17: Pooled data of WFPS in R-W-M- cropping system

Treatments	Rice	Wheat	Mungbean
FYM+CR+B	70.8±2.37^{ab}	66.9±1.86^{ab}	69.4±1.70^{ab}
VC+CR+B	72.6±1.73^{a}	67.9±1.27^{a}	72.3±1.81^{a}
FYM	66.2±2.11^{c}	65.9±2.40^{ab}	62.2±3.82^{c}
VC	68.3±1.95^{bc}	62.3±1.95^{cd}	69.4±1.19^{ab}
VC+CR	73.0±2.95^{a}	64.8±1.71^{b}	65.6±1.73^{c}
CONTROL	49.5±2.12^{d}	46.8±2.12^{f}	51.9±1.42^{d}
FYM+CR	64.9±2.48^{c}	60.7±2.67^{d}	64.1±2.11^{c}
CONVENTIONAL	44.5±1.0^{e}	49.4±2.89^{e}	50.8±1.05^{d}
Mean	63.7	60.6	63.2
LSD (*p = 0.05*)	3.19	2.45	2.71

WFPS value in rice was found significantly higher in the VC+CR plot (72.6±1.73%) followed by FYM+CR+B (72.6±1.73%), VC (68.3±1.95%), and lowest in conventional (44.5±1.0%).In wheat, it was seen higher in the VC+CR+B (67.9±1.27%) followed by FYM+CR+B (66.9±1.86%), FYM VC (65.9±2.40%), and lowest in Conventional (49.4±2.89%). In mungbean, it was also higher in the VC+CR+B (72.3±1.81%) followed by FYM+CR+B (69.4±1.70%), VC (69.4±1.19%), and lowest in Conventional (50.8±1.05%).Among all organic plots, the value of WFPS was almost higher than the control(**Fig. 4.23**).

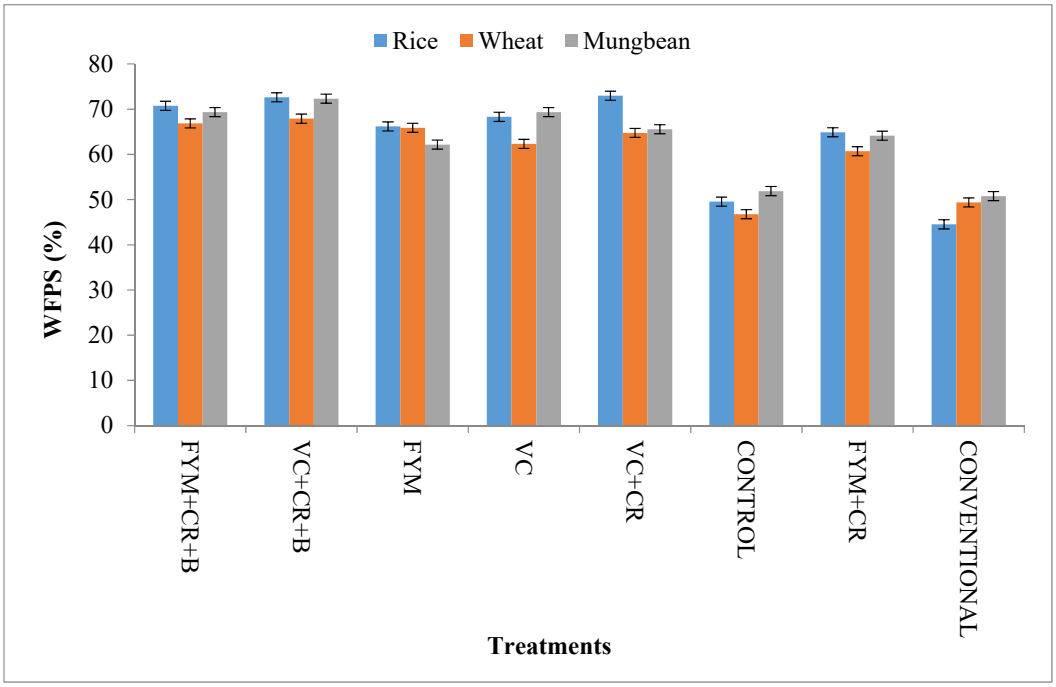

Fig. 4.23: Pooled data of WFPS in R-W-M- cropping system

4.5.6. Soil Nitrogen

Nitrogen (N) fractions [(Total N, organic N, nitrate-N (NO3--N) and ammonium-N ($NH4^+$-N)] were strongly influenced by long-term organic and conventional amendments and results are presented below.

4.5.6.1. Total Soil Nitrogen

Total soil Nitrogen values for rice, wheat, and mungbean for both the year (2016 and 2017) under conventional and the organically treated plots are given in Annexure 2d. Total Soil N in rice (2015-16) ranged from 437.8 to 1148.8kg ha^{-1}, while in 2016-17, it ranged from 474.4 to 1245.0kg ha^{-1}(Annexure-2d). In wheat (2015-16), it was varied from 406.5 to1133.8kg ha^{-1}, while in 2016-17, it ranged from 440.5 to 1228.8 kg ha^{-1}(Annexure-2d). In mungbean (2015-16), it ranged from 469.9-1174.4 kg ha^{-1}, while in 2016-17, it ranged from 509.2 to 1272.8 kg ha^{-1}(Annexure-2d). The polled value of Total soil Nitrogen for both the year is presented in **Table 4.18a.** The results showed that the total soil Nitrogen values were significantly higher in the conventional system than the organic farming system (**Fig. 4.24a**). The value for total soil Nitrogen within the crop grown under both systems ranged from 423±24.0 to 1223±69.5kg/ha. The highest total soil Nitrogen values recorded during mungbean as compared to wheat and rice crops (**Table 4.18a.**).

Table 4.18a.: Pooled data of Total Soil N (kg/ha) in R-W-M- cropping system

Treatments	Rice	Wheat	Mung
FYM+CR+B	827±47.0^{c}	846±48.1^{c}	905±51.4^{c}
VC+CR+B	985±56.0^{b}	1047±59.5^{b}	1045±59.4^{b}
FYM	757±43.0^{d}	690±39.2^{d}	797±45.3^{d}
VC	704±40.0^{d}	780±44.3^{c}	733±41.6^{e}
VC+CR	608±34.5^{e}	646±36.7^{e}	695±39.5^{e}
CONTROL	456±25.9^{f}	423±24.0^{d}	489±27.8^{f}
FYM+CR	677±38.5^{e}	624±35.4^{d}	737±41.9^{e}
CONVENTIONAL	1196±68.0^{a}	1181±67.1^{a}	1223±69.5^{a}
Mean	777	780	828
LSD (*p = 0.05*)	56.15	72.12	52.90

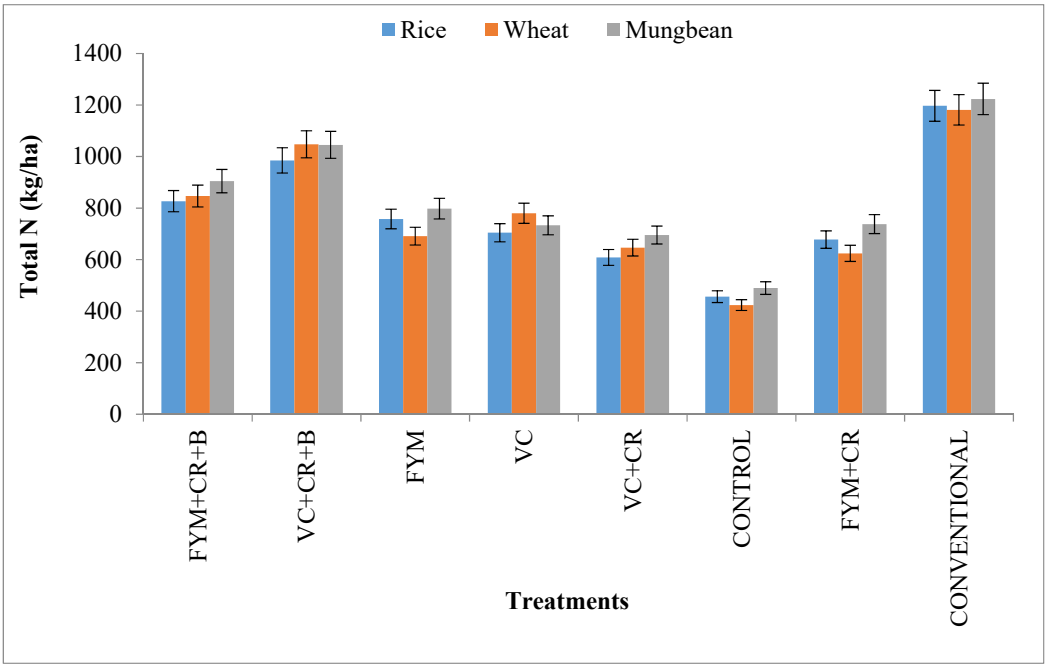

Fig. 4.24a: Pooled data of Total Soil N in R-W-M- cropping system

Total Soil N value in rice found significantly higher in the conventional plot (1196±68.0 kg/ha) followed by VC+CR+B (985±56.0 kg/ha), FYM+CR+B (827±47.0 kg/ha) and lowest in control (456±25.9 kg/ha). In wheat found significantly higher in conventional plot (1181±67.1 kg/ha) followed by VC+CR+B (1047±59.5 kg/ha), FYM+CR+B (846±48.1 kg/ha) and lowest in control (423±24.0 kg/ha). In mungbean,

it was also higher in the conventional plot (1223±69.5 kg/ha) followed by VC+CR+B (1045±59.4 kg/ha), FYM+CR+B (905±51.4 kg/ha) and it was lowest in control (489±27.8 kg/ha) (**Table 4.18a).**Among all organic plots, Soil Nitrogen was lowest in VC+CR applied plot.

4.5.6.2. Nitrate-Nitrogen (NO_3^--N)

Nitrate-Nitrogen (NO_3^--N) values for rice, wheat, and mungbean for both the year (2016 and 2017) under conventional and the organically treated plots are given in Annexure 2d. NO_3^--N in rice (2015-16), it ranged from 12.5 to 38.0 kg ha^{-1} while in 2016-17, it ranged from 13.6 to 41.2 kg ha^{-1} (Annexure-2d). In wheat (2015-16), it ranged from 14.1 to 41.3 kg ha^{-1} while in 2016-17, it ranged from 15.3 to 44.8 kg ha^{-1} (Annexure-2d). In mungbean (2015-16), it ranged from 13.3 to 44.3 kg ha^{-1} while in 2016-17, it ranged from 14.4 to 48.0 kg ha^{-1} (Annexure-2d).The polled value of NO_3^--N for both the year is presented in **Table4.18b**.

Table 4.18b: Pooled data of Nitrate-N (kg/ha) in R-W-M- cropping system

Treatments	Rice	Wheat	Mungbean
FYM+CR+B	27.4±1.6^{bc}	27.6±1.5^{c}	29.2±1.7^{b}
VC+CR+B	28.5±1.4^{b}	30.6±1.7^{b}	29.5±1.8^{b}
FYM	23.7±1.3^{d}	22.2±1.2^{bc}	24.3±1.4^{b}
VC	24.9±1.9^{cd}	25.2±1.4^{bc}	24.8±1.1^{b}
VC+CR	27.7±1.5^{bc}	26.9±1.5^{bc}	27.3±1.5^{b}
CONTROL	13.0±0.7^{e}	14.7±0.8^{d}	13.8±0.9^{c}
FYM+CR	28.0±1.9^{bc}	28.3±1.1^{bc}	29.1±1.7^{b}
CONVENTIONAL	39.5±2.2^{a}	43.0±2.4^{a}	46.1±2.6^{a}
Mean	26.6	27.4	28.1
LSD (*p = 0.05*)	3.69	6.71	5.32

NO_3^--N was also found higher in conventional treatment as compared to organically treated plots and minimum in control (**Fig. 4.24b**).Soil NO_3^--N value in rice found significantly higher in conventional treatment (39.5±2.2 kg/ha) followed by VC+CR+B (28.5±1.4 kg/ha), FYM+CR (28.0±1.9kg/ha) and lowest in control (13.0±0.7 kg/ha). In wheat, it was found higher in conventional treatment (43.0±2.4 kg/ha) followed by VC+CR+B (30.6±1.7 kg/ha), FYM+CR(28.3±1.1kg/ha) and lowest in control (14.7±0.8 kg/ha). In mungbean, it was also higher in the conventional plot

(46.1±2.6 kg/ha) followed by VC+CR+B (29.5±1.8 kg/ha), FYM+CR+B (29.2±1.7 kg/ha) and lowest in Control (13.8±0.9 kg/ha).Among different cropping seasons, the mungbean recorded the highest values for NO_3^--N followed by wheat and rice (**Table4.18b**).

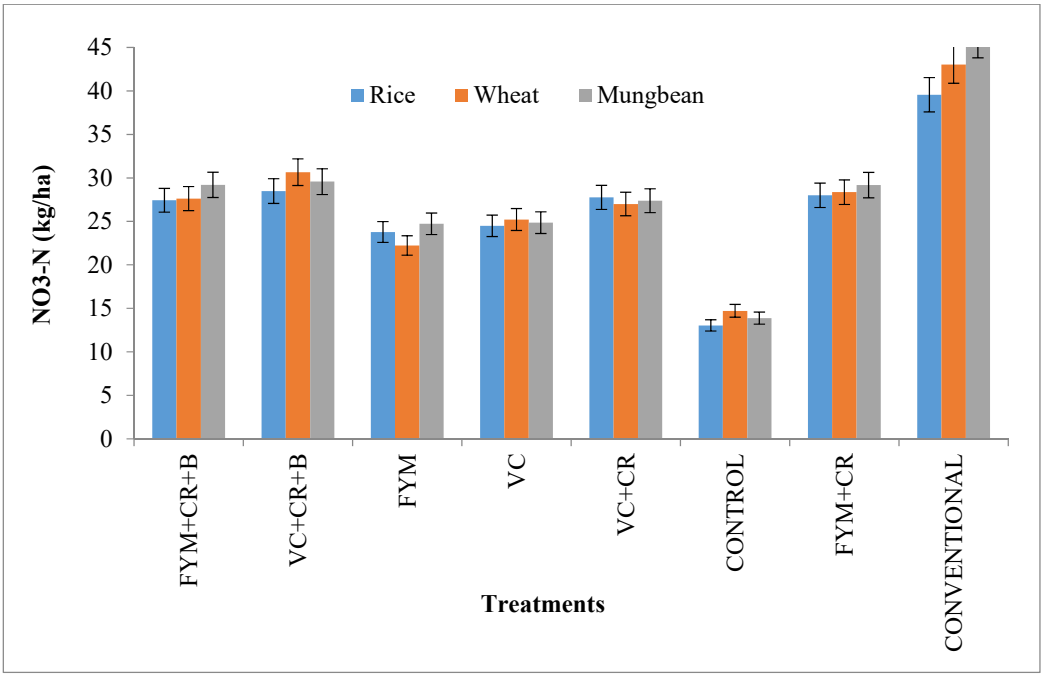

Fig. 4.24b: Pooled data of Nitrate-N (NO_3^--N) in R-W-M- cropping system

4.5.6.3.Ammoniacal-Nitrogen (NH_4^+-N)

Ammoniacal-nitrogen (NH_4^+-N) values for rice, wheat, and mungbean for both the year (2016 and 2017) under conventional and the organically treated plots are given in Annexure 2d. The polled value of NH_4^+-N for both the year is presented in **Table4.18c**. NH_4^+-Nin rice (2015-16) ranged from 32.0 to 94.4 meq/100g soil, while in 2016-17, it ranged from 34.7 to 102.3 meq/100g soil (Annexure-2d). In wheat (2015-16), it ranged from 30.3 to 83.7 meq/100g soil, while in 2016-17, it ranged from 32.9 to 90.7 meq/100g soil (Annexure-2d). In mungbean (2015-16), it was ranged from 28.7 to 96.6 meq/100g soil, while in 2016-17, it ranged from 31.1 to 104.7 meq/100g soil (Annexure-2d).

NH_4^+-N showed similar trends like NO_3^--N for rice-wheat and mungbean. Soil NH_4^+-N value in rice found significantly higher in the conventional plot (98.3±5.6 meq/100g) followed by VC+CR+B (75.5±4.2 meq/100g), FYM+CR (66.2±3.7meq/100g), and it was lowest in control (33.4±1.9 meq/100g). In wheat, it

was found higher in conventional treatment (87.1±4.9 meq/100g) followed by VC+CR+B (70.8±4.0 meq/100g), FYM+CR (63.2±3.5 meq/100g), and it was lowest in control (31.6±1.8 meq/100g). In mungbean, it was also higher in conventional treatment (100.6±5.7 meq/100g) followed by VC+CR+B (75.5±4.2 meq/100g). In contrast to NO_3^--N, NH_4^+-N was higher during rice season followed by mungbean and wheat season (**Table4.18c** and**Fig. 4.24c**).

Table 4.18c: Pooled data of NH_4^+-N (meq/100g soil) in R-W-M- cropping system

Treatments	Rice	Wheat	Mungbean
FYM+CR+B	59.7±3.3^{d}	52.1±2.9^{cd}	52.0±2.9^{de}
VC+CR+B	75.5±4.2^{b}	70.8±4.0^{b}	75.5±4.2^{b}
FYM	45.6±2.6^{e}	42.0±2.4^{e}	48.5±2.7^{e}
VC	46.2±2.6^{e}	48.0±2.7de	50.9±2.9 ^{cd}
VC+CR	59.1±3.4^{d}	53.2±3.0^{cd}	60.8±3.4^{cd}
CONTROL	33.4±1.9^{f}	31.6±1.8^{f}	29.8±1.7^{f}
FYM+CR	66.2±3.7^{c}	63.2±3.5^{bc}	67.9±3.8^{bc}
CONVENTIONAL	98.3±5.6^{a}	87.1±4.9^{a}	100.6±5.7^{a}
Mean	60.5	56.0	60.8
LSD (*p = 0.05*)	5.84	10.30	11.34

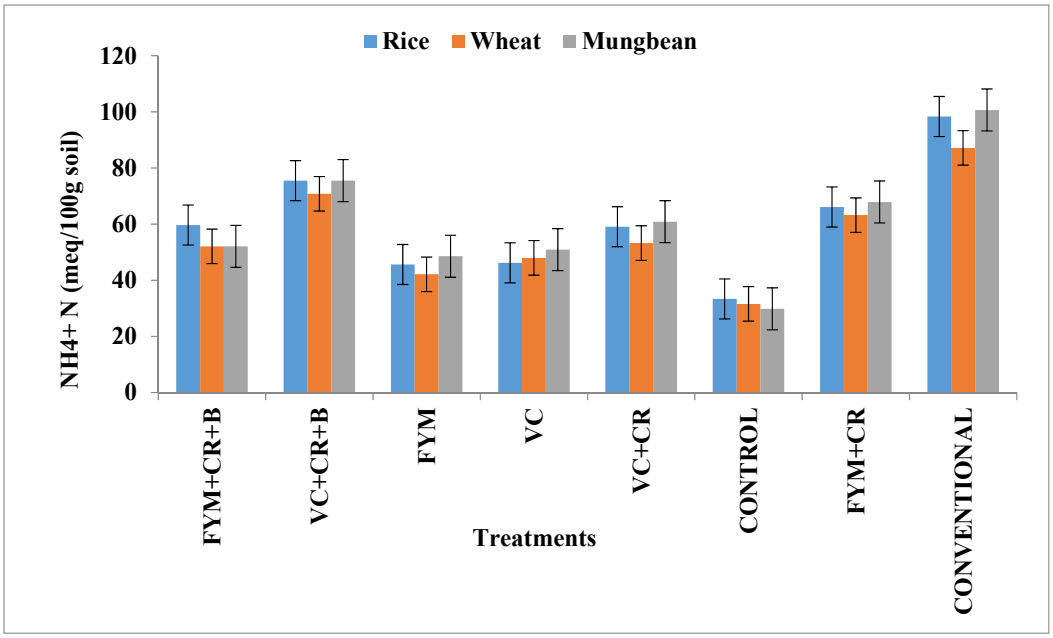

Fig. 4.24c: Pooled data of NH_4^+-N in R-W-M- cropping system

4.6. Impact of organic amendment on soil microbiological properties

Soil enzymatic activity was different or varied according to inputs applied in organic and conventional rice-wheat systems. Results are elaborated based on mean (pooled) values of concerned enzymatic activity for 0-15 cm soil layer.

4.6.1. Microbial Biomass Carbon (MBC)

MBC value for rice, wheat, and moonbeam for both the year (2016 and 2017) under conventional, and the organically treated plots are given in Annexure 3a, 3b, and 3c. MBC in rice (2015-16) ranged from 67.0 to 165.4 µg C g^{-1} soil, while in 2016-17, it ranged from72.6 to 179.3 µg C g^{-1} soil (Annexure-3a). In wheat (2015-16), it ranged from 82.5 to 200.0 µg C g^{-1} soil, while in 2016-17, it ranged from 89.4 to 216.7 µg C g^{-1} soil (Annexure-3b). In mungbean (2015-16), it ranged from 77.7 to 180.5 µg C g-1 soil, while in 2016-17, it ranged from 84.2 to 195.6 µg C g-1 soil (Annexure-3c). The polled value of MBC for both the year is presented in **Table 4.19.**

Table 4.19: MBC (µg C g^{-1} soil) in R-W-M- cropping system

Treatments	Rice	Wheat	Mungbean
FYM+CR+B	172.3±9.8^{a}	208.4±12.0^{a}	188±10.7^{a}
VC+CR+B	146.9±8.3^{bc}	183.6±10.4^{b}	161.4±9.2^{b}
FYM	159.8±9.1^{ab}	168.5±9.6^{bc}	168.9±9.6^{ab}
VC	142.8±8.1^{b}	163±9.3^{bcd}	155.2±8.8^{b}
VC+CR	136.9±7.8^{c}	139.6±7.9^{de}	149±8.5^{bc}
CONTROL	69.8±4.0^{d}	85.9±4.9^{f}	81±4.6e
FYM+CR	133.6±7.6^{c}	149.6±8.5^{c}	131.6±7.5c
CONVENTIONAL	85.7±4.9^{d}	119.6±6.8^{e}	107.6±6.1d
Mean	130.9	152.3	142.8
LSD (*p = 0.05*)	22.16	23.82	21.64

Impacts of organicamendment and conventional inputs added in the rice-wheat system on MBC are depicted in **Fig. 4.25**. The results showed that the soil MBC values were significantly higher in theorganicamended than the conventional system (**Fig. 4.25**). The value for MBC within the crop grown under both systems ranged from 69.8±4 to 208.4±12 µg C g^{-1} soil. The lower MBC values recorded during rice as compared to wheat and mungbean crops (**Table 4.19**).

MBC value for rice found significantly higher in FYM+CR+B (172.3±9.8 µg C g^{-1} soil) followed by FYM (159.8±9.1 µg C g^{-1} soil), VC+CR+B (146.9±8.3 µg C g^{-1} soil) and it was lowest in control (69.8±4.0 µg C g^{-1} soil). In wheat, it was found significantly higher in FYM+CR+B (208.4±12.0 µg C g^{-1} soil) followed by VC+CR+B (183.6±10.4µg C g^{-1} soil), FYM (168.5±9.6µg C g^{-1} soil) and it was lowest in control (85.9±4.9 µg C g^{-1} soil). In mungbean, it was found significantly higher in FYM+CR+B (188±10.7 µg C g^{-1} soil) followed by FYM (168.9±9.6^{ab}µg C g^{-1} soil), VC+CR+B (161.4±9.2µg C g^{-1} soil) and it was lowest in control (81±4.6e µg C g^{-1} soil).Microbial Biomass Carbon of FYM+CR+B was observed highest among all organic treatments. Crop Residue (CR) applied plots had comparatively less MBC than other organic plots. Even the conventionally managed plot was low in MBC, and the lowest was found in unfertilized control**(Fig. 4.25)**.

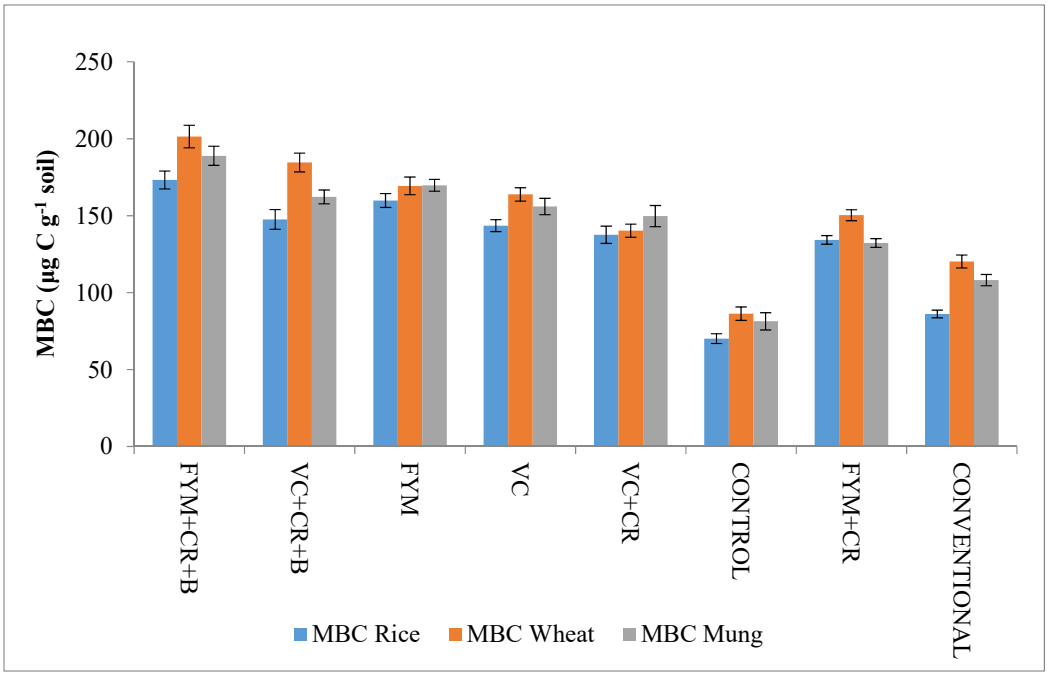

Fig. 4.25: Microbial Biomass Carbon (MBC) in R-W-M- cropping system

4.6.2. Microbial Biomass Nitrogen (MBN)

MBNcontent for rice, wheat, and moonbeam for both the year (2016 and 2017) under conventional, and the organically treated plots are given in Annexure 3a, 3b, and 3c.MBN in rice (2015-16) ranged from 14.0 to 32.3 µg N g^{-1} soil, while in 2016-17, it ranged from 15.2 to 35.0 µg N g^{-1} soil (Annexure-3a). In wheat (2015-16), it varied from 15.8 to 38.3 µg N g^{-1} soil, while in 2016-17, it ranged from 17.2 to 41.5 µg N g^{-}

^{1}soil (Annexure-3b). In mungbean (2015-16), it varied from 17.6 to 44.3 µg N g^{-1} soil, while in 2016-17, it ranged from 19.1 to 48.1 µg N g^{-1} soil (Annexure-3c).

The polled value of MBN for both the year is presented in **Table 4.20**. Impacts of organic amendment and conventional inputs added in the rice-wheat system on MBN is depicted in **Fig. 4.26**. The results showed that the soil MBN content was higher in the organic amended than the conventional system (**Fig. 4.26**).The value for MBN within the crop grown under both systems ranged from 14.6±0.8 to 46.2±2.6µg N g^{-1} soil. The lower MBN values recorded during rice as compared to wheat and mungbean crops (**Table 4.20**).

MBN value for rice found significantly higher in FYM+CR+B (33.6±1.9 µg N g^{-1} soil) followed by VC+CR+B (26.5±1.5 µg N g^{-1} soil), FYM (26.2±1.5 µg N g^{-1} soil) and it was lowest in Control (14.6±0.8 µg N g^{-1} soil). In wheat, it was found significantly higher in FYM+CR+B (39.9±2.3µg N g^{-1} soil) followed by VC+CR+B (34.3±1.9 µg N g^{-1} soil), VC+CR (29.4±1.7 µg N g^{-1} soil) and it was lowest in control (16.5±0.9µg N g^{-1} soil). In mungbean, it was found significantly higher in FYM+CR+B (46.2±2.6 µg N g^{-1} soil) followed by VC+CR+B (42.0±2.4 µg N g^{-1} soil), FYM+CR (41.6±2.4 µg N g^{-1} soil) and it was lowest in control (18.3±1µg N g^{-1} soil)**(Table 4.20)**.

Table 4.20: MBN (µg N g^{-1} soil) in R-W-M- cropping system

Treatments	Rice	Wheat	Mungbean
FYM+CR+B	33.6±1.9^{a}	39.9±2.3^{a}	46.2±2.6^{a}
VC+CR+B	26.5±1.5^{b}	34.3±1.9^{b}	42.0±2.4^{ab}
FYM	26.2±1.5^{b}	27.5±1.6^{d}	29.7±1.7^{c}
VC	22.4±1.3^{b}	28.1±1.6^{bcd}	33.9±1.9^{bc}
VC+CR	25.0±1.4^{b}	29.4±1.7^{b}	33.7±1.9^{bc}
CONTROL	14.6±0.8^{c}	16.5±0.9^{e}	18.3±1d
FYM+CR	24.3±1.4^{b}	33±1.9^{bc}	41.6±2.4^{ab}
CONVENTIONAL	24.4±1.4^{b}	26.7±1.5^{d}	29±1.6^{c}
Mean	24.62	29.41	34.33
LSD(*p = 0.05*)	6.50	5.51	8.50

Similarly, MBN was recorded highest in FYM+CR+B among all organic treatments. Crop Residue (CR) applied plots had comparatively less MBN than other organic plots. Even the conventionally managed plot was low in MBN, and the lowest was found in unfertilized control **(Fig. 4.26)**.

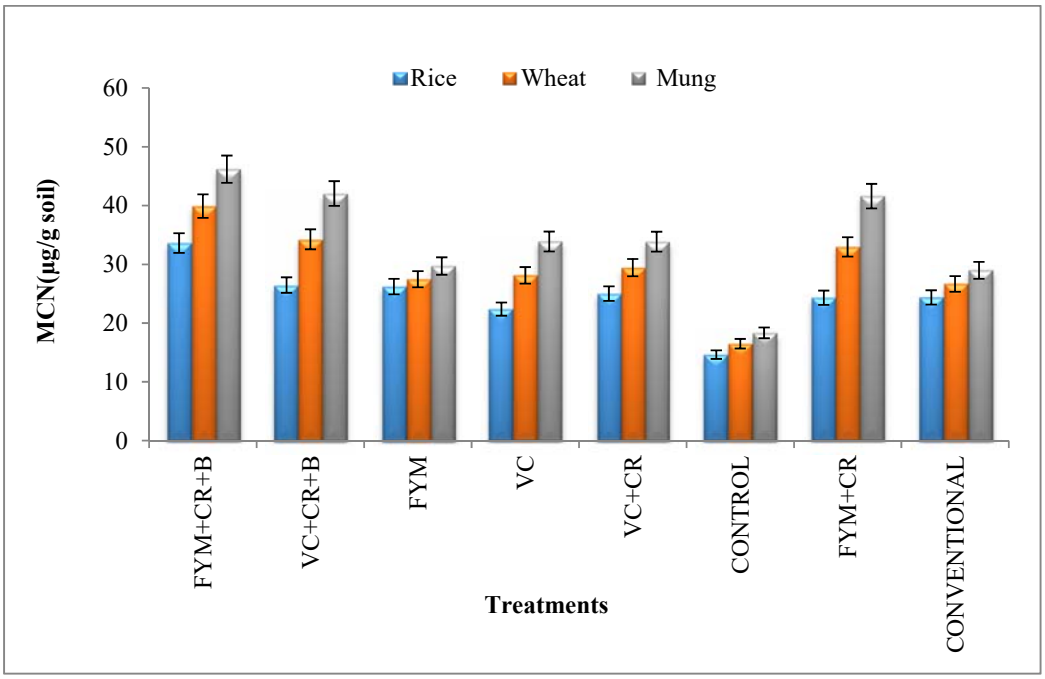

Fig. 4.26: Microbial Biomass Nitrogen (MBN) in R-W-M- cropping system

4.6.3. Dehydrogenase enzyme activity (DHase)

Dehydrogenase enzyme (DHase) activity for rice, wheat, and moonbeam for both the year (2016 and 2017) under conventional, and the organically treated plots are given in Annexure 3a, 3b, and 3c. Dehydrogenase in rice (2015-16) ranged from 167.6 to 280.4 µg TPF g^{-1} soil $24hr^{-1}$, while in 2016-17, it ranged from 181.6 to 303.8 µg TPF g^{-1} soil $24hr^{-1}$(Annexure-3a). In wheat (2015-16), it ranged from 168.9 to 324.9 µg TPF g^{-1} soil $24hr^{-1}$ while in 2016-17, it ranged from 183.1 to 352.1 µg TPF g^{-1} soil $24hr^{-1}$(Annexure-3b). In mungbean (2015-16), it ranged from 211.2 to 354.2 µg TPF g^{-1} soil $24hr^{-1}$, while in 2016-17, it ranged from 228.9 to 383.9 µg TPF g^{-1} soil $24hr^{-1}$ (Annexure-3c).

The polled value of DHase-enzyme activityfor both the year is presented in **Table 4.21**.Impacts of organic amendment and conventional inputs added in the rice-wheat system on DHase-enzyme activity is depicted in **Fig. 4.27**. The results showed that the soil DHase-enzyme activitywas higher in the organic amended than the conventional system (**Fig. 4.27**). The value for DHase-enzyme activity within the crop grown under both systems ranged from 174.6±14.3 to 369±25 µg TPF g^{-1} soil $24hr^{-1}$.The lower DHase-enzyme activity recorded during rice as compared to wheat and mungbean crops (**Table 4.21**).

Table 4.21: Dehydrogenase enzyme activity in R-W-M- cropping system

Treatments	Rice	Wheat	Mungbean
FYM+CR+B	292.1±34.5^{a}	339±31.7^{a}	369±25^{a}
VC+CR+B	299.6±27.7^{ab}	323±24.8^{ab}	354±21^{a}
FYM	253.3±29.1^{c}	294±19.6^{c}	316±23.7^{cd}
VC	228±19.2^{c}	263±16.7^{d}	295±15.4^{d}
VC+CR	261.2±22.1^{bc}	306±24.3^{c}	332±28.5^{bc}
CONTROL	174.6±14.3^{d}	176±11.2^{e}	220±12.6^{e}
FYM+CR	260.6±31.3^{bc}	309±20.3^{bc}	323±27.4^{dc}
CONVENTIONAL	179±15.8^{d}	196±12.4^{e}	234±13.1^{ab}
Mean	244	276	306
LSD (*p = 0.05*)	34.5	29.7	37.2

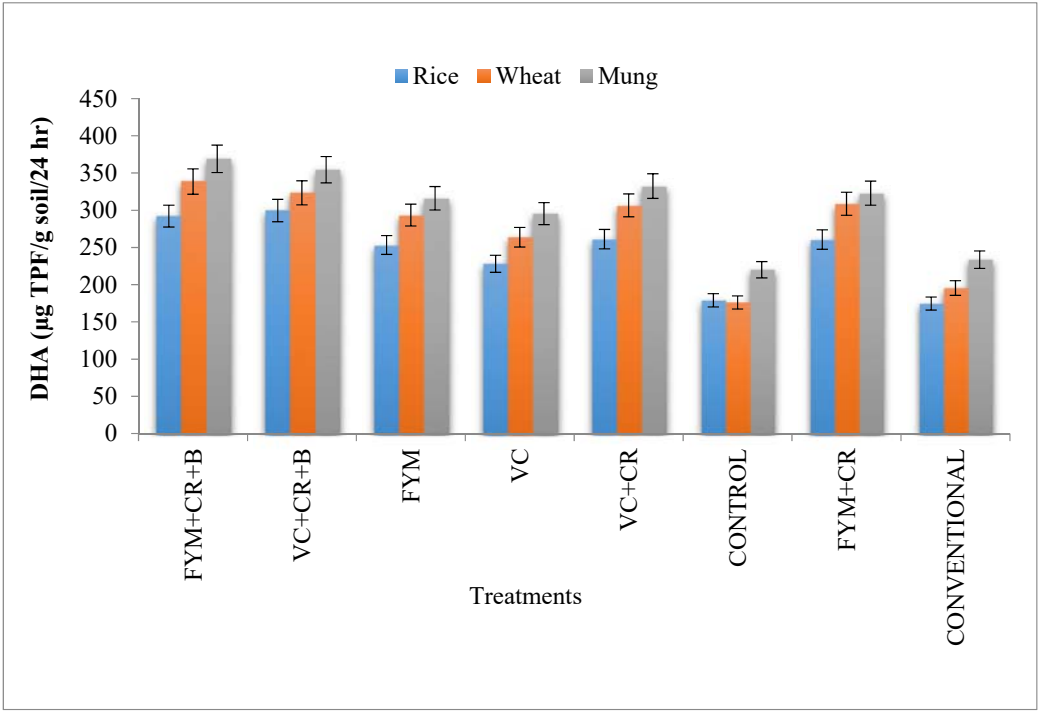

Fig. 4.27: Dehydrogenase enzyme activity in R-W-M- cropping system

Dehydrogenase enzyme activity in rice found significantly higher in VC+CR+B (292.1±34.5µg TPF/g soil/24 hr) followed by FYM+CR+B (292.1±34.5 µg TPF/g soil/24 hr), VC+CR (261.2±22.1µg N g^{-1} soil). It was lowest in control (174.6±14.3µg

TPF/g soil/24 hr).In wheat it was found higher in FYM+CR+B (339±31.7µg TPF/g soil/24 hr) followed by VC+CR+B (323±24.8 µg TPF/g soil/24 hr), FYM+CR (309±20.3µg N g^{-1} soil) and it was lowest in control (176±11.2 µg TPF/g soil/24 hr). Inmungbean, it was found significantly higher in FYM+CR+B (369±25µg TPF/g soil/24 hr) followed by VC+CR+B (354±21µg TPF/g soil/24 hr), FYM+CR (323±27.4 µg N g^{-1} soil). It was lowest in control (220±12.6 µg TPF/g soil/24 hr)**(Table 4.21**).Similarly, DHase-enzyme activity was recorded highest in FYM+CR+B among all organic treatments. Crop Residue (CR) applied plots had comparatively less DHase-enzyme activity than other organic plots. Even the conventionally managed plot was low in DHase-enzyme activity, and the lowest was found in unfertilized control **(Fig. 4.27)**.

4.6.4. β-Glucosidaseenzyme activity

β-Glucosidaseactivity for rice, wheat, and moonbeam for both the year (2016 and 2017) under conventional, and the organically treated plots are given in Annexure 3a, 3b, and *3c. β-Glucosidase in rice (2015-16) ranged from 64.6 to 180.6 nmols g^{-1} dry soil hr^{-1}, while in 2016-17, it ranged from 70.1 to 195.7 nmols g^{-1} dry soil hr^{-1}*(Annexure-3a*). In wheat (2015-16), it ranged from 76.0 to 159.2 nmols g^{-1} dry soil hr^{-1}, while in 2016-17, it ranged from 82.4 to 172.6 nmols g^{-1} dry soil hr^{-1}*(Annexure-3b). *In mungbean (2015-16), it ranged from 84.4 to 164.6 nmols g^{-1} dry soil hr^{-1}, while in 2016-17, it ranged from 91.4 to 178 nmols g^{-1} dry soil hr^{-1} (Annexure-3c).*

The polled value of β-Glucosidaseenzyme activityfor both the year is presented in **Table 4.22**.Impacts of organic amendment and conventional inputs added in the rice-wheat system on β-Glucosidaseenzyme activity are depicted in **Fig. 4.28**. The results showed that the soil β-Glucosidaseenzyme activity was higher in the organic amended than the conventional system (**Fig. 4.28**). The value for β-Glucosidaseenzyme activity within the crop grown under both systems ranged from77.3±3.8 to188.1±11nmols g^{-1} dry soil hr^{-1}. The lower β-Glucosidaseenzyme activity recorded during rice as compared to wheat and mungbean crops (**Table 4.22**).

β-Glucosidase enzyme activity in rice found significantly higher in FYM+CR+B (188±11*nmols g^{-1} dry soil hr^{-1}*) followed by VC+CR+B (171±9.7*nmols g^{-1} dry soil hr^{-1}*), VC+CR (169±9.6*nmols g^{-1} dry soil hr^{-1}*). It was lowest in FYM+CR(77±3.8*nmols g^{-1} dry soil hr^{-1}*)**(Table 4.22)**.

Table 4.22: β-Glucosidase enzyme activity in R-W-M- cropping system

Treatments	Rice	Wheat	Mungbean
FYM+CR+B	188±11^{a}	172±9.7^{a}	166±9.4^{a}
VC+CR+B	171±9.7^{a}	158±9.2^{a}	147±8.4^{b}
FYM	121±6.9^{c}	135±7.7^{c}	142±8.1^{c}
VC	113±5.9^{d}	128±7.3	117±6.7^{c}
VC+CR	169±9.6^{b}	138±7.8^{c}	149±8.5^{ab}
CONTROL	100±5.7^{c}	129±7.3	132±7.5^{cd}
FYM+CR	77±3.8^{d}	88±5.0	79±4.5^{d}
CONVENTIONAL	100.8±5.7^{c}	108±6.1	121±6.9^{c}
Mean	128.3^{c}	132.4	132.3
LSD (*p = 0.05*)	23.9	21.1	23.8

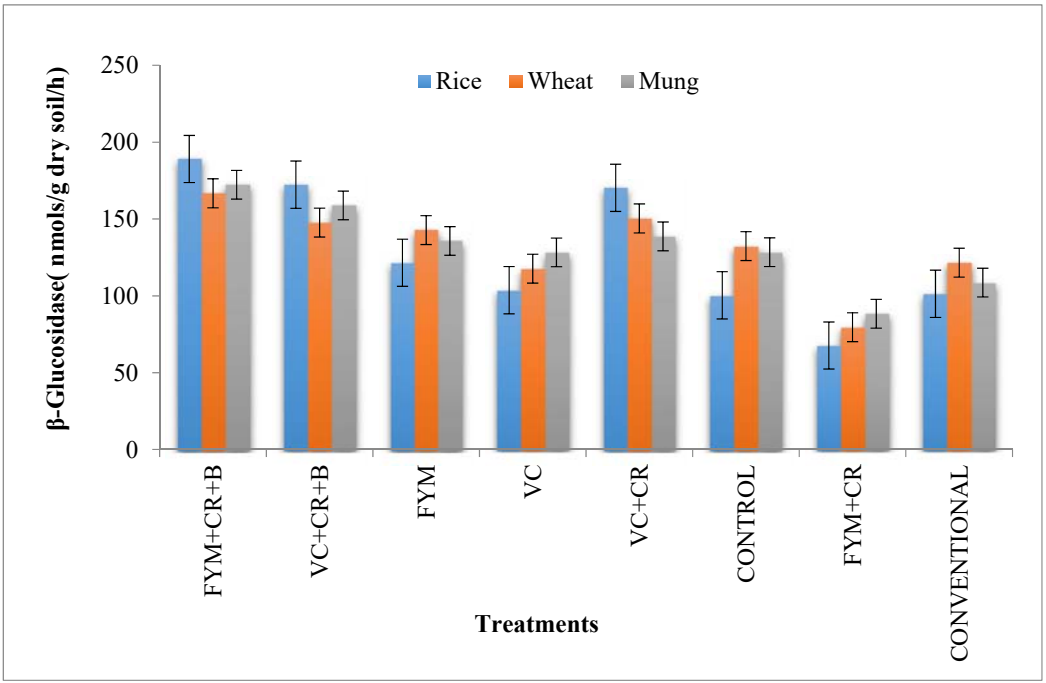

Fig. 4.28: β-Glucosidase enzyme activity in R-W-M- cropping system

In wheat, it was found higher in FYM+CR+B (172±9.7nmols g^{-1} dry soil hr^{-1}) followed by VC+CR+B (158±9.2nmols g^{-1} dry soil hr^{-1}**),** VC+CR (138±7.8nmols g^{-1} dry soil hr^{-1}) and it was lowest in FYM+CR (88±5.0 nmols g^{-1} dry soil hr^{-1}) **(Table 4.22)**.

Inmungbean, it was found significantly higher in FYM+CR+B (166±9.4nmols g^{-1} dry soil hr^{-1}) followed by VC+CR (149±8.5 nmols g^{-1} dry soil hr^{-1}**),** VC+CR+B (147±8.4nmols g^{-1} dry soil hr^{-1}) and it was lowest in FYM+CR (79±4.5nmols g^{-1} dry soil hr^{-1})**(Table 4.22)**.Similarly, β-Glucosidaseenzyme activity was recorded highest in FYM+CR+B among all organic treatments. FYM+CR plot strangely recorded low value for β-Glucosidase activity as compared to other organic treatments**(Fig. 4.28)**.

4.6.5. α-Glucosidase enzyme activity in R-W-M- cropping system

α-Glucosidaseactivity for rice, wheat, and moonbeam for both the year (2016 and 2017) under conventional, and the organically treated plots are given in Annexure 3a, 3b, and 3c. *α-Glucosidase*in rice *(*2015-16) ranged from 16.1 to 51.9 *nmols* g^{-1} *dry soil* hr^{-1}, while in 2016-17, it ranged from 17.5 to 56.3 *nmols* g^{-1} *dry soil* hr^{-1}(Annexure-3a). In wheat (2015-16), it ranged from 21.0 to 63.4 *nmols* g^{-1} *dry soil* hr^{-1}*,* while in 2016-17, it ranged from 22.8 to 68.7 *nmols* g^{-1} *dry soil* hr^{-1}(Annexure-3b). I*n* mungbean (2015-16), it ranged from 17.1 to 58.5 *nmols* g^{-1} *dry soil* hr^{-1}, while in 2016-17, it ranged from 18.5 to 63.4 *nmols* g^{-1} *dry soil* hr^{-1}(Annexure-3c).The polled value of α-Glucosidaseenzyme activityfor both the year is presented in **Table 4.23**.

Table 4.23:α-Glucosidase enzyme activity in R-W-M- cropping system

Treatments	Rice	Wheat	Mung
FYM+CR+B	54.1±4.3^{a}	66.1±5.2^{a}	60.9±3.7^{a}
VC+CR+B	41.4±4^{bc}	57.3±4.6^{b}	50.9±4.7^{b}
FYM	20.2±2^{e}	26.9±3.1^{cd}	22.2±2.9^{de}
VC	38.4±2.5^{c}	31.3±3.5^{c}	33.5±2.7^{c}
VC+CR	45.4±3.1^{b}	37.5±4^{bc}	34.6±3.6^{c}
CONTROL	16.8±2.2^{e}	21.9±2e	17.8±3^{e}
FYM+CR	36.8±2c	25.8±1.8^{de}	27.7±2.2^{cd}
CONVENTIONAL	21.8±2.9^{de}	26.4±3.1^{de}	26.2±3.4^{cd}
Mean	34.4	36.6	34.2
LSD **(***p = 0.05***)**	9.05	9.16	9.17

Impacts of organic amendment and conventional inputs added in the rice-wheat system on α-Glucosidaseenzyme activity are depicted in **Fig. 4.29**. The results showed that the soil β-Glucosidaseenzyme activity was higher in the organic amended than the

conventional system (**Fig. 4.29**). The value for α-Glucosidaseenzyme activity within the crop grown under both systems ranged from 16.8±2.2 to 66.1±5.2 nmols g^{-1} dry soil hr^{-1}. The lower α-Glucosidaseenzyme activity recorded during rice as compared to wheat and mungbean crops (**Table 4.23**). α-Glucosidase enzyme activity value for rice found significantly higher in FYM+CR+B (54.1±4.3nmols g^{-1} dry soil hr^{-1}) followed by VC+CR (45.4±3.1nmols g^{-1} dry soil hr^{-1}), VC+CR+B (41.4±4nmols g^{-1} dry soil hr^{-1}) and it was lowest in control (16.8±2.2nmols g^{-1} dry soil hr^{-1}).

In wheat, it was found significantly higher in FYM+CR+B (66.1±5.2 nmols g^{-1} dry soil hr^{-1}) followed by VC+CR+B (57.3±4.6^{b}nmols g^{-1} dry soil hr^{-1}), VC+CR (37.5±4nmols g^{-1} dry soil hr^{-1}) and it was lowest in control (21.9±2 nmols g^{-1} dry soil hr^{-1}). Inmungbean, it was found significantly higher in FYM+CR+B (60.9±3.7nmols g^{-1} dry soil hr^{-1}) followed by VC+CR+B (50.9±4.7nmols g^{-1} dry soil hr^{-1}), VC+CR (34.6±3.6nmols g^{-1} dry soil hr^{-1}) and it was lowest in control (17.8±3nmols g^{-1} dry soil hr^{-1}).The α-Glucosidase activity also exhibited a similar trend, with the maximum being in FYM+CR+B among all organic treatments. Even the conventionally managed plot was low in α-Glucosidaseenzyme activity, and the lowest was found in unfertilized control (**Fig. 4.29**).

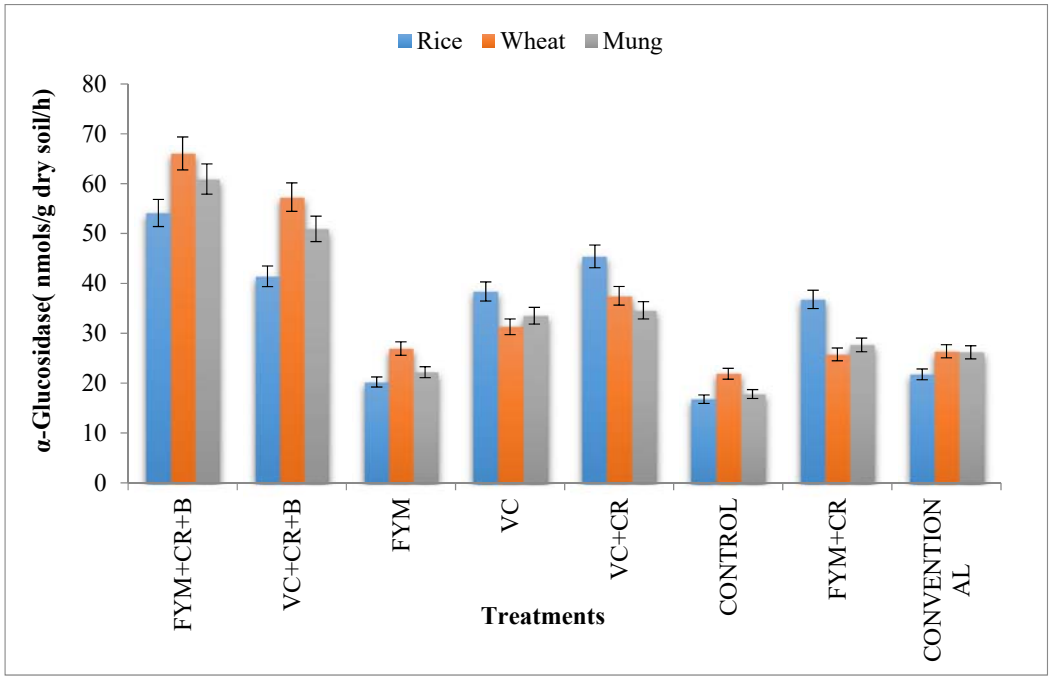

Fig. 4.29:α-Glucosidase enzyme activityin R-W-M- cropping system

4.6.6. Leucine amino-peptidase in R-W-M- cropping system

Leucine amino-peptidase (LAP) activity for rice, wheat, and moonbeam for both the year (2016 and 2017) under conventional, and the organically treated plots are given in Annexure 3a, 3b, and 3c. *Leucine amino-peptidase in rice* (2015-16) ranged from 259.6 to 583.8 nmols g^{-1} dry soil hr^{-1}, while in 2016-17, it varied from 281.4 to 632.7 nmols g^{-1} dry soil hr^{-1}(Annexure-3a). In wheat (2015-16), it ranged from 237.49 to 541.18 nmols g^{-1} dry soil hr^{-1}, while in 2016-17, it ranged from 257.38 to 586.51 nmols g^{-1} dry soil hr^{-1}(Annexure-3b). In mungbean (2015-16), it ranged from 265.4 to 524.2 nmols g^{-1} dry soil hr^{-1}, while in 2016-17, it ranged from 287.7to 568.1nmols g^{-1} dry soil hr^{-1} (Annexure-3c).

The polled value of LAP enzyme activityfor both the year is presented in **Table 4.24**.Impacts of organic amendment and conventional inputs added in the rice-wheat system on LAP enzyme activity is depicted in **Fig. 4.30**. The value for LAP enzyme activity within the crop grown under both systems ranged from 247±14.1to 609±34.6nmols g^{-1} dry soil hr^{-1}. The lower LAP enzyme activity recorded during mungbeanas compared to riceand wheat crops (**Table 4.24**).

Table 4.24: Leucineaminopeptidaseactivity in R-W-M- cropping system

Treatments	Rice	Wheat	Mungbean
FYM+CR+B	291±16.5d	329±18.7^{c}	315±17.9^{c}
VC+CR+B	608±34.6^{a}	516±29.3^{a}	455±25.9^{b}
FYM	609±34.6^{a}	547±31.1^{a}	546±31^{a}
VC	553±31.4^{b}	564±32.1^{a}	516±30^{a}
VC+CR	337±19.2^{d}	399±22.7^{b}	338±19.2^{b}
CONTROL	271±15.4d	247±14.1^{d}	311±17.7^{c}
FYM+CR	304±17.3cd	270±15.4^{d}	277±15.7^{c}
CONVENTIONAL	394±22.4^{c}	341±19.4^{c}	354±20^{b}
Mean	421	402	389
LSD (*p = 0.05*)	65.3	65.2	66.1

Leucine amino-peptidase activityvalue for rice found significantly higher in FYM (609±34.6nmols g^{-1} dry soil hr^{-1}) followed by VC+CR+B (608±34.6nmols g^{-1} dry soil hr^{-1}), VC (553±31.4nmols g^{-1} dry soil hr^{-1}) and it was lowest in control

(271±15.4nmols g^{-1} dry soil hr^{-1}). In wheat, it was found significantly higher in VC (564±32.1 nmols g^{-1} dry soil hr^{-1}) followed by FYM (547±31.1 nmols g^{-1} dry soil hr^{-1}), VC+CR+B (516±29.3nmols g^{-1} dry soil hr^{-1}) and it was lowest in control (247±14.1 nmols g^{-1} dry soil hr^{-1}.

In mungbean, it was found significantly higher in FYM (546±31 nmols g^{-1} dry soil hr^{-1}) followed by VC (516±30nmols g^{-1} dry soil hr^{-1}), VC+CR+B (455±25.9 nmols g^{-1} dry soil hr^{-1}) and it was lowest in FYM+CR (277±15.7nmols g^{-1} dry soil hr). LAP activity also exhibited a similar trend with the maximum being in FYM among all organic treatments. The activity ofLAP in the conventional plot was comparable with many organic plots. The lowest activity was observed in non-amended Control (**Fig. 4.30**).

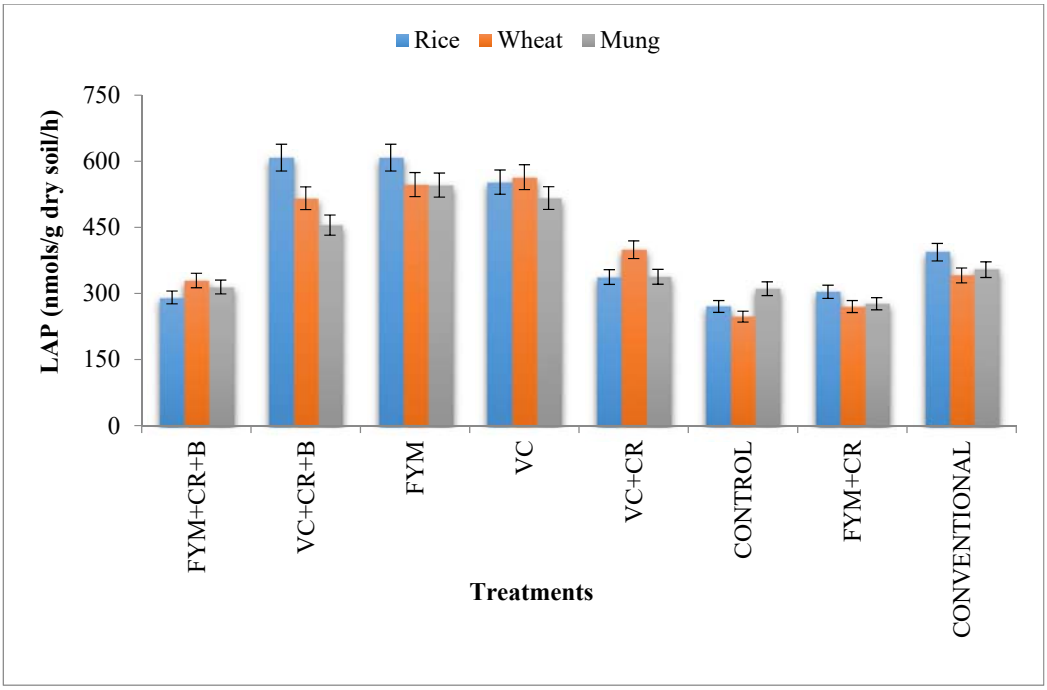

Fig. 4.30: Leucineaminopeptidaseactivity in R-W-M- cropping system

4.6.7. Phosphatase activity

Phosphatase activity for rice, wheat, and moonbeam for both the year (2016 and 2017) under conventional, and the organically treated plots are given in Annexure 3a, 3b, and 3c. Phosphatase in rice (2015-16) ranged from 267.1 to 584.6 nmols/g dry soil/h. While in 2016-17, it ranged from 289.5 to 633.5 nmols g^{-1} dry soil hr^{-1} (Annexure-3a). In wheat (2015-16) ranged from 318.2 to 532.6 nmols g^{-1} dry soil hr^{-1}, while in 2016-17, it ranged from 344.9 to 577.2 nmols g^{-1} dry soil hr^{-1} (Annexure-3b).

In mungbean (2015-16), it ranged from 282.5 to 531.8 nmols g^{-1} dry soil hr^{-1}, while in 2016-17, it ranged from 306.1 to 576.4 nmols g^{-1} dry soil hr^{-1} (Annexure-3c).

The polled value of phosphatase enzyme activityfor both the year is presented in **Table 4.25**.Impacts of organic amendment and conventional inputs added in the rice-wheat system on phosphatase enzyme activity are depicted in **Fig. 4.31**. The results showed that the soil phosphatase enzyme activity was higher in the conventional than the organic amendment and (**Fig. 4.31**). The value for phosphatase enzyme activity within the crop grown under both systems ranged from 278.3±15.8to 609.1±34.6nmols g^{-1} dry soil hr^{-1}. The lower phosphatase enzyme activity recorded during rice as compared to wheat and mungbean crops (**Table 4.25**).

Table 4.25: Phosphatase activity in R-W-M- cropping system

Treatments	Rice	Wheat	Mungbean
FYM+CR+B	423.2±24.1^{c}	377.7±21.5^{c}	380.8±21.6^{c}
VC+CR+B	499.9±28.4^{b}	441.1±25.1^{b}	480.7±27.3^{a}
FYM	567.1±32.2^{a}	512.3±29.1^{a}	515.5±29.3^{a}
VC	609.1±34.6^{a}	551.9±31.5^{a}	554.1±31.5^{a}
VC+CR	449.7±25.6^{b}	412.1±23.4^{b}	411.1±23.4^{b}
CONTROL	278.3±15.8^{d}	331.6±18.9^{bc}	294.3±16.7^{d}
FYM+CR	374.8±21.3^{cd}	344.5±19.6^{bc}	354.4±20.1^{c}
CONVENTIONAL	560.1±31.8^{a}	487.2±27.7^{b}	498.6±28.3^{a}
Mean	470.3	432.7	436.2
LSD (*p = 0.05*)	36.6	41.5	36.6

Phosphatase activity value for rice found significantly higher in VC (609.1±34.6nmols g^{-1} dry soil hr^{-1}) followed by FYM (567.1±32.2nmols g^{-1} dry soil hr^{-1}), VC+CR+B (499.9±28.4nmols g^{-1} dry soil hr^{-1}) and it was lowest in control (278.3±15.8nmols g^{-1} dry soil hr^{-1}). In wheat, it was found significantly higher in VC (551.9±31.5nmols g^{-1} dry soil hr^{-1}) followed by FYM (512.3±29.1nmols g^{-1} dry soil hr^{-1}), VC+CR+B (441.1±25.1nmols g^{-1} dry soil hr^{-1}) and it was lowest in control (331.6±18.9nmols g^{-1} dry soil hr^{-1}). In mungbean, it was found significantly higher in VC (554.1±31.5nmols g^{-1} dry soil hr^{-1}) followed by FYM (515.5±29.3nmols g^{-1} dry soil hr^{-1}), Conventional (498.6±28.3nmols g^{-1} dry soil hr^{-1}) and it was lowest in control (294.3±16.7nmols g^{-1} dry soil hr^{-1}) (**Table 4.25)**.

Phosphatase activity also exhibited a similar trend with the maximum being in VC, followed by FYM among all organic treatments. The activity ofphosphatasein the conventional plot was comparable with many organic plots. The lowest activity was observed in non-amended Control **(Fig. 4.31)**.

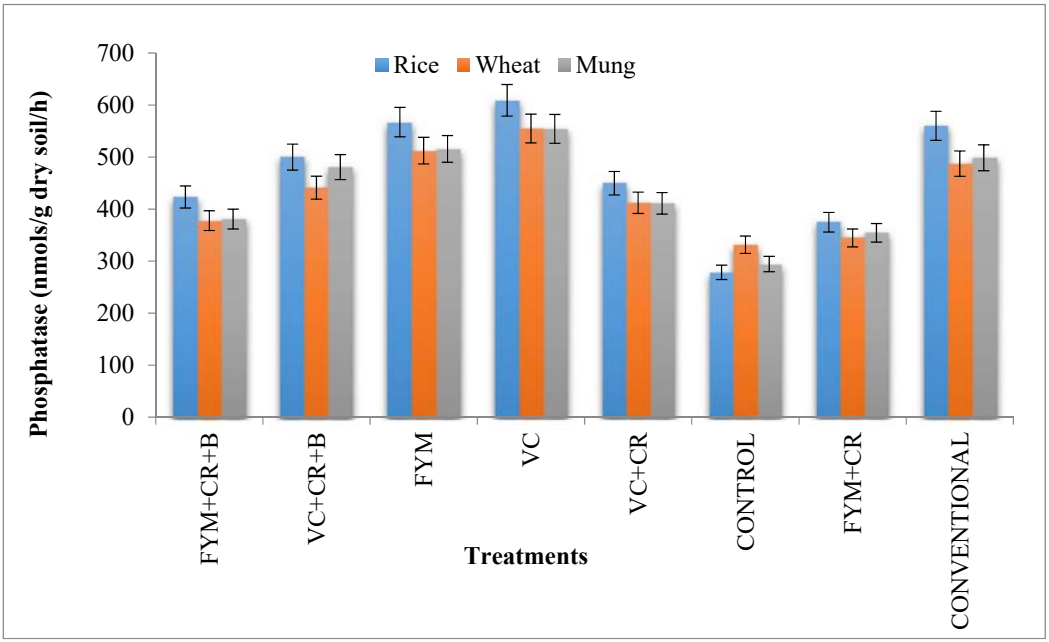

Fig. 4.31: Phosphatase activity in R-W-M- cropping system

4.6.8. N-acetyl-β-glucosaminidase activity in R-W-M- cropping system

N-acetyl-β-glucosaminidase (NAG) activity for rice, wheat, and moonbeam for both the year (2016 and 2017) under conventional, and the organically treated plots are given in Annexure 3a, 3b, and 3c. *NAG* in rice (2015-16) ranged from 5.7 to 20.3 nmols g^{-1} dry soil hr^{-1}, while in 2016-17, it ranged from 6.2 to 22.1 nmols g^{-1} dry soil hr^{-1} (Annexure-3a). In wheat (2015-16), it ranged from 7.1 to 23.1 nmols g^{-1} dry soil hr^{-1}, while in 2016-17, it ranged from 7.7 to 25.0 nmols g^{-1} dry soil hr^{-1} (Annexure-3b). In mungbean (2015-16), it ranged from 8.2 to 26.0 nmols g^{-1} dry soil hr^{-1}, while in 2016-17, it ranged from 8.9 to 28.2 nmols g^{-1} dry soil hr^{-1} (Annexure-3c).

The polled value of NAG enzyme activityfor both the year is presented in **Table 4.26**.Impacts of organic amendment and conventional inputs added in the rice-wheat system on NAG enzyme activity is depicted in **Fig. 4.32**. The results showed that the soil NAG enzyme activity was higher in the conventional than the organic amendment and (**Fig. 4.32**).The value for NAG enzyme activity within the crop grown under both systems ranged from 5.9±0.3 to 27.1±0.9 nmols g^{-1} dry soil hr^{-1}. The lower NAG

enzyme activity recorded during mungbean as compared to wheat and rice crops (**Table 4.26**).

N-acetyl-β-glucosaminidase activity value for rice found significantly higher in Conventional (21.2±1.0 nmols g^{-1} dry soil hr^{-1}) followed by VC (14.5±0.8nmols g^{-1} dry soil hr^{-1}), VC+CR (12.6±0.7 nmols g^{-1} dry soil hr^{-1}) and it was lowest in control (5.9±0.3 nmols g^{-1} dry soil hr^{-1}). N-acetyl-β-glucosaminidase activity value for wheat found significantly higher in Conventional (24.0±1.3 nmols g^{-1} dry soil hr^{-1}) followed by VC+CR (16.16±0.9nmols g^{-1} dry soil hr^{-1}), FYM+CR+B (15.54±0.9 nmols g^{-1} dry soil hr^{-1}) and it was lowest in control (7.35±0.4 nmols g^{-1} dry soil hr^{-1}) (**Table 4.26)**.

Table 4.26: N-acetyl-β-glucosaminidase activityin R-W-M- cropping system

Treatments	Rice	Wheat	Mungbean
FYM+CR+B	19±1.1^{a}	15.54±0.9^{c}	16.39±0.9^{b}
VC+CR+B	7.6±0.4^{d}	8.57±0.5^{e}	10.86±0.6^{cd}
FYM	6.8±0.4^{d}	9.36±0.5^{de}	8.95±0.5^{d}
VC	14.5±0.8^{b}	11.79±0.7^{cd}	11.17±0.6^{c}
VC+CR	12.6±0.7^{b}	16.16±0.9^{b}	11.08±0.6^{c}
CONTROL	5.9±0.3^{e}	7.35±0.4^{e}	8.57±0.5d^{e}
FYM+CR	12.6±0.7^{bc}	10.23±0.6^{cd}	9.82±0.6^{cd}
CONVENTIONAL	21.2±1.0^{a}	24.0±1.3^{a}	25.1±0.9^{a}
Mean	12.5	12.9	13.0
LSD (*p = 0.05*)	3.74	4.97	4.39

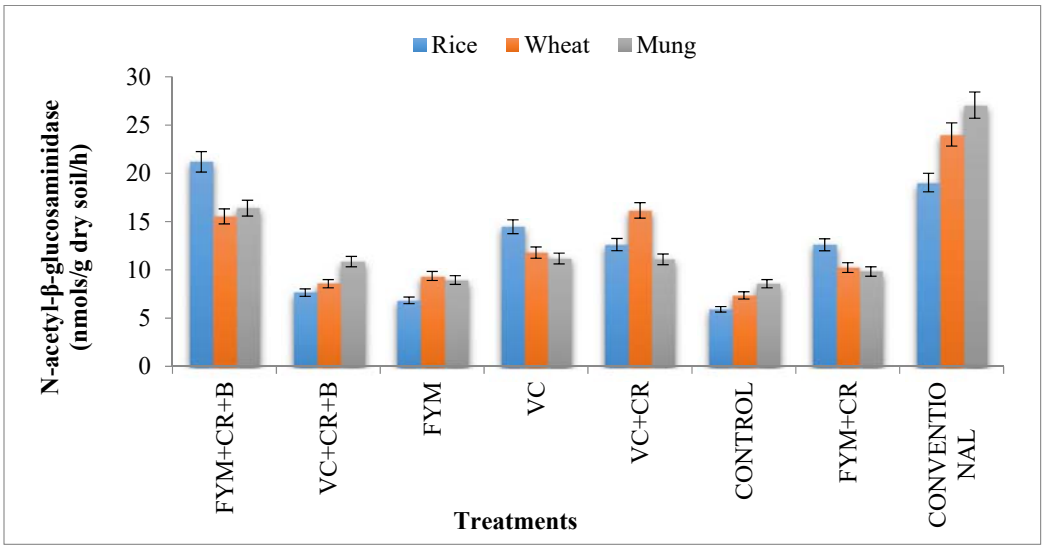

Fig. 4.32: N-acetyl-β-glucosaminidase activityin R-W-M- cropping system

N-acetyl-β-glucosaminidase activity value for rice found significantly higher in Conventional (25.1±0.9nmols g^{-1} dry soil hr^{-1}) followed by FYM+CR+B (16.39±0.9 nmols g^{-1} dry soil hr^{-1}), VC (11.17±0.6nmols g^{-1} dry soil hr^{-1}) and it was lowest in control (8.57±0.5dnmols g^{-1} dry soil hr^{-1}).NAG activity also exhibited a similar trend with the maximum being in FYM+CR+B, followed by VC and VC+CR among all organic treatments (**Fig. 4.32)**.

4.6.9. Basal Respirationin R-W-M- cropping system

Basal respiration (BR) in rice, wheat, and moonbeam for both the year (2016 and 2017) under conventional and the organically treated plots are given in Annexure-3d. Basal Respiration in rice (2015-16) ranged from 136.6 to 383.0 µg CO_2-C/g/h, while in 2016-17, it ranged from 134.7 to 345.7 *10^{-3}µg CO_2-C/g/h. In wheat (2015-16), it ranged from 207.2 to 442.2 *10^{-3}µg CO_2-C/g/h, while in 2016-17, it ranged from 227.0 to 436.1 *10^{-3}µg CO_2-C/g/h. In mungbean (2015-16), it ranged from 172.9 to 417.3 *10^{-3}µg CO_2-C/g/h, while in 2016-17, it ranged from 170.5 to 411.6 *10^{-3}µg CO_2-C/g/h (Annexure-3d).

Table 4.27: Basal Respiration in R-W-M- cropping system

Treatments	Rice	Wheat	Mungbean
FYM+CR+B	348.1±3.4^{b}	424.9±4.2^{b}	405.9±4^{b}
VC+CR+B	380.3±3.7^{a}	439.1±4.3^{a}	414.5±4.1^{a}
FYM	276.0±2.7^{d}	367.0±3.6^{c}	324.4±3.2^{d}
VC	308.2±3.0^{c}	350±3.4^{d}	359.5±3.5^{c}
VC+CR	223.8±2.2^{e}	309.2±3^{e}	295.9±2.9^{e}
CONTROL	135.6±1.3^{g}	205.8±2^{h}	171.7±1.7^{h}
FYM+CR	212.4±2.1^{f}	277.9±2.7^{e}	272.2±2.7^{e}
CONVENTIONAL	222.9±2.2^{e}	228.6±2.2^{g}	260.8±2.6g
Mean	263.4	325.3	313.1
LSD (*p = 0.05*)	5.69	6.07	4.75

The polled value of basal respiration (BR) for both the year is presented in **Table 4.27**.Impacts of organic amendment and conventional inputs added in the rice-wheat system on BR are depicted in **Fig. 4.33**. The value for BR within the crop grown under both systems ranged from 135.6±1.3 to 439.1±4.3*10^{-3}µg CO_2-C/g/h. The lower BR was recorded during rice as compared to wheat and mungbean crops (**Table 4.27**).

It was observed that the basal respiration under organic treatments was comparatively higher, with the maximum being observed in VC+CR+B, followed by FYM+CR+B, VC, FYM, and VC+CR. The values were statistically similar in VC, and FYM applied plots. On the other hand, the lowest basal respiration values were registered for conventional and non-amended control (**Fig. 4.33)**.

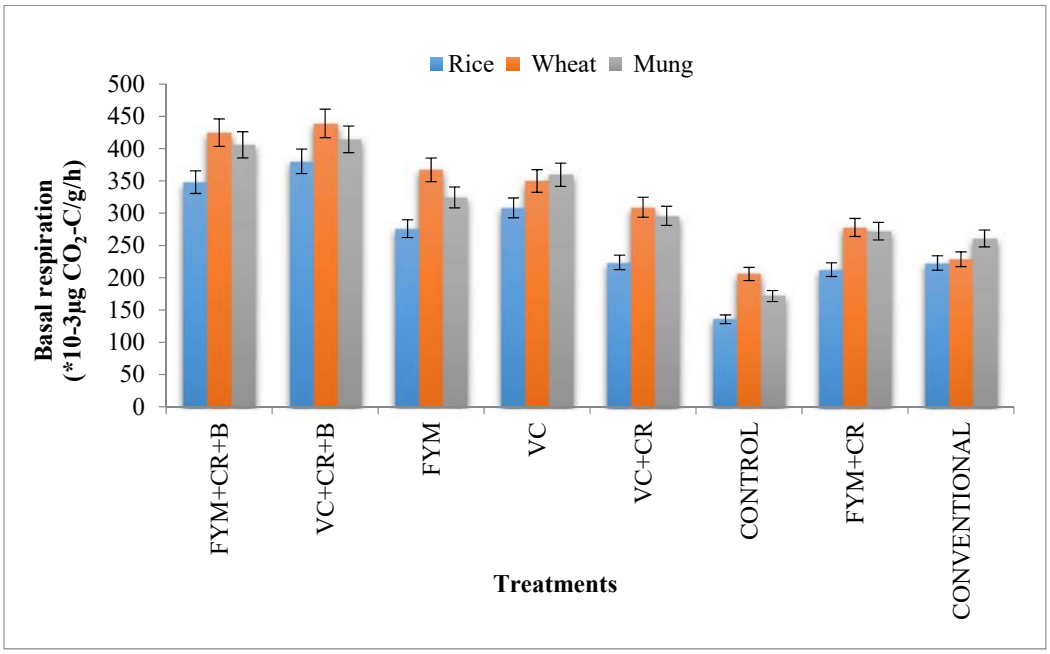

Fig. 4.33: Basal Respiration in R-W-M- cropping system

4.6.10. Metabolic Quotient in R-W-M- cropping system

Metabolic Quotient (MQ) in rice, wheat, and moonbeam for both the year (2016 and 2017) under conventional and the organically treated plots are given in Annexure-3d.Metabolic Quotient in rice (2015-16) ranged from 1.46 to 2.39 µg CO_2-Cµg/biomass C/h, while in 2016-17 it ranged from 1.60 to 2.62 µg CO_2-C µg/ biomass C/h. In wheat (2015-16), it ranged from 1.71 to 2.20 µg CO_2-C µg/ biomass C/h, while in 2016-17 it ranged from 1.87 to 2.42 µg CO_2-C µg/ biomass C/h. In mungbean (2015-16), it ranged from 1.76 to 2.36µg CO_2-C µg/ biomass C/h, while in 2016-17 it ranged from 1.94 to 2.59 µg CO_2-C µg/ biomass C/h (Annexure-3d).

The polled value of metabolic Quotient (MQ) for both the year is presented in **Table 4.28**.Impacts of organic amendment and conventional inputs added in the rice-wheat system on MQ is depicted in **Fig. 4.34**. The value for MQ within the crop grown under both systems ranged from 1.5±0.10 to 2.5±0.16 µg CO_2-C µg/ biomass C/h. The metabolic quotient values were higher for organic plots. VC+CR+B and VC+CR shown

maximum metabolic quotient followed by FYM+CR+B and FYM. The values of the metabolic quotient in conventional plots were almost like many organically amended plots. The lowest value of metabolic quotient was observed in non-amended control (**Fig. 4.34**).

Table 4.28: Metabolic Quotient activity in R-W-M- cropping system

Treatments	Rice	Wheat	Mungbean
FYM+CR+B	1.9±0.13[a]	2.0±0.13[a]	2.1±0.14[a]
VC+CR+B	2.5±0.16[a]	2.3±0.15[a]	2.5±0.16[a]
FYM	1.7±0.11[b]	2.1±0.14[a]	1.9±0.12[a]
VC	2.1±0.14[a]	2.1±0.14[a]	2.2±0.15[a]
VC+CR	1.6±0.1[b]	2.1±0.14[a]	1.9±0.13[a]
CONTROL	1.9±0.12[a]	2.3±0.15[a]	2±0.13[a]
FYM+CR	1.5±0.1[b]	1.8±0.12[b]	2±0.13[a]
CONVENTIONAL	2.5±0.16[a]	1.8±0.12[a]	2.3±0.15[a]
Mean	1.96	2.06	2.12
LSD (*p = 0.05*)	0.27		

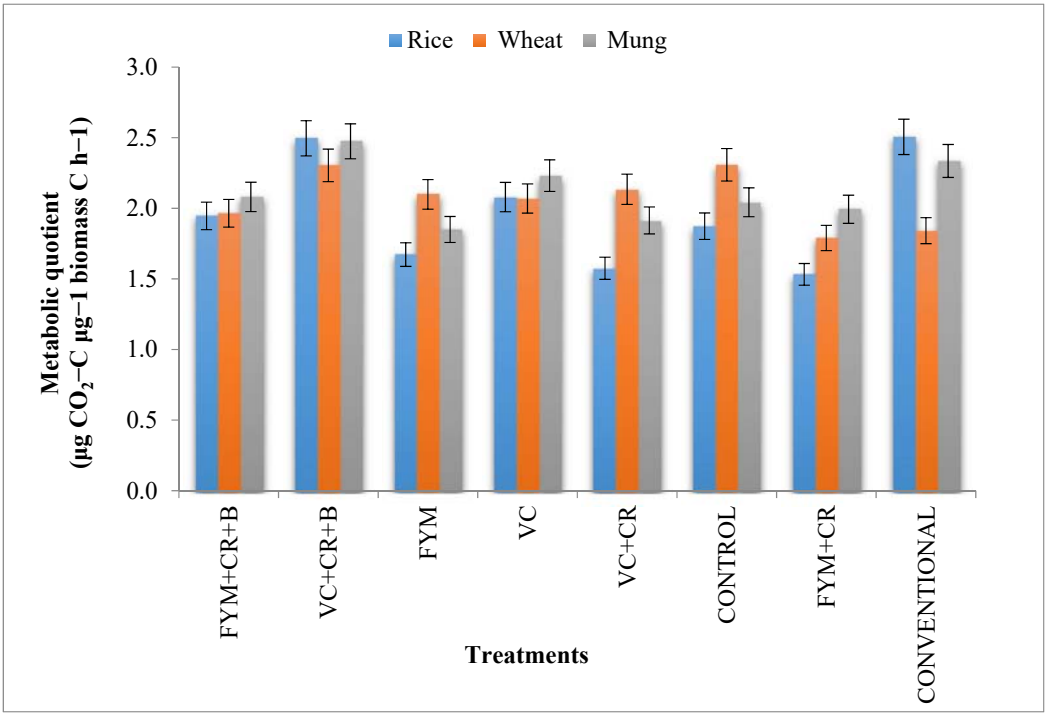

Fig. 4.34: Metabolic Quotient in R-W-M- cropping system

4.7. Correlation of soil physico-chemical & microbial properties with GHG

Different soil parameters and greenhouse gas emission were correlated during the study, and findings are represented below:

4.7.1. Correlation of physico-chemical properties with GHG emission

Correlation of soil pH, EC, and BD with CH_4 and CO_2 flux in the R-W-M cropping system is shown in **Table 4.29a.** The result showed that pH and EC had no significant correlation with CO_2 and CH_4 emission. While bulk density (BD) was negatively correlated with methane emission (-0.811) from rice. BD was also negatively correlated with CO_2 emission from wheat (-0.775 and mungbean (-0.736).

Table 4.29a: Correlation of soil pH, EC, and BD with CH_4 and CO_2 flux

	pH	EC	BD	CH_4 Rice	CO_2 Wheat	CO_2Mung
pH	1					
EC	0.425	1				
BD	0.886	0.486	1			
CH_4 Rice	-0.566	-0.494	-0.811**	1		
CO_2 Wheat	-0.507	-0.403	-0.775*	0.990	1	
CO_2Mung	-0.500	-0.327	-0.736*	0.940	0.9633	1

Probability levels are indicated by ***, ** and * for 0.001, 0.01 and 0.05, respectively

The correlation of soil pH, EC, and BD with N_2O flux is shown in **Table 4.29b**. The result showed that the pH, EC, and BD of soil had no significant correlation with N_2O emissions from rice, wheat, and mungbean system.

Table 4.29b: Correlation of soil pH, EC, and BD with N_2O flux

	pH	EC	BD	N_2O Rice	N_2O Wheat	N_2O Mung
pH	1					
EC	-0.550	1				
BD	0.886	-0.736	1			
N_2O Rice	0.239	0.200	0.201	1		
N_2O Wheat	0.192	0.271	0.132	0.991	1	
N_2O Mung	0.193	0.296	0.124	0.992	0.989	1

Probability levels are indicated by ***, ** and * for 0.001, 0.01 and 0.05, respectively

Correlation of soil organic carbon (SOC) with CH_4 and CO_2 flux in R-W-M cropping is shown in **Table 4.29c**. Soil Organic Carbon values were positive and significantly correlated with CH_4 flux from rice (+0.944) and CO_2 flux from wheat (+0.930) and mungbean (+0.911).

Table 4.29c: Correlation of soil organic carbon (SOC) with CH_4 and CO_2 flux

	SOC Rice	SOC Wheat	SOC Mung	CH_4 Rice	CO_2 Wheat	CO_2Mung
SOC Rice	1					
SOC Wheat	0.985	1				
SOC Mung	0.896	0.879	1			
CH_4 Rice	0.944***	0.933	0.863	1		
CO_2 Wheat	0.954	0.930***	0.912	0.990	1	
CO_2Mung	0.963	0.912	0.911***	0.940	0.963	1

Probability levels are indicated by ***, ** and * for 0.001, 0.01 and 0.05, respectively

4.7.2. Correlation of Nitrogen with GHG emission

Correlation of total N, NH_4^+-N and NO_3^--N with N_2O emission in the R-W-M cropping system is shown in **Table 4.30a**. The positive and significant correlation was observed between the N_2O flux from rice and total N (+0.977), NO_3^--N (+0.845), and NH_4^+-N (+0.738). The positive and significant correlation was also observed between the N_2O flux from wheat and Total N (+0.858), NO_3^--N (+0.826), and NH_4^+-N (+0.738). The correlation between the N_2O flux from mungbean and total N (+0.887), NO_3^--N (+0.799), and NH_4^+-N (+0.735) were found to be significantly positive.

Table 4.30a:Correlation between Soil Nitrogen and N_2O Flux in Rice

	Total N	NH_4^+-N	NO_3^--N	Rice N_2O
Total N	1			
NH_4^+-N	0.884	1		
NO_3^--N	0.846	0.905	1	
Rice N_2O	0.917***	0.738*	0.845**	1

Probability levels are indicated by ***, ** and * for 0.001, 0.01 and 0.05, respectively

Result also showed a positive and significant correlation between the N_2O flux from wheat with total N (+0.858), NO_3^--N (+0.826) and NH_4^+-N (+0.738) (**Table 4.30b**).

Table 4.30b:Correlation between Soil Nitrogen and N_2O Flux in Wheat

	Total N	NH_4^+-N	NO_3^--N	Wheat N_2O
Total N	1			
NH_4^+-N	0.857	1		
NO_3^--N	0.825	0.949	1	
Wheat N_2O	0.858**	0.738*	0.826**	1

Probability levels are indicated by ***, ** and * for 0.001, 0.01 and 0.05, respectively

The correlation between the N_2O flux from mungbean and total N (+0.887), NO_3^--N (+0.799) and NH_4^+-N (+0.735) was found significantly positive (**Table 4.30c**).

Table 4.30c: Correlation between Soil Nitrogen and N_2O Flux in Mungbean

	Total N	**$NH4^+$-N**	**NO_3^--N**	**Mung N_2O**
Total N	1			
NH_4^+-N	0.795	1		
NO_3^--N	0.870	0.781	1	
Mung N_2O	0.887**	0.735*	0.799*	1

Probability levels are indicated by ***, ** and * for 0.001, 0.01 and 0.05, respectively

4.7.3. Correlation of microbial properties with GHG emission

Correlation of MBC with CH_4 and CO_2 flux in R-W-M cropping is presented **Table 4.31a**.Statistical analysis showed that MBC was positively and significantly correlated with CO_2 and CH_4 emission. Result also showed a positive and significant correlation between the MBC andCH_4flux from rice (+0.881), while a significant correlation was found between the MBC andCO_2 flux in wheat (+0.847), and mungbean (+0.899) (**Table 4.31a**).

Table 4.31a: Correlation between MBC with CH_4 and CO_2 flux

	MBC Rice	**MBC Wheat**	**MBC Mung**	**Rice CH_4**	**Wheat CO_2**	**Mung CO_2**
MBC Rice	1					
MBC Wheat	0.941	1				
MBC Mung	0.982	0.959	1			
Rice CH_4	0.881**	0.833	0.909	1		
Wheat CO_2	0.872	0.847**	0.912	0.990	1	
Mung CO_2	0.875	0.889	0.899**	0.940	0.963	1

Probability levels are indicated by ***, ** and * for 0.001, 0.01 and 0.05, respectively

Correlation of MBN with N_2O flux in R-W-M cropping is presented in**Table 4.31b**.No significant statistical correlation was observed between Microbial Biomass Nitrogen (MBN) and N_2O flux from rice, wheat, and mungbean (**Table 4.31b**).

Table 4.31b: Correlation between MBN with N_2O flux in R-W-M cropping

	MBN Rice	MBN Wheat	MBN Mung	N_2O Rice	N_2O Wheat	N_2O Mung
MBN Rice	1					
MBN Wheat	0.940	1				
MBN Mung	0.853	0.980	1			
N_2O Rice	0.513	0.325	0.198	1		
N_2O Wheat	0.571	0.387	0.259	0.991	1	
N_2O Mung	0.590	0.397	0.263	0.992	0.989	1

Probability levels are indicated by ***, ** and * for 0.001, 0.01 and 0.05, respectively

Correlation of dehydrogenase (DHA) with CH_4 and CO_2 fluxes in R-W-M is presented in**Table 4.31c**.The CH_4 flux was significantly correlated (+0.877) with DHA activity. Similarly, CO_2 flux was also significantly correlated with dehydrogenase activity in wheat (+0.857) and mungbean (+0.913) (**Table 4.31c**).

Table 4.31c: Correlation between DHA activity with CH_4 and CO_2 flux

	DHA Rice	*DHA Wheat*	*DHA Mung*	*CH_4 Rice*	*CO_2 Wheat*	*CO_2 Mung*
DHA Rice	1					
DHA Wheat	0.983	1				
DHA Mung	0.990	0.993	1			
Rice CH_4	0.877**	0.889	0.919	1		
Wheat CO_2	0.844	0.857**	0.894	0.990	1	
Mung CO_2	0.864	0.888	0.913***	0.940	0.963	1

Probability levels are indicated by ***, ** and * for 0.001, 0.01 and 0.05, respectively

Correlation of α-Glucosidase,β-Glucosidase,Phosphatase,and N-acetyl-β-glycosaminidase (NAG) activity with CH_4 and CO_2 flux in R-W-M is presented in **Table 4.31d**. Soil enzymes like α-Glucosidase and β-Glucosidase were positively correlated with CO_2 and CH_4 emission, while phosphatase does not show any correlation with GHG emission. CH_4 flux from the rice was positively correlated with α-Glucosidase (+0.833) and β-Glucosidase (+0.755). CO_2 flux from wheat was

positively correlated with α-Glucosidase (+0.851) and β-Glucosidase (+0.788). Similarly, CO_2 flux from mungbean was also positively associated with α-Glucosidase (+0.871) activity.

Correlation of α-Glucosidase,β-Glucosidase,Phosphatase, and N-acetyl-β-glycosaminidase (NAG) with N_2O flux in R-W-M is presented in **Table 4.31e**. Result showed that theonly N-acetyl-β-glycosaminidase (NAG) activity was significantly correlated with N_2O emission from rice (+0.778), wheat (+0.783), and mungbean (+0.774). There was no significant correlation of α-Glucosidase,β-Glucosidase,Phosphataseenzymes with N_2O emission from rice, wheat, and mungbean.

Table 4.31d: Correlation between α and β -glucosidase,Phosphatase and NAGactivity with CH_4 and CO_2 flux in R-W-M cropping

	α-Glucosidase	*β -Glucosidase*	*Phosphatase*	*NAG*	*CH_4 Rice*	*CO_2 Wheat*	*CO_2Mung*
α-Glucosidase	1						
β-Glucosidase	0.734	1					
Phosphatase	-0.003	0.050	1				
NAG	0.212	0.051	0.258	1			
CH_4 Rice	0.833**	0.755*	0.191	0.049	1		
CO_2 Wheat	0.851**	0.788*	0.171	0.119	0.990	1	
CO_2Mung	0.871**	0.677	0.093	0.214	0.940	0.963	1

Probability levels are indicated by ***, ** and * for 0.001, 0.01 and 0.05, respectively

Table 4.31e: Correlation between α and β -glucosidase,Phosphatase and NAGactivity with N_2O flux in R-W-M cropping

	α-Glucosidase	*β-Glucosidase*	*Phosphatase*	*NAG*	*N_2O Wheat*	*N_2O Rice*	*N_2O Mung*
α-Glucosidase	1						
β-Glucosidase	0.734	1					
Phosphatase	-0.003	0.050	1				
NAG	0.212	0.051	0.258	1			
N_2O Wheat	0.175	0.122	0.590	0.783*	1		
N_2O Rice	0.157	0.144	0.547	0.778*	0.991	1	
N_2O Mung	0.238	0.214	0.524	0.774*	0.989	0.992	1

Probability levels are indicated by ***, ** and * for 0.001, 0.01 and 0.05, respectively

CHAPTER 5
DISCUSSION

In the present study, we quantified the emission of greenhouse gases (CH_4, N_2O, and CO_2) in a rice-wheat-mungbean cropping system and assessed the long term impact of organic and conventional treatments on physico-chemical and biological properties of soil followed by their correlation with GHGemission. We also quantified the net global warming potential (GWP) of different organic and conventional treatments under rice-wheat-mungbean cropping system. The results obtained from field experiment, varied according to different treatments, and the reason behind these variations have been discussed below:

5.1 Greenhouse gas emission from rice, wheat and mungbean fields

Eight different treatments, i.e., Control, Conventional, FYM, VC, FYM+CR, VC+CR, FYM+CR+B and VC+CR+B in rice, wheat, and mungbean crops for two consecutive years (2015-16 to 2016-17) were tested. There were significant variations in GHGs emissions and GWP of rice, wheat, and mungbean crops. The salient findings in terms of differences in GHG emission and GWP among different treatments are discussed below.

5.1.1 Emission of CH_4

The cumulative CH_4 emission under rice treatments varied from 10.51 to 34.28 kg CH_4 ha^{-1} and 11.93 to 34.84 kg CH_4 ha^{-1} in the first and second years, respectively (**Table 4.1).** Similar results were also obtained by Gupta *et al.*, 2016. Organic and conventional rice plots had shown noticeable variations in average greenhouse gas emissions during both the years. Organic plots treated with FYM+CR+B and VC+CR+B were recorded highest in methane (CH_4) emission (**Table 4.1**), while CH_4 emission was relatively lower in organic treatments such as FYM+CR and VC than other organic treatments. Though, the initial CH_4 emissions from these plots were comparable with FYM+CR+B and VC+CR+B applied plots (**Fig.4.1 and 4.2**). CH_4 emission from non-amended control and Conventional plots were less as compared to all organic plots. Methane emission from all the plots increased gradually after transplanting, attains peaks about 40 days after transplanting (DAT), and then decreased until harvesting (**Fig.4.1 and 4.2**). The peak of emission appeared after around 40 DAT

probably because soil redox potential (Eh) values decreased rapidly after flooding and stabilized at −200 to −240 mV within 5–7 weeks to produce significant amount of methane (Ali, 2008).

Overall, CH_4 emission in organic rice was considerably high as compared to conventional and control plots. High flux from organic plots might be happened due to a low C/N ratio of organic manures added, resulted in faster mineralization to emit high CH_4 during crop growth. Organic matter acts as a source of the electron (Singh *et al.*, 1998) and favours CH_4 emission in anaerobic (flooded) condition. Bhatia *et al.*, 2005 also reported that FYM + SGM + crop residue followed by FYM + NPK plots were high in total CH_4 emission. The availability of more amount of labile carbon substrate at the methanogenic environment enhances CH_4 emission (Zhu *et al.*, 2017;Singla*etal.*, 2014; Ali, 2019).

The temporal pattern and magnitude of CH_4 fluxes during rice significantly differed among the treatments (**Fig. 4.1 and 4.2**). However, high fluxes of CH_4 were observed during the tillering to reproductive stages in all the treatments. It might be due to the reduction in the oxidation rate of CH_4 due to direct transport by aerenchyma to the atmosphere after the formation of tillers. At the beginning of the crop cycle, bubble formation and vertical movement is the primary CH_4 transfer mechanismin the soil. After tillering, diffusion through the aerenchyma becomes the dominant process, responsible for more than 90% of the CH_4 emission during active tillering and reproductive stage (Tyler *et al.,* 1997). The observed trend was in agreement with Ahmad *et al*., 2009, Liu *et al.,* 2011, Malla*et al.,* 2005, Pandey *et al.,* 2012 and Pathak *et al.,* 2003.

When compared to a conventional plot, organic treatments increased CH_4 emissions in flooded rice system as nitrogen fertilization in conventional plot stimulates the growth and activity of CH_4 oxidizing bacteria (methanotrophs), leading to a reduction in emissions. The same was also reported by Bodelier and Laanbroek, 2004 andLinquista*et al.,* 2012.

Occurrence of aerobic condition in soil, during most part of the crop growth leads to almost zero or somewhat negative net emission of CH_4 under wheat (**Table 4.4)** and mungbean (**Table 4.7)** cropping seasons with no definite patterns observed among the various organic and conventional treatments. Similar results were also

reported by Singh *et. al.,* 1996 and Pathak *et. al.,* 2003 in winter irrigated wheat of northern Indo Gangetic Plains of India.

5.1.2 Emission of N_2O

N_2O in the soil is mainly produced by the microbial processes of nitrification and denitrification (Granli and Bockman, 1994; Snyder *et al.,* 2009; Davidson, 2009). In the case of rice, N_2O emission was highest from conventionally managed plots and even higher after 1st and 2nd dose of synthetic nitrogen (N) application through fertilizer. In conventional plots high N_2O fluxes might be because of readily available N added through fertilizer responsible for more denitrification losses. Among organic treatments, VC+CR+B applied plots were high in emitting N_2O followed by FYM+CR+B and FYM (**Fig. 4.3 and 4.4 and Table 4.2**). Narrow C/N ratio of FYM and VCmight be mineralized faster and made available NH_4^+ substrate for nitrification enhanced N_2O emission (Bhatia *et al.,* 2005).

In conventional wheat, N_2O emission was found higher after fertilizer application and subsequent to irrigation. N_2O fluxes after irrigation were also high in all organic treatments and unfertilized control. N_2O fluxes after irrigation might be because of the creation of an anoxic condition after each irrigation speed up the denitrification process (Arah and Smith, 1989).N_2O emission from Conventional plot was about 3 to 4 times higher than organic treatments during the study. Colin Skinner *et al.*, 2019 also reported that organic farming emitted on average 2.78 kg less N_2O-N ha^{-1} than non-organic farming on annual basis. Ali *et al.*, 2015 also reported the reduction in seasonal cumulative N_2O emission with biochar and biochar plus Azolla-cyanobacteria amendments.

During all the cropping seasons, peaks of emission were observed in Conventional plot following fertilizer and irrigation application. In the organic plots, N_2O emissions were comparatively higher during the latter crop growth period. The N_2O flux from Control plot was lowest among all the treatments. Azolla cover increased N_2O emission from rice paddies due to N-fixation by Azolla, providing a source for N_2O production through nitrification and de-nitrification (Ma *et al.*, 2012). This might be probable reason for higher emission of N_2O from biofertilizer applied plots as compared to other organic plots.

N_2O flux from the treatments showed more or less similar temporal trends with the appearance of a peak after 3-4 days of urea applications during both the years. However, the magnitude of flux differed. The observed pattern of N_2O flux was in agreement with Bhatia *et al.* (2012) and Malla*et al.* (2005). Urea takes two to three days for hydrolysis into NH_4^+-N under optimum moisture and temperature condition (Yadav*et al.*, 1987), which undergoes further nitrification to NO_3^--N resulting in a peak of N_2O flux generally three to four days after urea application. The Lowest N_2O emission flux was observed in control treatment compared to the other treatments throughout the cropping seasons. It might be due to the lower availability of nitrogenous substrate for nitrification and denitrification process. However, in control treatment,aslightly higher flux of N_2O emission was also observed after the irrigation of crop.

N_2O emission from soils is greatly affected by fertilizer application in particular nitrogenous (N) fertilizers. The application of N fertilizer directly influences the availability of NO_3^- and NH_4^+ substrate for nitrification and denitrification process (Lloyd and Sheaffe, 1973). The emission of N_2O increases significantly after the application of nitrogenous (N) fertilizers (Wrage*et al.,* 2001; Linquista*et al.,* 2012). In conventional treatment the peak of N_2O emissions was higher than the other treatments. This might be due to the higher amount of substrate availability. The greater the amount of substrate in the fertilizer, the higher will be the nitrification process and higher will be N_2O emission (Mosier, 2001; Khalil *et al.,* 2004; Liu *et al.,* 2005). The observed trend of N_2O emission flux was in line/agreement with the Malla*et al.*, 2005; Bhatia *et al.*, 2005 and 2012; Gupta *et al.,* 2016.

Organic amendments are a source of carbon (C) and nitrogen (N) substrate in the soil and thus strongly affect GHG emission. Higher denitrification rates were reported by Aulakh*et al.*, 1991 as a result of the application of farmyard manure. However, emission of N_2O and organic manure mineralization are dependent on C:N ratio of organic manure (Huang *et al.,* 2004). In present study, FYM+CR+B, FYM and VC+CR+B exhibited higher N_2O fluxes than the control treatment during the first few days after the application in rice, wheat and mungbean crops (Table 4.2, 4.5 and 4.8). These higher emissions are results of rapid nitrification and denitrification processes induced by organic manure because they contain considerable amounts of readily available organic carbon and ammonium (Granli and Bockman, 1994). Increasing the

soil organic carbon content can also increase the N_2O production (Brentrup*et al.*, 2000) but not as significant as application of N-fertilizers.

5.1.3 Emission of CO_2

The CO_2 emission from the soil is mainly due to the decomposition of soil organic matter by heterotrophic micro-organism and root respiration by higher plants (Hanson, *et al.* 2000; Rastogi*et al.,* 2002). In all the three crops, from all the treatments we observed lower CO_2 flux after sowing of crops. However, during later crop growth stage, particularly vegetative growth the CO_2 emission flux increased significantly and reached its maximum value during 60-80 DAT in rice, 40-80 DAS in wheat, and 30-55 DAS in mungbean crop.

At the initial stage of seed germination, CO_2 emission mainly occurs due to the decomposition of soil organic matter however, in the later stage, when plant gets established CO_2 emission from root respiration enhanced the total CO_2 flux. The higher root respiration during the active crop growth period might be the reason for the higher CO_2 flux under all the treatments in both wheat and mungbean crop since root respiration accounts for 30 - 50% of the total CO_2 flux (Rochette*et al.,* 1999; Curtin *et al.,* 2000). This higher flux might also be observed due to the higher availability of the carbon substrates in corresponding period and higher microbial activity (Campbell *et al.,* 2001; Iqbal *et al.*, 2009). In rice crop the highest CO_2 flux during this period has also been reported (Pandey *et al.*, 2012; Bhattacharyya *et al.,* 2012).

The quality and availability of soil carbon affect CO_2 emission. In general application of organic matter in the soil leads to increased CO_2 emission (Moore and Dalva, 1993; Rao and Pathak, 1996). The soluble/labile organic carbon is the immediate source of carbon for microorganisms and it enhances CO_2 emission (McGill *et al.,* 1981; García-Marco *et al.,* 2014). This might be probable reason for higher CO_2 emission from FYM+CR+B and VC+CR applied plots followed by VC+CR+B, FYM and VC used plots than the conventional and control treatments during the crop growth periods in all the three crops, which result in significantly higher cumulative CO_2-C emission from organic treatments. These results are in line with Huifang*et al.,* 2014. Similar kind of results was also reported by Jianwen*et al.*, (2004) under application of rapeseed cake and wheat straw application, respectively in rice-wheat system.

5.1.4 Global Warming Potential

Net Global Warming Potential was calculated by adding the GWPs of all three greenhouse gases from the RWM cropping system. GWP of the rice-wheat-mungbean system was depended on flux of CH_4, CO_2 and N_2O from these crops. Among all three crops, rice crop had highest values of global warming potential (GWP).

Net global warming potential of conventional treatment was significantly higher as compared to the organic treatments. Lowest GWP was observed in unfertilized control. The high Global Warming Potential from some of the organic plots was due to higher flux of CH_4 that may be attributed to high carbon substrate available in these plots to be acted upon by the microorganisms, i.e. *methanogens* (Zhu *et al.*, 2017). Historically, carbon losses from agricultural soils have contributed to the increase in the global greenhouse gas budget (Lal, 2004). But overall GWP of organic plots was lower than the conventional plot because of much less emission of N_2O from these plots as compared to the conventional one. Due to the high global warming potential (GWP), the reduction of N_2O emission gives organic farming an additional advantage over conventional farming decreasing overall GWP significantly. (Ventere*a et al.*, 2012).

Different organic treatment combinations led to about a 1.73 to 26.84 %, 20.04 to 35.44 % and 9.2 to 31.3 % reduction in GWP over the conventionaltreatment in rice, wheat and mungbean crops respectively. Similar results were also obtained by Ali *et al.*, 2015 with biochar amendments in paddy soils of Japan and Bangladesh, where decrease in seasonal cumulative N_2O emissions by 31.8 and 20.0%, respectively was observed, followed by 26.3 and 25.0% reduction with biochar plus Azolla-cyanobacteria amendments.

5.2 Impact on soil physico-chemical properties

The pH of the soil decreased slightly with the addition of organic amendments as compared to conventional ones over the initial value that might be attributed to the formation of organic acids during the decomposition of organic matter. A maximum reduction in soil pH was observed during the rice crop. Among organic treatments, maximum reduction in soil pH value was found in VC and VC+CR plots followed by FYM (**Table 4.13**). A slight decrease in soil pH with addition of FYM has also been reported by Laxminarayana and Patiram (2005). Whalen *et al.*, 2000 observed that compounds other than carbonates and bicarbonates, such as organic acids with carboxyl

and phenolic hydroxyl groups have an essential role in buffering soil acidity and decreasing the pH of underlying soils amended with organic manures.

Data showed that treatments significantly impacted the Electrical Conductivity **(Table 4.14)** of soil. The organic treatments significantly increased the EC compared to conventional ones. The highest EC was observed under FYM+CR+B, VC, and VC+CR+B applied plots, which were considerably higher than conventional and control. Similar trends were observed for all the cropping seasons,*i.e*. rice, wheat, and mungbean. The increase in soil electrical conductivity as impacted by organic manure addition might be due to the amount of dissolved salts in the manures. Similarly, Eghball (2002) also reported that increasing manure rate also increased the soil EC with the application of P and N-based manure on a clay loam textured soil in Nebraska. Similar findings were also reported by Eigenberg*et al.*, 2002.

Our results showed that organic farming practices resulted in lower soil bulk densities as compared to conventional and control.The lower bulk density observed in the organic system is due to permanent addition of organic amendments that contribute to increased organic matter input, decreasing soil bulk density (Valpassos*et al.*, 2001). The results concerning soil bulk density indicated that the increase in pore space was accomplished by decrease in soil bulk density, as reported by Werner, 1997 in organic systems. Araújo*et al.*, 2009 also reported that Soil bulk density was lower in organic management than in conventional management. Lower bulk density was recorded in long-term application of FYM treated plots with high SOC content at 0-15 cm soil layer (Chakraborty*et al.*, 2010). In our study, all organic treatments had much-reduced values for bulk density, possibly because of higher values of SOC content in soil and recorded lower penetration resistance (soil strength) compared to conventional fertilizer treatment and unfertilized control also.

The soil organic carbon content was positively and significantly influenced by the cropping system and organic nutrient sources. FYM+CR+B applied plots exhibited a maximum amount of soil organic carbon followed by VC+CR+B and other organic treatments, whereas the Conventional and Control plots were lowest in soil organic carbon content (**Fig.4.21**). Similar findings were also reported by Singh *et al.*, 2015 in rice, wheat, and mungbean cropping system. The results indicated that application of FYM or VC either alone or in combination with CR increased the SOC compared to the control plot, where no organics were applied. Repeated applications of compost at

an annual rate of about 6.8 t ha^{-1} of organic C, with or without inorganic fertilizer, increased the TOC by about 50% (Leita*et al.*, 1999).

Total nitrogen, nitrate-nitrogen, and ammonical-nitrogen values were significantly enhanced by the conventional application of fertilizers as compared to organic treatments (**Table 4.18a, 4.18b and 4.18c**). The results were in line with the findings of Briggs *etal.*,2005. Inorganic N is readily available to plants in the forms in which it commonly occurs (mostly ammonium and nitrate). However, over 90% of the N in most soils is held in organic forms, which must first undergo mineralization. The use of N-fertilizers influences directly the amount of NH_4^+-Nor NO_3^--N available in the soil. (Khalil *et al.,* 2004; Liu *et al.*, 2005).

The presence of a higher quantity of organic matter significantly increased soil water-filled pore space (WFPS). WFPS was highest in VC+CR+B plots, followed by FYM+CR+B and other organic plots. It was minimum in control and conventional plots. Bhattacharyya *et al.*, 2006 also reported similar kind of results. Incorporation of crop residue during rice and farmyard manure during wheat notably increased macro-aggregates with improved carbon content (Das *et al.*, 2014).

5.3 Impact on soil microbial properties

Microbial biomass is one of the most labile pools of soil comprising organic matter. An increase in MBC and MBN is likely to better represent changes in the nutrient-supplying capacity of organic matter than an increase in total organic matter (Gunapala& Scow, 1998). MBC and MBN values were observed highest in FYM+CR+B plots followed by FYM and VC+CR+B plots, whereas the lowest values were observed in conventional and control plots (**Table 4.19 and 4.20**). The present results are supported by observations of previous workers (Albiach*et al.*, 2000; Singh *et al.*, 2015), who also found the increased microbial biomass carbon after addition of organic amendments.

Basal Respiration was significantly enhanced by the input of crop residue to plots receiving FYM and Vermicompost, whereas Metabolic Quotient (qCO_2) was the highest in plots receiving a combination of VC, Crop Residue and Bio-fertilizer. The metabolic quotient (qCO2) evaluates the efficiency of soil microbial biomass in using the organic C compounds (Anderson and Domsch, 1989). The application of CR in combination with FYM, VC, and/or biofertilizer resulted in high qCO_2 values. This

shows that those soils which receive inputs of a readily degradable carbon account for the high qCO_2 values mainly due to more available carbon present in crop residue. A high microbial quotient generally implies a ready supply of fresh organic wastes (Anderson &Domsch, 1989). The higher qCO_2 values in these treatments could reflect an increase in the ratio of active:dormant components of the microbial biomass.

The increase in Basal Respiration activity following the addition of Crop residue (CR) to FYM and VC may be attributed to the enhanced availability of carbon as an energy source for micro-organisms native to the soil as well as those present in FYM and VC, leading to increased mineralization. CR supplies C as an energy source for micro-organisms and increases the microbial activity (Rousk and Baath 2007; Smith*et al.*, 1993). Karmegam and Rajasekar (2012) have reported that microbial population in VC differs qualitatively and quantitatively from that of the compost, and VC is an effective medium to support the growth of bio-inoculants. Interestingly, the highest value of soil microbial biomass carbon was recorded in VC+CR+B, indicating the efficient incorporation of C in the microbial cell mass.

Dehydrogenase activity was more in organic plots as compared to conventional and control with the maximum being in FYM+CR+B and VC+CR+B plots **(Fig. 4.27).** Dehydrogenase is an intracellular enzyme and shows a positive correlation with soil microbial activity (Bello *et al.*, 2013). Hence, it can be concluded that more carbon substratemeanshigher the dehydrogenase activity in soil.

Overall, our results showed that organic farming practices resulted in higher soil microbial activity measured by MBC, MBN, dehydrogenase activity, and soil respiration. This was caused by the higher inputs of organic matter, an energetic substrate for the present microbial communities that were activated to assure the turnover of applied nutrients. Liang *et al.*, 2005 and Rao and Pathak (1996) also observed similar results.

Soil enzymatic activities were also greatly influenced by the application of organic amendments and found relatively low in conventional plot and lowest in unfertilized control plots. The addition of organic substrate increased the biomass of soil microbes (Witter and Kanal, 1998) and thereby indicated more oxidative activity (Nannipieri*et al.*, 1990).

This study concludes that the application of all combinations of organic nutrient sources in the Rice-Wheat-Mungbean cropping system significantly improved the enzyme activity compared with the control. Plots receiving FYM+CR+B and VC+CR+B showed the highest stimulation of β-glucosidase and α-Glucosidase activities in the RWM cropping system. Similar findings were reported by Singh *et al.*,2015. The hydrolysis products of β-glucosidases are believed to be vital energy sources for soil micro-organisms (Tabatabai, 1994). β-glucosidases are essential enzymes in the carbon cycle and play a crucial role in hydrolytic processes that take place during organic matter breakdown. Overall, it appears that glucosidase enzyme activity increases with the use of organic nutrients, which subsequently results in high available carbon in the soil and improves the microbial population in soil. Similar results have been reported by Zhang *et al.*, 2010.

Phosphatase activity was obviously higher in organic plots than the unfertilized control plot. The conventional plot also exhibited higher phosphatize activity, which was comparable to many organic plots. Increased activity of phosphatizing in conventional treatment was also reported by Gaind and Singh, 2016. From these results, we can say that the addition of organic matter enhanced the activity of phosphatase. However, its activity was influenced by quantity and quality of applied organic matter (OM) with showing differ in values up to some extent. It was clearly indicated that plots having more MBC were also high in phosphatase, as phosphomonoesteraseis secreted by soil microbes (Chhonkar*et al.*, 2007).

N-acetyl-β-glucosaminidase (NAG) activity was reported highest in conventional plot followed by other organic plots, and it was lowest in unfertilized control. Riah*et al.*, 2013 also reported that the highest activity of NAG in biowaste compost plots as compared to the control plots. Allison and Jastrow (2006) observed higher potential activities of β-glucosidase and NAG enzymes in particulate organic matter fractions and suggested that active microbes in these fractions synthesize more enzymes to degrade plant-rich materials.

Leucineaminopeptidase activity was also higher in organic plots and comparatively lower in conventional and lowest in the control plot. This result also agrees with the results of other researchers, which showed that increased inorganic N availability has adverse effects on the activity of N-acquiring enzymes (Stursova*et al.*, 2006;Ceninі*et al.*, 2016).

5.4 Correlation between GHG emission and various soil properties

Among soil pH, EC, and bulk density, only bulk density was found to be correlated with CO_2 emission from rice, wheat, and mungbean. The correlation was significantly negative. A similar result was also reported by Novara *et al.,* 2012. Bauer *et al.*, 2006 showed that in conventional tillage, CO_2 efflux had a negative correlation with bulk density. According to the findings of Chappell Christopher and Johnson Andra (2015), there was no significant relationship between pH and CO_2 efflux, but there was a substantial relationship between bulk density and CO_2 efflux.

Soil organic carbon (SOC) also exhibited positive and significant correlation with CH_4 flux from rice and CO_2 flux from rice, wheat, and mungbean crops. Soil organic carbon contains readily available carbon substrate for the microorganisms and contributes to CH_4 and CO_2 emissions. There was a highly significant ($P < 0.01$) correlation between the measured SOC contents and simulated CO_2 emissions (Abbasand Fares, 2009). Our findings are in concurrence with those of Lal and Logan (1995) and Akala and Lal (2001).

The positive and significant correlation was also observed between the N_2O flux from the RWM cropping system and total N, NO_3^--N, and NH_4^+-N (**Table 4.30a, 4.30b, and 4.30c**).The use of N substrates directly influences the amount of NH_4^+ or NO_3^- available in the soil. Ammonium nitrogen (NH_4^+-N) and nitrate-nitrogen (NO_3^--N) are the substrates of nitrification and denitrification respectively, and both can affect soil nitrous oxide emission.Thehigher the amount of NH_4^+-N, the greater will be the nitrification process (Khalil *et al.,* 2004; Liu *et al.,* 2005). As a consequence, the loss of N_2O increases, because the NO_2^- formed during the nitrification process can be used as electron acceptor, if O_2 is limited, and also because the denitrification can occur after the nitrification when soil conditions are favorable. Emissions of N_2O will also be more significant when NO_3^--N in the soil is high as reported by Ruser*et al.*, 2006 and Zanatta*et al.*,2010. When the NO_3^--N availability decreases, N_2O emissions will also decrease because denitrification is reduced (Hellebrand*et al.*, 2008 and Sánchez-Martín *et al.*, 2008.

Microbial biomass carbon (MBC) was found in a positive correlation with CH_4 flux from rice and CO_2 flux from rice, wheat, and mungbean (**Table 4.31a**). This may be attributed to the enhanced mineralization of available soil carbon and increase in basal respiration activity following the release of CO_2. Inubushi*et al.*, 2010 also

reported similar findings where CH_4 oxidation activity was positively correlated with microbial biomass carbon. Similarly microbial biomass nitrogen (MBN) was also associated with N_2O flux but the correlation was insignificant.

In the present study, CH_4 flux from the rice was significantly correlated with dehydrogenase activity (**Table 4.31c**). Similarly, CO_2 flux was also significantly correlated with dehydrogenase activity in RWM cropping system.Włodarczyk*et al.*, 2002 reported that soil dehydrogenase activity was significantly related tothegeneration of CO_2 under flooded conditions and the final cumulative CO_2 production increased curvilinearly with dehydrogenase activity.

Correlation analysis showed that activities of the soil enzymes were correlated with GHG efflux. The correlation matrix also defined the relationship between enzyme activities and GHGs (**Table 4.31d and 4.31e**). Soil enzymes like α-Glucosidase and β-Glucosidase were positively correlated with CO_2 and CH_4 emission, while phosphatase does not show any correlation with GHG emission. CH_4 flux from the rice and CO_2 flux from wheat and mungbean were positively correlated with α and β-Glucosidase enzymes. Xuexia*et al.*, 2006 also found a positive correlation between α-glucosidase activity and CO_2 efflux. Similar findings of soil enzymes and their relationship with GHG efflux were also reported by Nigel Hoilett, 2011. The positive correlations among GHG and nutrient cycling enzymes also suggest that substrate availability affected GHG efflux since mineralizing enzymes are integral in the release of nutrients from organic matter.

CHAPTER 6
SUMMARY AND CONCLUSION

GHG flux varies with the interactions among physical, chemical, and biological properties of soil. Soil micro-organisms are involved in virtually all soil processes, mediating soil organic matter decomposition and nutrient cycling and are also involved in GHG dynamics between the soil and atmosphere. The main contributor to potential greenhouse gases, i.e., CO_2, CH_4, and N_2O to the atmosphere is believed to be the terrestrial carbon pool. The rate of exchange between the terrestrial pool and the atmosphere is generally affected by various soil biological, physical, and chemical properties, including soil organic matter content, soil enzyme, soil micro-organisms and management practices.

These greenhouse gases are produced or consumed as a result of microbial activity in the soil, but the intensity of the fluxes between the soil and the environment depends massively on soil physical and chemical factors. Therefore, an understanding of the relationship between soil enzyme activity and GHG efflux could provide policymakers with useful information to assist in making meaningful recommendations to minimize GHG contributions.

The conventional system of growing rice in IGPs contributes significantly to the GHG emission having a greater GWP due to higher emissions of CH_4 and N_2O. The adoption of organic system of farming can significantly reduce GHG emission from agriculture. In our study, cumulative $CH_4$and CO_2 emission from rice-wheat-mungbean cropping system were recorded much higher from organic plots as compared to conventional plots whereas cumulative N_2O emission was lower from organic plots. Organic and conventional rice plots had shown noticeable variations in average greenhouse gas emissions during both the years. Organic plots treated with FYM+CR+B and VC+CR+B were recorded highest in methane (CH_4) emission while CH_4 emission from non-amended control and Conventional plots were less as compared to all organic plots. Occurrence of aerobic condition in soil, during most part of the crop growth leads to almost zero or somewhat negative net emission of CH_4 under wheat and mungbean cropping seasons with no definite patterns observed among the various organic and conventional treatments.

In the case of rice, N_2O emission was highest from conventionally managed plots and even higher after 1st and 2nd dose of synthetic nitrogen (N) application through fertilizer. In the case of wheat and mungbean, N_2O emission was higher in all treatments

as compared to N_2O emission from rice. In conventional wheat, N_2O emission was found higher after fertilizer application and subsequent to irrigation. N_2O fluxes after irrigation were also high in all organic treatments and unfertilized control. The Lowest N_2O emission flux was observed in control treatment compared to the other treatments throughout the cropping seasons that might be attributed to the availability of nitrogenous substrate for nitrification and denitrification process.

In all the three crops, from all the treatments we observed lower CO_2 flux after sowing of crops. However, during later crop growth stage, particularly vegetative growth the CO_2 emission flux increased significantly and reached its maximum value during 60-80 DAT in rice, 40-80 DAS in wheat, and 30-55 DAS in mungbean crop. The soluble/labile organic carbon is the immediate source of carbon for microorganisms and it enhances CO_2 emission. This might be probable reason for higher CO_2 emission from FYM+CR+B and VC+CR applied plots followed by VC+CR+B, FYM and VC used plots than the conventional and control treatments.

This study indicated that, replacement of existing conventional system with various organic practices can reduce GWP of rice, wheat and mungbean systems by 1.73 to 26.84%, 20.04 to 35.44% and 9.2 to 31.3% respectively. Net GWP (CH_4, N_2O and CO_2) of organic plots was lower than the conventional plot because of much less emission of N_2O from these plots as compared to the conventional one. Nitrogen sources like VC, FYM, Crop Residue and also biofertilizers can be effectively utilised for reduction of N_2O emission under organic farming. In the longer term, this practice might also lead to an increase in soil organic carbon. These results indicate that adoption of organic practices over conventional one can be an efficient low carbon emitting option. It may be concluded that organic farming delivers greater ecosystem services, social and environmental benefits and thus needs to be considered for the development of sustainable farming systems.

The various physico-chemical properties of soil (pH, Bulk Density, Total Nitrogen etc.) significantly decreased over the initial values during the long term organic farming of rice-wheat-mungbean cropping system while some of the properties improved over time i.e. Soil Organic Carbon (SOC), Water Filled Pore Space (WFPS), Soil Electrical Conductivity (EC) etc. Among biological (microbial) properties, Microbial Biomass Carbon, Microbial Biomass Nitrogen, Dehydrogenase activity, α and β-Glucosidase activity improved during the study. These soil properties were correlated with the Greenhouse Gas flux from different organic and conventional treatments.

Among soil pH, EC and bulk density, only bulk density was found to be correlated with CO_2 emission from rice, wheat and mungbean and the correlation was significantly negative. Soil organic carbon (SOC) also exhibited positive and significant correlation with CH_4 flux from rice and CO_2 flux from rice, wheat and mungbean crops. Soil organic carbon contains readily available carbon substrate for the microorganisms and contributes to CH_4 and CO_2 emissions. The positive and significant correlation was also observed between the N_2O flux from RWM cropping system and total N, NO_3^--N, and NH_4^+-N. The use of nitrogenous fertilizers directly influences the amount of NH_4^+ or NO_3^- available in the soil. Ammonium nitrogen (NH_4+-N) and nitrate nitrogen (NO_3--N) are the substrates of nitrification and denitrification respectively, and both can affect soil nitrous oxide emission.The greater the amount of NH_4^+-N, the greater will be the nitrification process.

Microbial biomass carbon (MBC) was found in positive correlation with CH_4 flux from rice and CO_2 flux from rice, wheat and mungbean. This may be attributed to the enhanced mineralization of available soil carbon and increase in basal respiration activity following the release of CO_2.The correlation matrix also defined the relationship between enzyme activities and GHGs. Soil enzymes like Dehydrogenase, α-Glucosidase and β-Glucosidase were positively correlated with CO_2 and CH_4 emission, while phosphatase does not show any correlation with GHG emission. CH_4 flux from the rice and CO_2 flux from wheat and mungbean were positively correlated with α and β-Glucosidase enzymes. The positive correlations among GHG and nutrient cycling enzymes also suggests that substrate availability affected GHG efflux since mineralizing enzymes are integral in the release of nutrients from organic matter. From these results it may be concluded that GHG flux varies with the interactions among physical, chemical, and biological properties of soil.Thus the factors that have a relationship with GHG emission are of the utmost importance to try to understand the dynamics of the greenhouse gases in the soil.

GREENHOUSE GAS EMISSION IN RICE-WHEAT-MUNGBEAN CROPPING SYSTEM UNDER ORGANIC AND CONVENTIONAL PRACTICES

ABSTRACT

Organic cultivation of crops is important for maintaining soil health and improving environmental quality. A field experiment was conducted at IARI, New Delhi to quantify the emission of methane (CH_4), nitrous oxide (N_2O), and corban dioxide(CO_2), and their global warming potential (GWP), and correlation with physico-chemical and biological properties of soil of different organic and conventional treatments under rice-wheat-mungbean cropping system. Treatments consisted of eight combinations namely: (T_1) non-amended control; (T_2) Recommended dose of fertilizers; (T_3) FYM; (T_4) VC; (T_5) FYM + CR; (T_6) VC+CR; (T_7) FYM + CR + B; and (T_8) VC+CR+B. Experimental results showed that cumulative CH_4 and CO_2 emission from rice-wheat-mungbean cropping systems were recorded higher from organic plots FYM + CR + B (T_7) and VC+CR+B (T_8) as compared to conventional plot treated with RDF (T_2). In contrast, cumulative N_2O emission was lower from organic plots. GWP of various treatments varied from 550.13 to 1636.44, 512.79 to 1372.71, and 507.40 to 1305.86 kg CO_2 eq. ha^{-1} during rice, wheat, and mungbean cropping, respectively. Different organic treatment combinations led to about 1.73 to 26.84%, 20.04 to 35.44% and 9.2 to 31.3% reduction in GWP over the conventional treatment in rice, wheat and mungbean crops respectively.

During the study, results also revealed that soil properties especially SOC, WFPS, EC, MBC, MBN, dehydrogenase activity, α- and β-glucosidase activity significantly improved. Among soil properties, SOC exhibited positive and significant relationships with CH_4 and CO_2 flux from rice, wheat and mungbean crops. N_2O flux had a positive correlation with total N, NO_3^--N, and NH_4^+-N. MBC also showed a positive association with CH_4 and CO_2 flux from rice, wheat and mungbean. Soil enzymes like dehydrogenase, α-and β-glucosidase were positively correlated with CO_2 and CH_4 emission, while phosphatase does not show any correlation with GHG emission. The positive relationships among GHG and enzymes also indicate that substrate availability affected GHG efflux since mineralizing enzymes are integral in the release of nutrients from organic matter. Overall, this study revealed that the replacement of existing conventional systems with various organic practices could reduce GWP and thus needs to be considered for sustainable farming systems.

जैविक तथा पारम्परिक खेती के तहत चावल-गेंहूँ-मूँग फसल प्रणाली से ग्रीनहाउस गैस उत्सर्जन

सारांश

मृदा स्वास्थ्य बनाए रखने और पर्यावरण गुणवत्ता में सुधार के लिए फसलों की जैविक खेती महत्वपूर्ण है। आईएआरआई,नई दिल्ली में मीथेन(CH_4), नाइट्रस ऑक्साइड(N_2O), और कॉर्बन डाइऑक्साइड(CO_2) उत्सर्जन, और उनकी ग्लोबल वार्मिंग क्षमता (GWP) को मापन करने, मिट्टी के भौतिक-रासायनिक और जैविक गुणों के साथ सहसंबंध हेतु चावल-गेहूं-मूंगबीन फसल प्रणालीके तहत विभिन्न कार्बनिक और पारंपरिक उपचार के साथ एक क्षेत्र प्रयोग किया गया। उपचार में आठ संयोजन: (T1) गैर-संशोधित नियंत्रण (Control); (T2) उर्वरकों की अनुशंसित खुराक (Conventional/RDF); (T3) FYM; (T4) VC; (T5) FYM+CR; (T6) VC+CR; (T7) FYM+CR+B; और (T8) VC+CR+B शामिल थे। प्रायोगिक परिणामों में पाया गया कि चावल-गेहूं-मुंगबीन फसल प्रणालियों से आरडीएफ (T2) के साथ ट्रीटेड/उपचारित किए गए पारंपरिक भूखंड की तुलना में कार्बनिक भूखंडों FYM+CR+B (T7) और VC+CR+B (T8) से संचयी CH_4 और CO_2 उत्सर्जन अधिक दर्ज हुई। इसके विपरीत, कार्बनिक भूखंडों से संचयी N_2O उत्सर्जन कम था। विभिन्न उपचारों में ग्लोबल वार्मिंग क्षमता (GWP) चावल, गेहूं और मूंग की फसल के दौरान क्रमशः 550.13 से 1636.44, 512.79 से 1372.71 और 507.40 से 1305.57 kg CO_2 eq. ha^{-1} तक भिन्न क्रम में है। चावल, गेहूं और मुंगबीन फसलों में विभिन्न कार्बनिक उपचार संयोजनों की तुलना में पारंपरिक उपचार से क्रमशः 1.73 से 26.84%, 20.04 से 35.44% और 9.2 से 31.3% ग्लोबल वार्मिंग क्षमता (GWP) की कमी की।

अध्ययन के दौरान, परिणामों से यह भी पता चला कि मिट्टी के गुण विशेष रूप से सोइल आर्गेनिक कार्बन, WFPS, EC, एमबीसी, एमबीएन, डिहाइड्रोजनेज, α- और β-ग्लाइकोसाइडेजसोइल एन्जाइमेटिक एक्टिविटी में काफी सुधार हुआ है। मृदा गुणों के बीच, आर्गेनिक कार्बन ने चावल, गेहूं और मूंग की फसलों से CH_4 और CO_2 प्रवाह के साथ सकारात्मक और महत्वपूर्ण संबंधों का प्रदर्शन किया। N2O प्रवाह का कुल N, NO_3^--N, और NH_4^+-N के साथ सकारात्मक सहसंबंध था। MBC ने चावल, गेहूं और मूंग से CH_4और CO_2 प्रवाह के साथ एक सकारात्मक जुड़ाव भी दिखाया। डीहाइड्रोजनेज, α-और β-ग्लाइकोसाइडेजजैसे मिट्टी के एंजाइमों को CH_4और CO_2 उत्सर्जन के साथ सकारात्मक रूप से सहसंबद्ध किया, जबकि फॉस्फेटेज़ GHG उत्सर्जन के साथ कोई संबंध नहीं दिखाता है। GHG और एंजाइमों के बीच सकारात्मक संबंध यह भी संकेत देते हैं कि खनिज पदार्थों को मिनरलीजिंग करने के बाद सब्सट्रेट की उपलब्धता जीएचजी को प्रभावित करती है जो कार्बनिक पदार्थों से पोषक तत्वों की रिहाई में अभिन्न हैं। कुल मिलाकर, इस अध्ययन से पता चला है कि विभिन्न जैविक पद्धतियों के साथ मौजूदा पारंपरिक प्रणालियों के प्रतिस्थापन से GWP को कम किया जा सकता है और इस तरह स्थायी कृषि प्रणालियों के लिए विचार किया जाना चाहिए।

Annexure-1a: GHG emission under organic and conventional amended plots in Rice (kg/ha)

Treatments	Methane (CH_4)		Carbon dioxide (CO_2)		Nitrous oxide (N_2O)	
	Seasonal cumulative		*Seasonal cumulative*		*Seasonal cumulative*	
	2015	**2016**	**2015**	**2016**	**2015**	**2016**
CONTROL	10.51±0.46	11.93±0.80	233.58±12.94	265.23±14.06	0.20±0.10	0.22±0.04
CONVENTIONAL	25.37±0.64	25.80±1.61	538.23±50.55	550.27±20.51	1.77±0.07	1.81±0.12
FYM	29.40±1.62	31.83±2.10	535.47±16.97	533.58±16.30	0.49±0.08	0.53±0.09
VC	27.48±2.49	29.91±2.63	469.74±15.31	484.74±19.91	0.35±0.08	0.41±0.07
FYM+CR	28.19±2.45	28.29±1.36	639.02±62.45	632.23±41.09	0.44±0.07	0.46±0.10
VC+CR	31.41±0.94	31.85±2.06	650.77±22.39	660.52±20.81	0.22±0.05	0.26±0.06
FYM+CR+B	34.28±2.66	34.84±1.45	702.23±33.53	710.58±14.11	0.54±0.06	0.60±0.05
VC+CR+B	32.10±2.59	33.53±1.52	710.55±26.23	710.44±37.86	0.56±0.13	0.61±0.11

Annexure-1b: GHG emission under organic and conventional amended plots in Wheat (kg/ha)

Treatments	Methane (CH_4)		Carbon dioxide (CO_2)		Nitrous oxide (N_2O)	
	Seasonal cumulative		*Seasonal cumulative*		*Seasonal cumulative*	
	2015	**2016**	**2015**	**2016**	**2015**	**2016**
CONTROL	-1.85±0.10	-1.14±0.12	504.62±24.15	472.15±27.78	0.17±0.04	0.19±0.04
CONVENTIONAL	-1.83±0.11	-1.26±0.07	845.79±23.62	848.51±32.56	1.76±0.12	1.84±0.14
FYM	-2.37±0.49	-1.67±0.22	918.11±29.13	883.42±26.46	0.46±0.04	0.49±0.11
VC	-1.77±0.12	-1.85±0.18	833.03±25.99	798.34±18.10	0.33±0.04	0.37±0.13
FYM+CR	-1.81±0.13	-1.24±0.07	953.33±37.27	952.55±25.52	0.42±0.11	0.46±0.07
VC+CR	-1.69±0.15	-1.21±0.12	1074.40±58.17	1039.71±44.70	0.24±0.10	0.21±0.06
FYM+CR+B	-1.91±0.02	-1.89±0.08	977.8±48.56	959.11±19.07	0.55±0.07	0.54±0.11
VC+CR+B	-1.72±0.13	-1.85±0.14	881.95±55.48	889.02±19.27	0.58±0.16	0.60±0.13

Annexure-1c: GHG emission under organic and conventional amended plots in Mungbean (kg/ha)

Treatments	Methane (CH_4)		Carbon dioxide (CO_2)		Nitrous oxide (N_2O)	
	Seasonal cumulative		*Seasonal cumulative*		*Seasonal cumulative*	
	2015	**2016**	**2015**	**2016**	**2015**	**2016**
CONTROL	-1.10±0.10	-1.20±0.18	459.21±19.31	510.88±16.92	0.13±0.06	0.17±0.06
CONVENTIONAL	-1.08±0.15	-1.18±0.11	811.12±37.14	825.05±16.29	1.67±0.14	1.63±0.11
FYM	-1.03±0.10	-1.14±0.21	1016.60±18.63	1020.54±25.45	0.57±0.15	0.59±0.08
VC	-1.03±0.12	-1.13±0.19	855.09±51.77	859.03±53.17	0.39±0.10	0.42±0.10
FYM+CR	-1.11±0.11	-1.22±0.12	793.41±11.37	772.76±28.04	0.45±0.06	0.44±0.10
VC+CR	-0.97±0.06	-1.07±0.10	1069.31±34.41	1040.97±80.46	0.48±0.08	0.50±0.06
FYM+CR+B	-0.98±0.08	-1.08±0.16	1109.08±62.89	1094.31±30.49	0.53±0.07	0.49±0.14
VC+CR+B	-0.99±0.11	-1.10±0.11	984.51±40.94	987.14±40.88	0.62±0.14	0.61±0.12

Annexure-1d: GWP under organic and conventional amended plots in Rice, Wheat and Mungbean (kg CO_2 eqha^{-1})

Treatments	Global Warming Potential (GWP)					
	Rice		*Wheat*		*Mungbean*	
	2015	**2016**	**2015**	**2016**	**2015**	**2016**
CONTROL	516.29±22.09	583.96±40.38	518.47±36.08	507.11±37.25	476.41±17.81	538.38±12.36
CONVENTIONAL	1619.70±36.44	1653.17±55.06	1352.96±56.11	1392.45±71.54	1306.14±57.79	1305.57±32.61
FYM	1304.77±68.14	1366.31±87.20	1010.94±49.30	1000.25±59.46	1171.67±63.47	1179.50±17.49
VC	1155.32±45.81	1239.95±50.95	898.16±39.04	874.19±48.12	954.36±46.86	965.50±46.15
FYM+CR	1367.41±94.69	1368.92±97.64	1045.52±51.15	1069.11±35.86	909.60±15.85	883.54±4.85
VC+CR	1378.58±52.58	1409.97±53.43	1113.31±89.47	1079.40±50.19	1197.74±60.19	1173.50±72.91
FYM+CR+B	1589.51±35.80	1628.22±31.14	1108.19±27.13	1086.82±21.01	1252.80±43.80	1223.53±64.67
VC+CR+B	1558.25±87.14	1603.67±99.63	1025.63±24.95	1036.17±58.66	1155.92±63.43	1153.14±79.51

Annexure-2a: Soil physico-chemical properties under rice

Treatments	pH		EC		OC (%)		BD		WFPS (%)	
Treatments	**2015**	**2016**	**2015**	**2016**	**2015**	**2016**	**2015**	**2016**	**2015**	**2016**
FYM+CR+B	8.13	8.93	200.2	217.0	0.77	0.84	1.34	1.46	67.5	74.0
VC+CR+B	8.05	8.85	196.4	212.8	0.69	0.75	1.35	1.46	71.9	73.3
FYM	8.11	8.91	174.2	188.7	0.62	0.67	1.37	1.49	65.0	67.3
VC	8.11	8.91	200.6	217.4	0.59	0.64	1.36	1.47	67.4	69.2
VC+CR	8.16	8.97	145.7	157.9	0.67	0.72	1.38	1.49	72.6	73.4
CONTROL	8.08	8.88	102.8	119.8	0.52	0.56	1.43	1.55	51.2	47.9
FYM+CR	7.97	8.75	160.4	173.9	0.61	0.66	1.38	1.49	64.5	65.3
CONVENTIONAL	8.24	9.05	145.8	166.4	0.51	0.55	1.43	1.55	44.5	44.6

Annexure-2b: Soil physico-chemical properties under wheat

	pH		EC		OC (%)		BD		WFPS (%)	
Treatments	**2015**	**2016**	**2015**	**2015**	**2015**	**2016**	**2015**	**2016**	**2015**	**2016**
FYM+CR+B	7.90	8.68	196.1	212.5	0.77	0.84	1.35	1.46	63.5	70.2
VC+CR+B	8.03	8.82	185.3	200.8	0.73	0.79	1.35	1.46	65.9	69.9
FYM	7.90	8.68	171.1	185.5	0.65	0.70	1.38	1.49	64.2	67.6
VC	7.62	8.37	187.6	203.3	0.63	0.68	1.36	1.47	57.6	67.1
VC+CR	7.74	8.51	117.6	127.4	0.69	0.75	1.38	1.49	61.3	68.3
CONTROL	8.02	8.81	101.0	117.8	0.56	0.61	1.43	1.55	47.9	45.7
FYM+CR	7.89	8.67	150.6	163.3	0.63	0.68	1.38	1.50	61.1	60.3
CONVENTIONAL	8.15	8.96	144.2	164.6	0.53	0.57	1.44	1.56	49.9	48.9

Annexure-2c: Soil physico-chemical properties under mungbean

	pH		EC		OC (%)		BD		WFPS (%)	
Treatments	**2015**	**2016**	**2015**	**2015**	**2015**	**2016**	**2015**	**2016**	**2015**	**2016**
FYM+CR+B	8.46	8.50	201.8	218.7	0.86	0.88	1.34	1.46	68.1	70.7
VC+CR+B	8.56	8.56	180.9	196.0	0.73	0.72	1.35	1.47	72.5	72.1
FYM	8.50	8.50	160.3	173.8	0.78	0.70	1.38	1.49	59.5	64.9
VC	8.25	8.30	188.5	204.3	0.66	0.60	1.35	1.47	68.7	70.1
VC+CR	8.36	8.41	126.1	136.6	0.70	0.67	1.36	1.47	64.5	66.7
CONTROL	8.53	8.57	99.8	116.6	0.59	0.55	1.42	1.54	53.5	50.3
FYM+CR	8.49	8.44	149.4	162.0	0.52	0.57	1.36	1.47	63.8	64.4
CONVENTIONAL	8.78	8.72	136.7	156.5	0.68	0.59	1.46	1.58	51.4	50.1

Annexure-2d: Soil nitrogen in R-W-M- cropping system

Treatments	**Rice**						**Wheat**						**Mungbean**					
	2016			**2017**			**2016**			**2017**			**2016**			**2017**		
	TN	NN	AN	TN	NN	AN	TN	NN	AN	TN	NN	AN	TN	NN	AN	TN	NN	AN
FYM+CR+B	793.6	26.3	57.3	860.1	28.5	62.1	812.9	26.5	50.0	881.0	28.7	54.2	868.5	28.0	50.0	941.3	30.4	54.2
VC+CR+B	945.5	27.3	72.5	1024.7	29.6	78.5	1005.4	29.4	68.0	1089.7	31.9	73.7	1003.3	28.4	72.5	1087.3	30.8	78.5
FYM	727.3	22.8	43.8	788.3	24.7	47.5	663.2	21.3	40.4	718.7	23.1	43.8	765.8	23.7	46.6	830.0	25.7	50.5
VC	676.0	23.5	44.4	732.6	25.5	48.1	748.7	24.2	46.1	811.4	26.2	49.9	703.8	23.9	48.9	762.8	25.9	53.0
VC+CR	584.0	26.6	56.7	632.9	28.9	61.5	620.4	25.9	51.1	672.3	28.1	55.4	667.4	26.3	58.4	723.3	28.5	63.3
CONTROL	437.8	12.5	32.0	474.4	13.6	34.7	406.5	14.1	30.3	440.5	15.3	32.9	469.9	13.3	28.7	509.2	14.4	31.1
FYM+CR	650.3	26.9	63.5	704.8	29.1	68.8	599.0	27.2	60.7	649.2	29.5	65.8	708.1	28.0	65.2	767.4	30.4	70.6
CONVENTIONAL	1148.8	38.0	94.4	1245.0	41.2	102.3	1133.8	41.3	83.7	1228.8	44.8	90.7	1174.4	44.3	96.6	1272.8	48.0	104.7

Note: TN-Total soil Nitrogen; NN-NO_3^--N; AN-NH_4^+-N

Annexure-3a: Microbial properties of soil under rice

Treatments	*MBC*		*MBN*		*DHase*		*α-Glucosidase*		*β-Glucosidase*		*LAP*		*Phosphatase*		*NAG*	
	2015	**2016**	**2015**	**2016**	**2015**	**2016**	**2015**	**2016**	**2015**	**2015**	**2015**	**2016**	**2015**	**2016**	**2015**	**2016**
FYM+CR+B	165.4	179.3	32.3	35.0	280.4	303.8	51.9	56.3	180.6	195.7	279.1	302.5	406.2	440.2	20.3	22.1
VC+CR+B	141.0	152.8	25.4	27.5	287.6	311.7	39.8	43.1	164.6	178.4	583.8	632.7	479.8	520.0	7.3	8.0
FYM	152.7	165.4	25.2	27.3	243.1	263.5	19.4	21.0	116.1	125.8	583.8	632.7	544.3	589.9	6.6	7.1
VC	137.1	148.6	21.5	23.3	218.8	237.2	36.8	39.9	99.0	107.3	530.5	574.9	584.6	633.5	13.9	15.1
VC+CR	131.4	142.4	24.0	26.0	250.7	271.7	43.6	47.2	162.7	176.3	323.6	350.7	431.6	467.8	12.1	13.1
CONTROL	67.0	72.6	14.0	15.2	171.8	186.2	16.1	17.5	95.8	103.9	259.6	281.4	267.1	289.5	5.7	6.2
FYM+CR	128.2	139.0	23.3	25.3	250.1	271.1	35.3	38.3	64.6	70.1	291.5	316.0	359.7	389.8	12.1	13.1
CONVENTIONAL	82.3	89.2	23.4	25.3	167.6	181.6	20.9	22.6	96.8	104.9	377.8	409.5	537.6	582.6	18.3	19.8

Annexure-3b: Microbial properties of soil under wheat

Treatments	*MBC*		*MBN*		*DHase*		*α-Glucosidase*		*β-Glucosidase*		*LAP*		*Phosphatase*		*NAG*	
	2015	**2016**	**2015**	**2016**	**2015**	**2016**	**2015**	**2016**	**2015**	**2015**	**2015**	**2015**	**2015**	**2016**	**2015**	**2016**
FYM+CR+B	200.0	216.7	38.3	41.5	324.9	352.1	63.4	68.7	159.2	172.6	316.1	342.6	362.5	392.9	14.9	16.2
VC+CR+B	176.3	191.0	32.9	35.6	310.4	336.5	55.0	59.6	141.0	152.8	495.3	536.8	423.4	458.8	8.2	8.9
FYM	161.8	175.3	26.4	28.6	281.7	305.3	25.8	28.0	136.4	147.8	524.9	568.9	491.7	532.9	9.0	9.7
VC	156.5	169.6	27.0	29.3	253.1	274.3	30.0	32.6	112.4	121.8	541.2	586.5	532.6	577.2	11.3	12.3
VC+CR	134.0	145.2	28.3	30.6	294.3	318.9	36.0	39.0	143.6	155.6	383.3	415.4	395.5	428.7	15.5	16.8
CONTROL	82.5	89.4	15.8	17.2	168.9	183.1	21.0	22.8	126.4	137.0	237.5	257.4	318.2	344.9	7.1	7.7
FYM+CR	143.6	155.6	31.6	34.3	296.3	321.1	24.7	26.8	76.0	82.4	259.4	281.1	330.7	358.4	9.8	10.6
CONVENTIONAL	114.8	124.4	25.6	27.7	187.7	203.4	25.3	27.5	116.2	125.9	327.1	354.5	467.6	506.8	23.1	25.0

Annexure-3c: Microbial properties of soil under mungbean

Treatments	*MBC*		*MBN*		*DHase*		*α-Glucosidase*		*β-Glucosidase*		*LAP*		*Phosphatase*		*NAG*	
	2015	**2016**	**2015**	**2016**	**2015**	**2016**	**2015**	**2016**	**2015**	**2016**	**2015**	**2016**	**2015**	**2016**	**2015**	**2016**
FYM+CR+B	180.5	195.6	44.3	48.1	354.2	383.9	58.5	63.4	164.6	178.4	302.0	327.3	365.5	396.1	15.7	17.1
VC+CR+B	154.9	167.9	40.4	43.7	340.1	368.6	48.9	53.0	151.7	164.4	436.8	473.4	461.4	500.0	10.4	11.3
FYM	162.1	175.7	28.5	30.9	303.4	328.8	21.3	23.1	129.6	140.5	524.2	568.1	494.8	536.3	8.6	9.3
VC	149.0	161.5	32.5	35.2	283.6	307.3	32.2	34.9	122.5	132.8	495.8	537.3	531.8	576.4	10.7	11.6
VC+CR	143.0	155.0	32.5	35.2	319.1	345.9	33.2	36.0	132.5	143.6	324.3	351.5	394.5	427.6	10.6	11.5
CONTROL	77.7	84.2	17.6	19.1	211.2	228.9	17.1	18.5	122.7	132.9	298.2	323.2	282.5	306.1	8.2	8.9
FYM+CR	126.3	136.9	39.9	43.3	309.9	335.9	26.5	28.8	84.4	91.4	265.4	287.7	340.1	368.6	9.4	10.2
CONVENTIONAL	103.3	112.0	27.8	30.1	224.2	243.0	25.1	27.2	103.7	112.4	339.8	368.3	478.6	518.7	26.0	28.2

Annexure-3d Basal Respiration and Metabolic Quotient

Treatments	Rice				Wheat				Mungbean			
	BR		*MQ*		*BR*		*MQ*		*BR*		*MQ*	
	2016	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**
FYM+CR+B	350.5	345.7	1.86	2.04	427.8	421.9	1.87	2.06	408.7	403.1	1.98	2.18
VC+CR+B	383.0	377.7	2.38	2.61	442.2	436.1	2.20	2.41	417.3	411.6	2.36	2.59
FYM	277.9	274.1	1.60	1.75	369.6	364.5	2.00	2.20	326.6	322.1	1.76	1.94
VC	310.4	306.1	1.98	2.18	352.4	347.5	1.97	2.16	361.9	357.0	2.13	2.33
VC+CR	225.4	222.3	1.50	1.65	311.3	307.0	2.04	2.23	298.0	293.9	1.83	2.00
CONTROL	136.6	134.7	1.79	1.96	207.2	204.4	2.20	2.42	172.9	170.5	1.95	2.14
FYM+CR	213.9	211.0	1.46	1.60	279.8	276.0	1.71	1.87	274.1	270.3	1.90	2.09
CONVENTIONAL	224.4	221.3	2.39	2.62	230.2	227.0	1.76	1.93	262.6	259.0	2.23	2.44

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