Effect of Long Term Application of Fertilizer and Manure on Soil Organic Carbon Fractions under Maize-Wheat Cropping Sequence in *Haplustepts*

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Thesis

Doctor of Philosophy in Agriculture

(Agricultural Chemistry and Soil Science)

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DEPARTMENT OF AGRICULTURAL CHEMISTRY AND SOIL SCIENCE
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CONTENTS

1. INTRODUCTION

In India, during the past three decades, intensive agriculture involving exhaustive high-yielding varieties of maize and wheat has led to heavy withdrawal of nutrients from the soil. Furthermore, imbalanced use of chemical fertilizers by farmers has deteriorated soil health. The widely practiced maize-wheat system in India is one such instance, where sustainability is under threat. Wheat is the premier food grain crops of the India and in particular of Rajasthan. There has been a phenomenal increase in their production after mid sixties with the introduction of high yielding verities. To curb this trend of declining yield, there is a need to adopt the concept of integrated nutrient management. Improving and maintaining soil quality for enhancing and sustaining agricultural production is of utmost importance for India's food and nutritional security. Though India is a food surplus nation at present with about 200 Mt food grain production per annum, it will require about 7-9 Mt additional food grains each year if the trend in rising population persists. This challenge can be met by greater and more efficient use of fertilizers and organic sources. Adoption of integrated plant nutrient supply and management strategies for enhancing soil quality, input use efficiency and crop productivity is extremely important for food and nutritional security in Indian agriculture (Sharma *et al.,* 2013).

Food security, nutritional security, maintenance of soil health, enhancement of productivity and leaving rightful heritage are the main focus of agricultural development. To improve and maintain soil health for enhancing and sustaining crop production is of prime importance. Long term sustainability of agriculture and crop productivity depends on soil health. Non-judicious and profit motivated use of many modern inputs like fertilizers, plant protection chemicals and herbicides have been observed to leave behind an adverse effect, on soil properties, resulting in decline of crop productivity over long time use. Further it has been envisaged that intensive cropping with cereal based cropping systems and use of sulphur and micronutrient free fertilizers gradually reduced inherent pools of soil nutrients, which ultimately affect the sustainability of soils. As the nutrient need of the crop to keep pace with nutrient removed by the crop cannot met either through mineral fertilizer or through organics, major source of plant nutrients viz., soil minerals, organic and biological materials in an integrated manner would be essential and inevitable. From the experiences of Long Term Fertilizers Experiment conducted in different part of country it has been established that crop productivity cannot be further enhanced under high input production system with incremental use of fertilizer alone, where addition of organic sources could again boos the yield through increased productivity and fertilizer use efficiency.

Integrated nutrient management (INM) or integrated nutrient supply (INS) system aims at achieving efficient use of chemical fertilizers in conjunction with organic manures. Long term fertilizer experiments involving intensive cereal based cropping systems reveal a declining trend in productivity even with the application of recommended levels of N, P and K fertilizers (Mahajan *et al*., 2002; Mahajan and Sharma, 2005). The crop productivity increases from the combined application of chemical fertilizers and organic manures. Such combination contributed to the improvement of physical, chemical and biological properties and soil organic matter and nutrient status.

Application of inorganic fertilizers results in higher soil organic matter (SOM) accumulation and biological activity due to increased plant biomass production and organic matter returns to soil in the form of decaying roots, litter and crop residues. Addition of SOM enhances soil organic carbon (SOC) content, which is an important indicator of soil quality and crop productivity. Sequestration of SOC is key to reduce greenhouse gas emissions and lower the carbon footprint of farming. Fertilizer applications could affect soil physical properties directly or indirectly such as aggregate stability, water holding capacity, porosity, infiltration rate, hydraulic conductivity and bulk density due to increases in SOM and SOC content. The SOM components such as humic molecules and polysaccharides increased aggregate stability by binding mineral particles into aggregates and reduced their susceptibility to erosion by wind or water. In turn, formation of stable aggregates enhances physical protection of SOM against microbial decomposition. Fertilizer additions also affect the chemical composition of soil solution which can be responsible for dispersion/flocculation of clay particles and thus, affects the soil aggregation stability. Beneficial effects of increasing SOM concentration on enhancing soil structural stability have been widely documented. Reduction in SOM can degrade soil quality and fertility resulting in reduced agronomic productivity. The SOM lowered the soil bulk density and compaction, resulting in increased total porosity and water infiltration rate (Brar *et al.*, 2015).

Long term fertilizer experiments are the best tool to assess the influence of continuous application of fertilizers, organic manures and their combined use on sustainability and soil fertility. Permanent manurial experiments provide valuable information on the impact of long term adoption of nutrient management system with varying sources, types and combinations of plant nutrient inputes of soil fertility and productivity (Subehia *et al*., 2005) These experiments too have witnessed the beneficial effects of soil organic matter (SOM) on system sustainability and soil health.

A good farming practice can decrease CO_2 evolution into the atmosphere and enhance soil fertility and thus productivity. This is more important in tropical and subtropical region where soils are inherently low in organic carbon content and production system is fragile (Mandal *et al.* 2005). Sustaining or increasing soil organic matter is of great importance in terms of cycling plant nutrients, minimizing the need of inorganic fertilizer, and improving soil physical, chemical and biological properties. The SOM pool comprises of active, intermediate/slow and passive pools, which act as sensitive indicators of soil quality. The active pools generally contribute about 10-20% towards to total SOM, whereas the stable or passive pools have 50-90% contribution towards total SOM (Brady and Weil, 2002). The SOC stock is comprised of labile or actively cycling pool. Labile C pool is the fraction of SOC with rapid turnover rates. Some carbon pools like CO_2 evolution, soil microbial biomass carbon, soil microbial biomass nitrogen, water soluble carbon, acid hydrolysable carbohydrates are used as an indicator of soil quality. Soil microbial biomass study reflects energy flow, acts as an agent of transformation of all substances and reflects on a labile pool of C, N, P, S and micronutrients (Mishra *et al*. 2008). They are first to be depleted as a result of cultivation or other perturbations (Sherrod *et al.* 2005). Significant changes in active pools of SOC due to different land management practices with different cropping systems, however, can only be observed after long periods of cultivation (Conant *et al.* 2003). Changes in labile pools of SOC due to different soil management practices have been studied mainly in cooler and temperate regions of the world, but such studies in tropical and subtropical regions of the world are very few (Kumari *et al.* 2011).

As a nutrient reservoir, there is a universal acknowledgement that SOM is the major indigenous source of considerable amount of nutrients. The SOM is highly linked to the desirable level of physical, chemical and biological properties and closely associated with the soil productivity. To maintain and buildup the soil organic matter levels, the input rate must be higher and at least equal to the organic matter decomposition rate. It is economically very significant as it regulates energy and nutrient recycling in biosphere. Furthermore, as a part of global C reservoir, SOM interact with the atmosphere and through affecting its CO_2 content, it influences the overall state of the environment. The quantity and quality of organic matter representative of humic and non-humic substances are greatly influenced by vegetation (Bhudhilal and Rao, 1977), climate (Gupta *et al.,* 1982), soil reaction (Ghosh and Schnitzer, 1980) and biological conditions.

The amount of SOM in soils of India is relatively low (0.1 to 1.0%) and typically less than 0.5%. The maintains of organic carbon in tropical soils up to a desirable level of 0.5- 1.0 per cent is extremely important for sustainable crop production (Swarup and Wanjari, 2000). In the tropics, SOM determines the fertility and productivity of soils, especially when these are highly weathered, with small or no reserves of nutrients and are managed without any external inputs of organic or inorganic fertilizer (Feller and Beare, 1997).

Williams *et al,* (2004) emphasized that soil is a potential C sink and could offset rising atmospheric carbon dioxide levels. A reduction in the rate of CO_2 accumulation in the atmosphere can be achieved through enhancement of long term carbon sequestration in the terrestrial biosphere through proper maintenance of SOM. The capacity of soils store and sequester C will depend on the rate of C inputs from plant productivity relative to C exports controlled by microbial decomposition. Balance fertilization for high intensity cropping system with NPK fertilizers is found to be more effective in enhancing C in soil, over unbalanced fertilization (Rudrappa *et al.,* 2006). Increased carbon sequestration is obtained by decreasing soil disturbance, enhancing rotational complexity and by a change from monoculture to continuous cropping. It is important to examine these practices in long term studies because of the time required for many of these management practices to significantly change SOC content (Varvel, 2006).

The SOM is composed of series of fractions from very active and passive pools. These fractions act as highly sensitive indicators of soil fertility and productivity. In the sequence of humification process, first the decomposition products of the original plant residues are active fractions. The active fractions include soil microbial biomass, water soluble carbohydrates and it rarely comprise more than 10 to 20 per cent of total SOM (Smith and Paul 1990). It provides most of the readily accessible food for the soil organisms. Microbial biomass represents a significant part of the active SOM pool (Schnurer *et al.*,1985). The subsequent decomposition/synthesis products of humification process are passive fraction of SOM. It includes humus physically protected in clay- humus complexes viz., humin and humic acids. The passive fractions contribute to the colloidal properties of soil, CEC and WHC (Smith and Paul 1990).

The long term fertilizer research is in progress since 1997 at the department of Agricultural Chemistry and Soil Science, Maharana Pratap University of Agriculture and Technology, Udaipur. Under this project very important information has been generated. However, since last 17 years, effect of organic manuring and inorganic fertilization treatments on different organic carbon pools of soil organics was not studied. Therefore present study on Effect of long term application of fertilizer and manure on soil organic carbon pools and yield under maize-wheat crop sequence in *Heplustepts* soils was initiated with following objectives:

- To study the effect of long term application of fertilizer and manure under maize-wheat cropping sequence on passive and active fraction of soil organic matter (SOM) in *Haplustepts*
- To establish relationship between passive and active fractions of soil organic carbon in *Haplustepts*
- To establish relationship between soil organic carbon fractions with yield of maize and wheat crops

2. REVIW OF LITERATURE

Generally two to three crops are being produced annually per unit area under intensive cultivation. This intensive cropping system removes large amount of nutrients from the soils. Increased application of chemical fertilizers and farmyard manure has been the major input in sustaining fertility status of the soils. Continuous application of chemical fertilizers and farmyard manure may have their effect on soil physical, chemical as well as biological properties. These effects can only be monitored through long-term fertilizer experiments. It is therefore imperative to have a close look towards the interrelations among soil organic carbon, active and passive, pools of soil organic matter. This may give a better understanding of processes/dynamics of soil major nutrients in and through the rhizosphere. In this context, a review pertaining to the present investigation on long term effect of fertilizer and manure application is narrated under the following subheads:

2.1 Status of soil organic carbon
2.2 Active and Passive fraction of soil organic matter (SOM)
2.3 Relationship among and between Active fractions and passive fractions of soil organic matter
2.4 Relationship between soil organic carbon fractions with crop yield and soil properties

2.1 STATUS OF SOIL ORGANIC CARBON

The status of SOC depends on climate, tillage practice and land use system. Soil organic matter is center of micro flora, fauna and the root system of higher plants. It serves as a source of energy to all living beings in the soil. It has been proved that nitrogen in the humic acid substances can remain in the soil up to a period of 3000 years. Constant supply of nitrogen is essential and it is the active part of the soil organic matter, namely non-humic matter, can constantly release a trickle of available nitrogen to the crop under ideal conditions. This released-nitrogen from the active part takes care of plant requirement for nitrogen. Soils that contain 5 to 10 per cent of soil organic matter are very easily cultivated and are very fertile. Any increase in the quantity of soil organic matter greatly improves the physical properties of soil.

Application of P had a pronounced effect on the organic carbon content of soil which resulted in enhanced root growth and accumulation of organic residues (Maurya and Ghosh, 1972). Krishnamoorthy and Ravi Kumar (1973) reported that addition of FYM continuously has a desirable influence on the amount of soil organic carbon and its build up in the soil under rainfed conditions. Mani *et al.* (1980) and Udayasoorian *et al.* (1988) also reported similar buildup of SOC under lowland conditions. Phosphorous fertilization also influences root proliferation which increased organic carbon content of the soil (Biswas *et al.,* 1971 and Muthuvel *et al.,* 1979). The relative increase in organic carbon due to FYM can be attributed largely to increased returns of organic materials in the form of crop residues (Rasmussen and Rhode, 1983).

The organic carbon and nitrogen contents of soil under 33 yearof cropping decreased with increasing frequency of fallow than under continuous cultivation. A soil with wheat-fallow rotation is likely to have much higher nitrogen requirement than similar soil subjected to continuous wheat production (Janzen, 1987). Bhriguvanshi (1988) observed a marginal increase in the organic carbon content of the soil due to N addition. Buildup of SOC due to continuous application of N was also reported by Haulin *et al.* (1990) and Patiram and Singh (1993).

Continuous application of FYM increased soil organic carbon content and water holding capacity. To some extent OC content and water holding capacity also increased with N, NP, NPK and lime + NPK treatments (Sarkar *et al.*, 1989). Soil organic carbon levels were studied by Holford (1990) in an eight-year rotation of sorghum (4 years) with lucerne (4 years) and reported that incorporation of sorghum residues raised soil organic carbon much larger than lucerne. These findings showed that continuous additions of organic manures improved the OC content of the soil.

Increased SOC by continuous application of fertilizers and manures reported by several workers (Sharma *et al.,* 1984 and Kukreja *et al.,* 1991). The results of long-term trials at ICAR, Ludhiana (Ustochrepts), Hyderabad and Bhubaneshwar (Tropaquept) and Palampur (Hapludalfs) for 15 years increased soil organic carbon. The increase was most distinct on laterite soils of Bhubaneshwar (Rajendra Prasad and Goswami, 1992).

Kumar and Yadav (1993) reported the favorable influence of continuous application of NPK fertilizers on the organic matter content of the soil. Application of FYM significantly increased the SOC, infiltration rate, water retention, and aggregation and aggregate stability. Application of inorganic fertilizers had a small but statistically significant increasing SOC (Benbi *et al.*, 1998)

Organic matter tended to decrease bulk density and increase infiltration rate. Organic matter tended to delay pH depression, slightly increased pH, available P, exchangeable K, Ca, and Mg, and to a certain extent decreased exchangeable Al and percent Al saturation (Cagmat, 1999).

Long-term fertilizer experiment (1939-1990) was conducted at Canada with two rotation i.e. wheat-fallow and wheat-oat-barley-hay. The inclusion of no fertilizer, fertilizer and farmyard manure, over 51 years showed that OC decreased both in wheat-fallow-nil and with fertilizer treatments but wheat fallow combined with FYM increased organic carbon status of soil. It would lead to a steady state of 2.9 times more C after a period of 60 years (1939), and 26 per cent higher than the native SOC content (Izaurralde *et al,* 2001).

Kanchikerimath and Singh (2001) found that soil organic matter content and soil microbial activities, vital for the nutrient turnover and long-term productivity of the soil, are enhanced by balanced application of nutrients and manure.

Singh *et al*. (2007) was recorded the highest increase in soil microbial biomass C (185.5%) and soil microbial biomass N (220.2%) over its initial value with the addition of FYM.

Wang *et al*. (2008) studied the effect of long term fertilization in brown soil at Beijing, China. The results revealed that long-term application of chemical fertilizer alone decreased soil FPOM-C content, but stabilized MOM-C, and increased soil TOC content.

Zhang Lu *et al.* (2009) in china he studied the content of total organic carbon in black soil, grey desert soil and red soil. Results showed that the TOC contents in 16 years in the control (no fertilizer) in the grey-desert soil significantly decreased by 11.7%, 34.9% and 5.4 percentage points, respectively.

2.2 ACTIVE FRACTIONS OF SOIL ORGANIC MATTER (SOM)

Plant residue is the primary source of SOM formation. Decomposition products are incorporate in soil as passive and active pools of soil organic matter (Stevenson, 1985). In the sequence of humification process, first the decomposition products of the original plant residues are active fractions (Williams, 1914). The active fraction includes Soil Microbial Biomass Carbon (SMBC), Soil Microbial

Biomass Nitrogen (SMBN), Soil Microbial Biomass Phosphorus (SMBP), Water soluble carbon, Water soluble carbohydrates and exocellular enzymes. This active fraction rarely comprises more than 10 to 20 per cent of the total soil organic matter (Smith and Paul, 1990). Microbial biomass represents significant parts of the active SOM pool (Schnurer *et al.,* 1985). This active fraction provides most of the readily accessible food for the soil organism. The size of this pool and its rate of turnover (0.2 - 1.4 years) are related with agricultural management, soil chemical and physical characteristics as well as climatic variables (Gregorich and Anderson, 1985; Insam *et al.,* 1989).

Harrison *et al.,* (1998) envisaged that active pool of organic matter responds significantly to changes in fertilization, changing climate and anthropogenic nitrogen deposition. Soil organic material has a passive component with a slow turnover time and an active component with a fast turnover time. The turnover time of passive soil carbon could be estimated from soil radiocarbon measurements made at depths where little or no active soil carbon is present. Radiocarbon data suggests that active soil carbon has a 25-years turnover time.

Manna *et al.* (2005) reported that the active fractions of SOC, viz., water-soluble carbon and hydrolysable carbohydrates, soil microbial biomass C and N, dehydrogenase and alkaline phosphatase activity, improved significantly with the application of NPK and NPK+FYM. The content of SOC significantly ($p<=0.05$) correlated with SYI and active fractions of SOC, which support better sustainable productivity. Results suggest that current fertilizer recommendations of 100% recommended NPK are adequate for maintaining SOC and its active fractions as well.

Saini *et al.* (2005) reported that the microbial biomass C, N, and P under soybean and winter maize were significantly higher when a combination of *Brady rhizobium japonicum* or *Azotobacter chroococcum* were used and was maximum with 50% recommended fertilizers for along with bio-inoculants and the results suggested that for maximum crop yield only 50% of the required fertilizer might be supplied along with bio-inoculants.

Manna *et al.* (2008) the active pools of SMBC comprised 3.2 to 5.6% of SOC in Vertisols and 1.2 to 5.7% of SOC in Alfisols. WSC comprised 0.80 to 14.1% of SOC in Vertisols and 1.5 to 4.9% of SOC in Alfisols. WS Carbohydrates comprised 15-40.3% of SOC in Vertisols and 10.5 to 25% of SOC in Alfisols. The soil biological activity in terms of SMBC, SMBN can be improved with concomitant increase of water-soluble carbon and carbohydrates by better management practices. Among field crops, legume-based intercropping system (soybean+ pigeonpea and greengram +pigeonpea) restored higher amount of SOC, SMBC compared to double crop in rotation (soybean-wheat cropping system).

Verma and Mathur (2007) observed that the application of FYM @ 20 ton/ha significantly increased the soil microbial biomass carbon, water soluble carbon, water soluble carbohydrates whereas maximum amount of soil microbial biomass nitrogen and dehydrogenase activity was found in 100% NPK + 10 ton FYM /ha treatment and maximum soil microbial biomass phosphorus was observed in 150% NPK treatment compared to sole use of chemical fertilizers integrated use of FYM alone exerted significant effect on the active pools of soil carbon.

Tarinder and Brar (2008) revealed that the Soil organic matter (SOM), soil microbial biomass, C mineralization and dehydrogenase activity were studied in soils under different fertilizer treatments. Application of balanced fertilizer NPK either alone or in combination with FYM maintained active pools of C and N in the surface soil layer (0-15 cm depth). This indicated that the organic pools of C-associated nutrients particularly N may be maintained in rhizosphere zone and thereby sustaining the soil quality and productivity. Improvement of water-soluble carbon and carbohydrates helped in improving soil nutrient dynamics and transformation through biological means. More intensive crop management systems that maintained residue cover provided the greatest benefit towards increasing the quantity of mineralizable nutrients within the active fraction of SOM, as well as increasing C sequestration. Thus, it is clear from the study that a more efficient and integrated nutrient supply strategy is necessary to sustain the long term productivity and soil quality.

Verma and Mathur (2009) studied the effect of integrated nutrient management (INM) on active pools of soil organic matter (SOM) under maize-wheat cropping sequence of a *Typic Haplustept* was studied in a long-term field experiment initiated during kharif 1997 at the Instructional Farm of Rajasthan College of Agriculture, Udaipur. Effect of varying doses of N, NP, NPK with FYM, Zn, S and Azotobacter on active pools of SOM viz., soil microbial biomass carbon, nitrogen and phosphorus; water soluble carbon; water soluble carbohydrates and dehydrogenase activity after 9th year of maize-wheat crop rotation was studied. Application of FYM @ 20 t ha^{-1} significantly increased the microbial biomass carbon (SMB-C), water soluble carbon (WS-OC) and water soluble carbohydrates (WS-CHO), whereas maximum amount of soil microbial biomass nitrogen (SMB-N) and dehydrogenase activity (DHA) was found in 100% NPK + 10 t FYM ha^{-1} treatment and maximum soil microbial biomass phosphorus (SMB-P) was observed in 150% NPK treatment compared to sole use of chemical fertilizers. Integrated use of FYM with chemical fertilizers or use of FYM alone exerted significant effect on the active pools of soil carbon. The C/N ratio was highly and significantly correlated with soil microbial biomass carbon (SMB-C), soil microbial biomass nitrogen (SMB-N), water soluble carbon (WS-OC), water soluble carbohydrates (WS-CHO) and dehydrogenase activity (DHA) under maize crop.

Kumari *et al.,* (2011) observed that continuous application of organic manure alone or in combination with inorganic fertilizer significantly influenced the soil microbial biomass carbon, nitrogen, phosphorus, water soluble carbon, carbohydrates, dehydrogenase activity, the active fraction of soil organic carbon (SOC) was significantly higher in a plot receiving 100% NP over the one receiving only 100% N or control.

From long-term experiment conducted on sandy loam soil of Kanpur (Uttar Pradesh), Venkatesh *et al.* (2013) reported that application of crop residues along with farmyard manure at 5 Mg ha^{-1} and bio fertilizers resulted in greater amounts of active and passive pools of carbon over control and the recommended inorganic (N,P,K,S) treatment, particularly in the system where pulses were included. The highest SMBC was recorded in pigeon pea-wheat followed by maize-wheat-mungbean, maize-wheat-maize-chickpea and was lowest in the maize-wheat system in the surface soil. Among nutrient management practices, significantly higher SMBC was recorded in the organic treatments followed by the inorganic treatments over control.

2.2.1 SOIL MICROBIAL BIOMASS CARBON

The mean soil microbial C, N and P, in the soils of Sonbhadra district of Uttar Pradesh ranged from 250-609 μgCg^{-1}, 27-65$\mu gN\ g^{-1}$ and 12-26 μgPg^{-1}, respectively (Srivastava and Singh, 1991).

Long-term changes in soil microbial biomass carbon (SMBC) were quantified in wheat, wheat-soyabean and wheat-soyabean-sorghum sequences with N fertilizers. Increasing cropping intensity increased SMBC up to 31 cent and SMBC averaged 18 per cent being greater in monoculture, probabh due to greater C input via crop roots and residues in rotation and a shorter fallow (Franzluebbers *et al.,* 1994).

Rochette and Gregorich (1998) revealed that soil microbial biomass carbon was highest under control i.e. 321.8 ppm as compared to fertilizer i.e. 233.4 ppm.

The SMBC contents in the soils ranged from 75.9 to 301.0 ug C g^{-1} with an average of 206.1 pg C g^{-1}, accounting for 1.36-6.24 per cent of the total soil organic C with an average of 3.07 per cent. The SMBN contents ranged from 0.51 to 68.40 ug N g^{-1} with an average of 29.4 pg N g^{-1}, accounting for 0.20-5.65 per cent of the total N in the soils with an average of 3.36 per cent. A close relationship was found between SMBC and SMBN, and they both were positively correlated with total organic C (Zhou-Jian *et al.*, 1998).

Katkar *et al.,* (2011) revelled that the availability of soil microbial biomass carbon were significantly increased with the integrated application of organic manure (FYM @ 10 tonnes/ha) and mineral fertilizers (100% NPK) over control and other fertilizer treatment.

Sofi *et al.,* (2012) the result show that there was significant improvement in the soil organic pools up to 40 of 50 years, there was marked depletion in the carbon stocks under present fertilization practice. At higher altitude significantly higher levels of soil organic carbon (1.16 g kg^{-1}) microbial biomass carbon (1.30 g kg^{-1}) were recorded. Other soil organic pools significantly decreased at the 15-30 cm soil depth; soil organic pool showed a reverse trend.

From long-term fertilizer experiment conducted on Alfisol of Ranchi (Jharkhand), Kumari *et al.* (2013) reported that addition of organic manure alone or in combination with inorganic fertilizers significantly increased the microbial biomass carbon over control.

Liu *et al.* (2013) conducted a long-term fertilizer experiment at Gansu(China) to study the effect of manure and fertilizer on soil organic carbon pools in calcarid regosols and found that microbial biomass carbon (MBC) in organic manure plus inorganic fertilizer treatments was increased by 78-99 per cent over the unfertilized control treatment.

Manna *et al.* (2013) studied the effect of long-term application of manure and fertilizers on the dynamics of soil organic carbon (SOC) pools in soybean-wheat cropping system in a Vertisol of Jabalpur (Madhya Pradesh) after thirty nine cropping cycle and revealed that microbial biomass carbon (MBC) was increased significantly with the application of NPK fertilizers along with FYM at a depth of 0–15 cm as compared to control.

Mandal *et al.* (2013) studied the effects of fertilizer NPK applied alone or in combination with organic inputs of varying nature and composition on soil organic carbon (SOC) fractions under the pigeon pea-wheat cropping system in a *Typic Haplustept* at New Delhi and found that use of FYM, sulphitation press mud along with NPK brought a significant increase in MBC content of surface soil compared with sole NPK.

The results from a long-term experiment on carbon and nitrogen mineralization in rice-rice system in sandy clay loam soil (pH 6.6) of Cuttack (Orissa) indicated that the continuous application of fertilizer combined with FYM increased the organic carbon over the control. The highest content of microbial biomass carbon was observed in NPK + FYM treated soil (Mohanty *et al.*, 2013).

Ingle *et al.* (2014) conducted a long-term fertilizer experiment at Akola (Maharashtra) to study the effect of long-term manuring and fertilization on soil biological properties in sorghum-wheat cropping sequence in Vertisol. The results revealed that soil microbial biomass carbon increased significantly with the combined application of NPK fertilizer + FYM @ 10 tonnes ha^{-1}(278.9 mg kg^{-1}) as compared to control (90.9 mg kg^{-1}).

Zhang *et al.* (2014) studied the effect of organic amendments on soil microbial carbon in Cambisol of Zhangwu (China) and it was found that MBC in the macro aggregates was significantly higher in straw retention (SR) system with incorporation of 9000 kg ha^{-1} chopped corn straw than conventional cropping system with no application of organic manure.

Tamilselvi *et al.* (2015) conducted a long-term fertilizer experiment in Alfisol (*Typic Haplustalf*) at Coimbatore (Tamil Nadu) and found that application of organic manure with chemical fertilizer and organic amendments alone improved the microbial biomass carbon contents.

2.2.2 SOIL MICROBIAL BIOMASS NITROGEN

Jenkinson and Ladd (1981) reported that microbial nitrogen comprises of 3-5 per cent of soil Nitrogen.

Beauchamp (1983) found that application of FYM in combination with inorganic fertilizers resulted in significantly higher soil microbial biomass nitrogen (SMBN) content as compared to the rest of treatments.

The total amount of microbial C and N in soil is generally greater in soils of cooler and wetter regions compared to warmer and drier regions. Studies conducted under both tropical and temperate conditions, have shown the significant build up in microbial biomass C,N and P in soils receiving manure (Collins *et al.*, 1992).

Long term changes in soil microbial biomass nitrogen (SMBN) were quantified in continuous wheat/ soyabean-sorghum sequence with and without fertilizers. Difference in crop management system significantly altered SMBN and the associated mineralizable N levels, which supplies crop with mineral N (Franzluebbers, *et al.*, 1994).

Billore *et al*., (1995) the soil microbial biomass N was underestimated by a factor of 2.6 compared with the results from a fumigation-extraction method, because of heavy N immobilization in the microbial biomass. This was in contrast to results from the forest soils, which did not immobilize N. Simple correlation coefficients indicated a significant positive relationship between biomass N and organic C in the soil and the N concentration in the litter, the main component of organic matter in the soils of the three ecosystems.

Ghoshal and Singh (1995) found that maximum increase in the microbial biomass, due to these inputs was observed under the manure+fertilizer treatment followed, in decreasing order, by manure alone and fertilizer alone. Within individual crop periods the levels of microbial biomass decreased sharply from the seedling to the flowering stage and then increased slightly with crop maturity. The maximum levels of microbial biomass C and P were observed during the summer fallow. The maximum accumulation of microbial biomass N occurred in the early rainy season, immediately after the soil amendments. Microbial biomass C, N, and P were positively related to each other throughout the annual cycle.

Salinas *et al.* (1997) reported that the greater amount of crop residues and N fertilizers provided subtract for maintenance of the longer soil microbial biomass pool and the higher C and N mineralizable in the 0 to 200 mm depth during the growing season.

In Kenya’s central highlands, soil microbial biomass C and N has been reported to be significantly high in productive acid soils (Murage *et al.*, 2000). Liebig *et al.*, (2002) has also observed significantly higher microbial N content in zero and low rate N treatment as compared to high rate N treatments.

Long-term changes in soil microbial biomass nitrogen (SMBN) were quantified in wheat, wheat-soyabean and wheat-soybean-sorghum sequences with N fertilizers (Franzluebbers *et al.,* 1994). The greater amount of crop residues and N fertilizers provided substrate for maintenance of the larger soil microbial biomass pool and the higher C and N mineralization in the 0 to 200 mm depth during the growing season (Salinas *et al.,* 1997). Soil microbial biomass nitrogen and carbon play an important role in nutrient cycling in soils (Oliveira *et al.,* 2001).

Manna *et al.* (2007) found that the Soil microbial biomass nitrogen (SMBN) were greater in NPK+FYM and NPK+lime as compared to other treatments, and also suggested that continuous use of NPK+FYM would sustain yield in a soybean-wheat system without deteriorating soil quality.

Liu-shoulong *et al.,* (2010) revealed that geostatistics were used to analyze the spital variability of soil microbial biomass nitrogen in a hilly red soil and the result revealed that the significant negative correlation of soil microbial biomass nitrogen elevation observed.

Katkar *et al.,* (2011) revelled that the availability of soil microbial biomass nitrogen were significantly increased with the integrated application of organic manure (FYM @ 10 tonnes/ha) and mineral fertilizers (100% NPK) over control and other fertilizer treatment.

Manna *et al.* (2013) studied the effect of long-term application of manure and fertilizers on the dynamics of soil organic carbon (SOC) pools in soybean-wheat cropping system in a Vertisol of Jabalpur (Madhya Pradesh) after thirty nine cropping cycle and revealed that microbial biomass nitrogen (MBN) was increased significantly with the application of NPK fertilizers along with FYM at a depth of 0–15 cm as compared to control.

The results from a long-term experiment on carbon and nitrogen mineralization in rice-rice system in sandy clay loam soil (pH 6.6) of Cuttack (Orissa) indicated that the continuous application of fertilizer combined with FYM increased the organic carbon over the control. The highest content of microbial biomass nitrogen was observed in NPK + FYM treated soil (Mohanty *et al*., 2013).

2.2.3 SOIL MICROBIAL BIOMASS PHOSPHORUS

Phosphorus is the second major nutrient in practical agriculture, being fairly immobile, becomes unavailable for plant uptake through conversion to insoluble form. Under such circumstances, microbial biomass although relatively small, can be an important source of P for microorganisms. Measurement of P content of soil biomass is essential for an accurate assessment of its important in P cycling crop nutrition (Rao and Khera 1995).

Microbial biomass phosphorus is a significant source of P to plants and its agricultural effectiveness could be modified by the addition of limestone, Fertilizer and organic amendment (He *et al,* 1998). The role of microorganisms in P turnover and P availability was found to be more important in the organic system (Fliessbach *et al.,* 1998). Eleven red soils varying in land use and fertility status were used to examine the effect of land use on microbial biomass-P and results revealed that microbial biomass-P in the soils ranged from 4.5 mg P kg^{-1} to 52.3 mg P kg^{-1} (Chen, 2003).

Santhy *et al.* (2004). Revealed that the amount of microbial biomass P was found to be the highest for the combined application of 100% NPK + farmyard manure (FYM) and declined with increased rates of fertilizer application.

Verma and Mathur (2009) observed that maximum soil microbial biomass phosphorus was observed in 150% NPK treatment compared to sole use of chemical fertilizers integrated use of FYM alone exerted significant effect on the active pools of soil carbon.

2.2.4 WATER SOLUBLE CARBON

Lysimetric observations (Herbauts, 1980) in deciduous forest soils showed that the leaching of water-soluble organic carbon through the moder humus of weakly podzolic soils was approximately twice of that through the mull humus of a leached brown soil.

The soluble organic matter in composted manure contains labile carbon that may stimulate microbial activity and the effects of water-soluble organic carbon on nitrogen mineralization. Three soils with textures varying from 3 to 54 per cent clay were amended with water extracts from composted dairy manure (0-80 mg C/kg soil) and incubated for 11 weeks at 23 ^{0} C. Water-soluble organic C additions enhanced net N mineralization only in the soil containing the higher amount of clay. Negative impact was observed by water-soluble organic carbon in the composted manure and had little effect on net N mineralization, in coarse textured soils (Liang *et al,* 1995).

Water-soluble organic carbon (Huang and Schoenau, 1996) was determined monthly from May to October 1994 in the forest floor horizons (L, F, H) and mineral soil (Ae). Results showed that L horizon had highest WSOC concentration i.e. 425 to 8690 ppm), followed by the F, H and Ae horizons. Water-soluble organic C in the Ae horizon was derived from the overlying organic layer by leaching. In laboratory incubation study, the rate of WSOC released decreased continuously. The rate of WSOC release decreased slightly early in the growing season, but increased later as new litter fall reached the forest floor. This indicates that litter fall is a major factor in the replenishment of WSOC.

Water soluble carbon appears to be the intermediate organic substrate for soil microorganisms (McGill *et al.*, 1986). Changes in water soluble carbon which is the most liable and mobile form of SOC, have received much less attenuation. Concentration of water soluble and bio-available SOC have reported to be high in agricultural soils (Boyer and Groffiman, 1996).

Water soluble organic carbon was studied by (Tao and Lin, 2000) from the Yichun River Basin, China and the contents of the WSOC in a wetland soil and the A horizon of an upland soil were found to be higher than those in the AB horizon of the upland soil and a river bottom sediment. Both parameters correlate positively with the humic substances content of the soil.

Xu *et al.* (2002) found that the cool water soluble organic carbon (CWSOC) and hot water soluble organic carbon (HWSOC) in soil under Chinese fir forest account for 1.11 per cent and 1.60 per cent of total soil organic carbon (TSOC), and 0.70 per cent and 1.19 per cent under mason pine forest soil, respectively. The CWSOC under Chinese fir forest was closely related to SOM and soil microbial biomass carbon r = 0.474* and 0.482* respectively, HWSOC, however, has little to do with SOM, SMBC and dehydrogenase activities.

Singh *et al.*, (2003) reported that the application of 100 per cent NPK + FYM for about twenty eight years increased water soluble carbon by about 32 to 41 per cent compared to the plot receiving only 100 per cent NPK. The water soluble carbon represents less than one per cent of the total C in soil. Liming had marked effect on this carbon fraction.

Yagi *et al.*, (2005) revealed that water soluble carbon reflects the initial stage of degradation of organic residue in the soil. Nitrogen fertilization at the rate of 120, 180 and 80 kg N ha $^{-1}$ in the corn-corn cropping system increased water soluble carbon content by about 15,24 and 12 per cent, respectively

Scaglia and Adani, (2009) found that the water soluble carbon biodegradability depend up on the both land use and management practice, and these results suggested the biodegradability test as suitabl method to characterize water soluble carbon and provide useful information to soil fertility.

Khursheed *et al.* (2013) conducted an experiment at Srinagar (J&K) to study the effect of organic sources of nitrogen on soil carbon pools and reported that application of poultry manure and vermicompost along with inorganic sources of NPK increased water soluble organic carbon significantly as compared to control.

From long-term fertilizer experiment conducted on Alfisol of Ranchi (Jharkhand), Kumari *et al.* (2013) reported that addition of organic manure alone or in combination with inorganic fertilizers significantly increased water soluble carbon over control.

Manna *et al.* (2013) studied the effect of long-term application of manure and fertilizers on the dynamics of soil organic carbon (SOC) pools in soybean-wheat cropping system in a Vertisol of Jabalpur (Madhya Pradesh) after thirty nine cropping cycle and revealed that water soluble carbon (WSC) was increased significantly with the application of NPK fertilizers along with FYM at a depth of 0–15 cm as compared to control.

2.2.5 WATER SOLUBLE CARBOHYDRATES

Carbohydrates are important component of the soil organic matter, commonly accounting for 5 to 20 per cent of soil organic matter. Carbohydrates comprise 50 to 70 per cent of the dry weight of most plant tissues and hence the most abundant material added to soil in the form of plant residues. These are also important constituents of soil microorganisms, being present both as extracellular and intracellular components (Lowe, 1978).

The effect of N and K fertilization on WSC was generally non-significant. Peaks of WSC content occurred in early spring and autumn, with levels generally higher in the cooler months and carbohydrates serve as building blocks for humus synthesis (Stevenson, 1982).

Changes in the organic matter and carbohydrate content of a silt loam were examined after 10 years of applying solid cattle manure; results indicated that continuous intensive cropping over the years significantly reduced acid hydrolysable carbohydrate carbon. (Riffaldi *et al.*,1994).

Silva *et al.*(2008) reported the quantify water soluble carbohydrates (WSCH) concentration present in sugarcane that nullifies ethanol production, and to evaluate the effects of WSC content on nutritive value and other fermentative characteristics of sugarcane silage. WSC resulted in negative linear effects on dry matter, WSC concentration, and in vitro digestibility of dry matter, but with linear increase for acid detergent fiber, neutral detergent fiber, and lignin concentration.

From long-term fertilizer experiment conducted on Alfisol of Ranchi (Jharkhand), Kumari *et al.* (2013) reported that addition of organic manure alone or in combination with inorganic fertilizers significantly increased water soluble carbohydrates over control.

Manna *et al.* (2013) studied the effect of long-term application of manure and fertilizers on the dynamics of soil organic carbon (SOC) pools in soybean-wheat cropping system in a Vertisol of Jabalpur (Madhya Pradesh) after thirty nine cropping cycle and revealed acid hydrolysable carbohydrates (AHC) was increased significantly with the application of NPK fertilizers along with FYM at a depth of 0–15 cm as compared to control.

2.2.6 DEHYDROGENASE ACTIVITY

Dehydrogenase activities were highest in the fertilized soil, intermediate in the manured soil and lowest in the unmanured soil (Eiland, 1980). Application of manures generally increased activity of dehydrogenase but depressed that of nitrogenase in clay loam and sandy soil (El-Shinnawi *et al.,* 1988). Riffaldi *et al.* (1994) showed that dehydrogenase activity was longer in soils from maize fields, which has been fertilized for 40 years in comparison to native grassland soil. Soil dehydrogenase activity declined with increasing soil pH (Kumar and Kapoor, 1995).

The effects of farmyard manure applied at 0, 4, 8 and 16 t ha^{-1} on microbial biomass C, N turnover of P and the activities of dehydrogenase were studied in a Typic Haplusterts under a soyabean-wheat system in Madhya Pradesh, India. At 4 t ha^{-1} FYM application, the microbial biomass increased to its maxima but further additions of FYM reduced rates of biomass turnover. The N and P contents and microbial biomass were higher under soybean than under wheat crop. Enzymes activities were positively correlated with biomass N and P. There was significant correlation between soil organic carbon and microbial biomass C, N and dehydrogenase activity (Manna *et al.,* 1996).

Application of farmyard manure increased dehydrogenase activity closely followed SMBC and there was a close linear correlation between SMBC and dehydrogenase (r= 0.95) (Dinesh *et al.,* 1998). Soil enzyme activities of dehydrogenase were distinctly higher in the organic systems *i.e.*41.5, 58.8, and 84.6 µ g triphenyl Formazon g^{-1} 6 h^{-1} under control and conventional with manure and organic treatments, respectively (Fliessbach *et al.,* 1998).

The soil dehydrogenase activity was significantly greater with wheat straw amendment and application of nitrogen fertilizers of dehydrogenase. Dehydrogenase activity, as a measure of soil microbial activity, is strongly influenced by the presence of nitrate, which serves as an alternative electron acceptor resulting in low activities (Sneh *et al,* 1998). Dehydrogenase activity was lower in soils that had received the largest amounts of fertilizers and further decreased in the absence of lime in 20 years of long-term fertilizers experiments (Simek *et al.*, 1999).

The activity of soil microorganisms is strongly linked to the activity of enzymes and soil management i.e. crop rotations, fertilization, tillage and crop residue placement strongly influences activity of soil enzymes (Klose *et al.,* 1999).

In the absence of lime, the effect of largest total fertilizer application was to reduce significantly the dehydrogenase activities in all four soils. This suggests that dehydrogease was highly sensitive to the inhibitory effects associated with large fertilizers additions (Simek *et al.,* 1999). The increase in macro pores, ranging from 50 to 500 u,m, in soils treated with organic fertilizers was mainly due to an increase in elongated pores, which are considered very important both in soil-water-plant relationships and in maintaining a good soil structure. Organic treatments stimulated dehydrogenase activity probably due to an enrichment of soil organic matter (Marinari *et al.,* 2000).

Dehydrogenase activity as influenced by continuous application of fertilizers and farmyard manure was monitored during 1972-92 in clay loam soils at Coimbatore, Tamil Nadu, India. Results indicate that FYM addition stimulates soil enzyme activity. Enhanced activity of soil enzymes upon addition of graded doses of NPK implies that continuous addition of inorganic fertilizers for 20 years has no marked detrimental effect on the enzyme dynamics of the soil (Singaram and Kamalakumari, 2000). Application of farmyard manure along with the recommended dose of fertilizer registered highest dehydrogenase activity in a medium black Vertic Ustochrept soil (Sriramachandrasekharan, 2002). Studies (69 years) conducted to investigate effects of long-term management practices P, NP, NPK, and NPK plus lime in silt loam soil indicated that dehydrogenase was significantly higher in the soil treated with cattle manure (Parham *et al.*, 2002).

Generally the enzyme activities in the soil are closely related to the organic matter content. The application of balanced amounts of nutrients and manures improved the organic matter and MBC status of soils, which corresponded with higher enzyme activity. It has been reported that the increase in dehydrogenase activity and microbial biomass were proportional to the addition of number and amount of nutrients. Dehydrogenase activity is influenced more by the quality than by the quantity of organic matter incorporated into soil. Thus, the stronger effects of FYM or sulphur on dehydrogenase activity might be due to the more easily decomposable components of crop residues on the metabolism of soil microorganisms (Mandal *et al.,* 2007).

Bhattacharyya *et al.* (2008) the application of NPK+FYM showed the highest levels of soil microbial-biomass C and dehydrogenase activity and the results reveal that current mineral-fertilizer recommendations are inadequate, whereas annual application of FYM along with NPK fertilizers sustains yield and soil productivity.

Katkar *et al.,* (2011) revelled that the availability of dehydrogenase activity were significantly increased with the integrated application of organic manure (FYM @ 10 tonnes/ha) and mineral fertilizers (100% NPK) over control and other fertilizer treatment.

2.2.7 CARBON MINERALIZATION

Incubation of the soil for 120 days with farmyard manure and wheat straw increased organic carbon content of soils by 104.4 and 66.1 per cent, respectively, over untreated un-incubated soil. Incubation without organic matter addition decreased organic carbon content by 26.6 per cent. Narrow C: N ratio material i.e. FYM caused considerable mineralization of C while wide-ratio materials i.e. wheat straw caused considerable immobilization of nitrogen, particularly during early stages of incubation. Additions of nitrogen fertilizer may therefore be necessary where organic materials are applied. Mineralization or immobilization patterns were analogous throughout the incubation period (Somani and Saxena, 1982).

Three-year field studies carried out by Uwe (1986) on carbon mineralization and its relationship to total annual mineralization in a loess chernozem during the period of vegetative inactivity from November to February increased in the order fallow (control), no-manure and farmyard manure treatments. The results revealed that the C mineralization ranged from 0.09 to 1.92 t ha^{-1} from the fallow to the farm yard manure treatment and the organic matter mineralized amounted to about 10 per cent of the total annual mineralization.

The effects of crop rotations and various cultural practices on SOM quantity and quality in a clayey Black Chernozem with a thin A horizon were determined by Campbell *et al.* (1991) in a long-term study, C respiration increased especially in the 7.5 to 15 cm depth with increasing frequency of cropping and with the inclusion of legumes and hay crop in the rotation.

Salinas *et al.* (1997) reported that the greater amount of crop residues and N fertilizers provided substract for maintaince of the longer soil microbial biomass pool and the higher C and N mineralizable in the 0 to 200 mm depth during the growing season.

Torbert *et al.* (1997) evaluated the effect of tillage intensity on carbon mineralization on a vertisol. The tillage intensity increased C mineralization and C turnover in the surface soil and indicated that intensively tilled soil had a greater capacity for C mineralization and reductions in soil organic C levels compared to less intensively tilled systems.

Higher carbon mineralization was observed in less fertile soils and vice versa. One ha of agricultural soil can release about 3 to 5 t carbon of organic matter during the vegetation period. Three categories of soils can be Identified from carbon minerealization point of view: soils with low intensities of carbon mineralization (below 0.03 g kg^{-1} as CO_2 within 14 days), soil with medium intensities (0.03 - 0.07g kg^{-1} C as $C0_2$ within 14 days), soil with high intensities (above 0.07g kg^{-1} C as CO_2 within 14 days). Map of carbon mineralization in Slovakian agricultural soils was created with the help of Geographical Information System (Bielek, 1998).

Organic amendments (manure and compost) were mixed with a soil: sand blend at 2 per cent by dry weight and blends were incubated at 12 per cent moisture for 24 weeks at 25°C. The mineralization of manure C averaged 35 per cent while compost C mineralization averaged only 14 per cent of initial C content (Hartz *et al,* 2000).

Alverez and Alverez (2000) reported that as the incubation time increased the contribution of carbon mineralized from resistant pool increases. Potentially mineralizable C was enhanced in EC (two time ambient CO_{2-} chamber) relative to the average of AC (ambient CO_{2-} chamber) and NC (no CO_2- in chamber) by 19 percent in 0- 5 cm and 24 percent in 5-15 cm depth (Williams, *et al.,* 2004).

Jurcova *et al.* (2001) observed that increase in clay content decreased C mineralization while increasing sand fractions increased it.

The carbon mineralization rate was greater in macro-aggregates than in micro-aggregates and were co related significantly with particulate organic matter C ($r= 0.67$, $P \leq 0.01$) Nitrogen – phosphorus – potassium + FYM improved overall soil aggregation (Manna *et al.,* 2005)

Garcia Pausas *et al.,* (2008) reported the large amount of soil carbon (C) is stored in subsurface soils, most studies on soil C dynamics focus on the upper layers. The aim of this study is to assess the factors that regulate Carbon mineralization in mountain grassland soils under standard laboratory conditions to compare regulation mechanisms at surface and subsurface horizons. For this purpose soil samples of surface and subsurface horizons from 35 locations were incubated under laboratory conditions, CO_2 efflux rates were measured and microbial biomass C (MBC) and net N mineralization were determined.

2.3 PASSIVE FRACTIONS OF SOIL ORGANIC MATTER

The subsequent Decomposition/synthesis products of humification process are passive fraction of soil organic matter consisting of stable materials remaining in soil for hundreds or even thousands of years. This fraction includes humus physically protected in clay-humus complexes Viz. humin and humic acids. The passive fraction accounts for 60 to 80 per cent of the organic matter in moist soils and its quality is increased or diminished only slowly. The passive fraction contributes to the colloidal properties of soil cation exchange capacity and water holding capacity (Smith and Paul, 1990). The important components that make up passive fraction of organic matter are humic acid, fulvie acid and humin. Basically these three are similar but they differ in molecular weight, ultimate analysis and functional groups (Swaby, 1980).

The quantity and quality of organic matter representative of humic and non humic substances were greatly influenced by vegetation (Palaniappan, 1975; Bhudhilal and Rao, 1977), climate (Mukhopadhyay *et al.*, 1982; Gupta *et al.*, 1982), soil reaction (Shindo *et al.*, 1978; Ghosh and Schnitzer, 1980) and biological condition. Soil and crop management systems accentuate humification and increase the passive fraction of soil organic matter (Lal and Kimble, 1995).

Helal (2007) result showed a high buffering capacity of the humic substances and indicated that these substances behave as weak-acid polyelectrolytes, fulvic acid was found very different from humic acid and humin in composition and reactivity.

Kumari *et al.* (2011) observed that continuous application of organic manure alone or in combination with inorganic fertilizer significantly influenced the humic fraction, carbon content in humic and fulvic acid fraction was generally higher under 100% NPK + FYM as compared to other treatments, however fulvic acid was higher than humic acid in all the treatment except in 100% NPK + lime.

2.3.3 HUMIN

Humin is dominant fraction of the organic matter; it increases from 62 per cent of organic matter (by weight) at the surface to 70-80 per cent at 2 m depth (Brenner *et al.,* 1978) which characterized the humus is in soil of widely different climatic zones of India. The humus content was found to be highest in pine forest Ustifluvent of Morni hills of Haryana and the lowest in Tripura under maize-wheat rotation. The humin fraction was pre dominant in those soils and constituted 18.5 to 57.6 per cent of total carbon in this form.The humin content of these soils was positively correlated with the exchangeable Ca and CEC of soils.

Usha and Jose (1984) reported that the humic acid accounted for 28.28 per cent of organic matter. Fulvic acid accounted for 36.51 per cent of total organic matter. Humin fraction accounted for 35.21 per cent of soil organic matter.

Yagi *et al.,* (2003) observed that carbon-humin fraction represents about 58 per cent of SOM, while HA-C fraction showed predominance over FA-C fraction. These workers showed a decline in the C-humic acid with use of vermicompost. Lime application, however, showed no effect on total organic matter. Waiker *et al.,* (2004) revealed that high altitude and high rain fall soils have large accumulation of humin and fulvic acid as compared to humic acid.

Lhadi *et al.* (2006) Suggested that the composting process preceded unhindered throughout the degradation of easily degradable materials like hemicellulose, and that of the rather less degradable cellulose and lipids, and the concentration of recalcitrant material, *i.e.* a ligno-humic (LU) fraction. i.e. humin fraction.

2.3.1 HUMIC ACID

Humification of organic matter, in general, proceeds in the soils which develop on base rich rocks resulting in the formation of humic acid (HA) type substances. Podzolic soils on the other hand, have fulvic acid (FA) type of humus but almost similar in characteristics with HA (Kononova *et al.,* 1966). Humic and Fulvic acid bound nutrients are the most important fractions of passive pool of nutrient and soil organic carbon whose improvement helps in nutrient restriction in soil for high yields. He further concluded that the findings of some long term experiments have shown a corresponding increase in the HA and FA content in manured plots.

The highest humic acid carbon (average of all the treatments) was recorded in Badami sandy soil (15 per cent) followed by Bangalore red sandy loam (8.7 per cent), Bijapur black soil (7.8 per cent) and Belgaum laterite soil (6.9 per cent). The extractable fulvic acid carbon also showed the same trend as shown by the humic acid carbon and the accumulation at the end of 20 weeks incubation was 60.8, 34.7, 18.3

and 14.0 per cent in Badami, Bangalore, Bijapur and Belgaum soils, respectively. Significant accumulations of organic, HA and FA acid carbon were observed in the straw, N and P supplemented soils at the end of the 20 weeks period as compared to the control (Rao, 1995).

Long-term application of chemical and organic fertilizers increased the number of soil microorganisms and contains of humic acid, fulvic acid and humin in the cultivated soil horizon and the ratio of HA/FA.

Sharma *et al.,* (1998) found that the treatments receiving chemical fertilizer alone, humus fraction were highest under 150% NPK; the addition of root residues consequent to higher biomass yield might have produced more amount of humus fraction.

One decade of tillage and nitrogen fertilization increased the humic and fulvic fractions. The highest of fulvic acid contents was found in combination of minimum tillage and 100 kg N ha^{-1} as the nitrogen fertilization tended to increase the humification degree as mentioned by Sarno *et al.* (1999).

A study by Santhy *et al.* (2001) on the status and content of humic and fulvic acid fractions of calcareous sandy clay loam soils with 100 % NPK, 100 % NPK + FYM @ 10 t ha^{-1} and control revealed that humic and fulvic acid content was 0.180 and 0.075; 0.210 and 0.115 and 0.05 and 0.030 per cent of SOM after finger millet, was 0.170 and 0.076; 0.210 and 0.085 and 0.115 and 0.045 per cent of SOM after maize and was 0.180 and 0.108; 0.230 and 0.133 and 0.128 and 0.055 per cent of SOM after cowpea, respectively.

Waiker *et al.,* (2004) reveled that there was a distinct effect of the major environmental factors namely rainfall and altitude, on the distribution of soil humus into humin, humic acid and fulvic acid fraction as well as the HA:FA ratio.

Gathala *et al.,* (2007) found that contents of humin,humic acid and fulvic acid in the soil significantly increased with the application of fertilizer and farm yard manure.

Manna *et al.* (2013) studied the effect of long-term application of manure and fertilizers on the dynamics of soil organic carbon (SOC) pools in soybean-wheat cropping system in a Vertisol of Jabalpur (Madhya Pradesh) after thirty nine cropping cycle and revealed that humic acid was higher in NPK + FYM treatment.

Results from the long-term fertilizer experiment conducted on an Inceptisol of Jagtial (Andhra Pradesh), Srilatha *et al.* (2013) revealed that the content of humic acid increased with increased levels of fertilizer application over control, respectively and higher content of humic acid and fulvic acid were recorded under 100% NPK+FYM followed by 150% NPK and in fallow treatment.

Song *et al.* (2014) studied the impact of long-term fertilization on soil humic substances under wheat-maize system in Gleyic Cambisols of North China and found that humic acid were increased significantly in the treatment when inorganic fertilizers were applied along with manure compared to application of NPK alone.

2.3.2 FULVIC ACID

The fulvic acid content is higher in the lower horizons. Generally the fulvic acid accumulation increases, but the humic acid decreases with the decrease in pH. Both fulvic acid and humic acid contents are usually higher in clay-enriched horizons (Sattar, 1987).

Excess moisture content and leaching in the region causes impoverishment in base supply, particularly of calcium, and consequent alteration in the qualitative composition of humus, with a predominance of fulvic over humic acids, a tendency reinforced by 150+210+210 N+P+K and 300+420+420 N+P+K + 40 t ha^{-1} FYM fertilizer variants (Senkiv *et al.*,1989). The tilled soil had the largest fraction of fulvic acid, relative to total soil C (Stearman *et al.*,1989).

Clayey soil holds a larger amount of organic matter and has more fulvic acid than humic acid throughout the profile. In the sandy soil, the reverse applies to the surface horizon, with equal amounts of humic and fulvic acids in lower horizons. The humic acid was about half as reactive as the fulvic acid in both soils. Fulvic acid is therefore the main source of charge in the clayey soil, but in the surface horizon of the sandy soil, humic acid contributes to more charge. The soils have low effective cation-exchange capacity values, which decrease with depth and depend primarily on the content of organic matter (Mendonca and Rowell, 1996).

Humus Conservation in soils is favourably influenced by N fertilization through maintenance of equilibrium between humification and mineralization processes where organo-mineral fertilization of cultivated soils increases the fertility by accumulation of organic matter (Tianu, 1997). The concentration of humic and fulvic acid regardless of the treatments. Wang and Zang (1998), observed an appreciable increase in SOM with the application of organo materials viz., compost and maize straw resulting in the pigment ratio (E_4:E_6) of humic acid after seventeen years of field experimentation.

Application of 40 m^{3}compost either alone or in combination with mineral fertilizers for about eleven years resulted in significant increase in carbon content of all organic matter fractions (Rochette and Gregorich 1998). Further, the application of compost with mineral fertilizer supplied greather amout of passive pools of SOC to the surface layer.

The fulvic acid is more acidic than humic acid due to high content of carboxyl group. Result of long term fertilized soils have indicated that frequent increase in SOM content could be attributed to resistance of HA fraction to microbial degradation (Filip and Kubat, 2001).

Long term application of organic fertilizers for considerable time results in increase of total humus and humic acid content and decline in fulvic acid while the use of mineral fertilizers alone results in decline fulvic acid content in the humus (Filon and Shelar, 2002). Thakre and Ravankar (2004) reported the long term effect on fertilization on fractionation of organic matter and found that OM, FA, HA content showed positive significant relationship with grain and fodder yield of sorghum.

Zhang and He (2004) reported improvement in the quality of SOM, characteristics by HA and FA ratio of 0.8 in the first fifteen years with gradual increase in the subsequent year in long term fertilizer field experiment.

Yagi *et al.*, (2005) reported 17 and 30 per cent less FA-C and HA-C, respectively in the 20 to 40 cm soil layer as compared to surface layer. In highly weathered tropical conditions, evolution of the effects of deforestation and subsequent arable cropping on the qualities and quantitative transformation of the humic pool of the soil at three locations in Nigeria. Cultivation reduced the humic pool in the order: Acetone –soluble hydrophobic fraction (HF) > humic acid (HA) > humin (HU) > Fulvic acid (FA), but not to the same degree at all three sites.

Manna *et al.* (2013) studied the effect of long-term application of manure and fertilizers on the dynamics of soil organic carbon (SOC) pools in soybean-wheat cropping system in a Vertisol of Jabalpur (Madhya Pradesh) after thirty nine cropping cycle and revealed that fulvic acid was higher in NPK + FYM treatment.

Results from the long-term fertilizer experiment conducted on an Inceptisol of Jagtial (Andhra Pradesh), Srilatha *et al.* (2013) revealed that the content of fulvic acid increased with increased levels of fertilizer application over control, respectively and higher content of humic acid and fulvic acid were recorded under 100% NPK+FYM followed by 150% NPK and in fallow treatment.

Song *et al.* (2014) studied the impact of long-term fertilization on soil humic substances under wheat-maize system in Gleyic Cambisols of North China and found that fulvic acid were increased significantly in the treatment when inorganic fertilizers were applied along with manure compared to application of NPK alone.

2.4 RELATIONSHIP BETWEEN SOIL ORGANIC MATTER POOLS

The application of manures and fertilizers significantly increase nutrient levels (N'Dayegamiye, 1990) and plant crop response to mineral fertilizers measured in subsequent years, (N'Dayegamiye, 1996).

Vance *et al.* (1987) observed a close linear relationship between biomass carbon and SOC with the regression accounting for 98.6 per cent of the variance in the data. Microbial biomass N ($r = 0.98$) and P ($r = 0.80$) was correlated significantly with microbial biomass carbon in a long term experiment (Manna *et al.*, 1996). Soil organic carbon also showed a positive correlation with biomass C ($r = 0.66$, $P < 0.01$) and reason attributed is the application of FYM, which supports-the development of microbial biomass during the entire growing period of crops. The P uptake in the pasture is well correlated with the sum of P. in biomass and soil available pools (He *et al.*, 1998).

Santhy *et al.* (1999) observed high correlation between organic carbon and biomass carbon ($r=0.845^{**}$) in an inceptisol. Further, biomass accorded for 78 per cent variability in biomass N under long-term cropping and manuring.

Verma and Mathur (2007) show relationship among active pools of soil organic matter and C/N, SMBC, SMBN, SMBP. The C/N ratio was highly and significantly correlated with soil microbial biomass carbon (SMBC), soil microbial biomass nitrogen (SMBN), water soluble carbon (WSC), water soluble carbohydrates (WS-CHO) and dehydrogenase activity (DHA) under maize crop.

2.5 RELATIONSHIP BETWEEN SOIL ORGANIC MATTER POOLS WITH CROP YIELD AND SOIL PROPERTIES

Soil biota is considered a very important component involving nutrient cycling. Addition of organics have a positive influence on the biological properties of soils viz., soil microbial biomass carbon, soil respiration and enzyme activities which serves as the biological indicator of soil health (Sarmah and Bordoloi, 1994). It has been well established that the more dynamic characteristics such as microbial biomass, soil enzyme activity and soil respiration respond more quickly to changes in crop management practices than do characteristics such as total SOM (Doran *et al.,* 1996). Thus, understanding of soil biological processes is of greater relevance to assess soil quality.

Bellakki and Badanur (1997) observed that long term application of organic fertilizers in combination with the inorganic fertilizers in dryland conditions increased available phosphorus content of soil significantly compared to fertilizer alone.

Sharma and Gupta (1998) stated that organic carbon content of the soil increased with incorporation of organic residues, while bulk density decreased. In an experiment with maize-wheat cropping system organic carbon, available nutrients and micronutrients of the soil tend to decline with cropping. Application of N, P and K significantly increased organic carbon status of the soil after harvest of both maize and wheat. The available N of the soil increased significantly with N application, whereas a decline in trend occurred with P dressings. Potassium application did not affect the soil available N content. The maximum decline in available P was observed under $N_{120}P_0K_{33.2}$ treatment, whereas a significant increase occurred in P treated plots. The available K status continued to decline in plots receiving increased rates of N and NP fertilizers. The soil available K status was maintained at its initial content in plots receiving fertilizer K with increasing rates of N with or without P.

Sheeba and Chellamuthu (1999) reported that long term application of organic manures increased the soil K. This might be attributed to greater capacity of organic colloids to hold K ions on the exchange sites.

Suresh *et al.* (1999) have also reported significant positive relationship between soil organic carbon and crop yield over the years.

Sheeba and Kumaraswamy (2001) observed a significant decrease in bulk density with increase in organic matter content.

Tiwari *el al.* (2002) found marked difference in the values of organic carbon, available N, P, K and S in soil and crop productivity after twenty-eight years of continuous intensive cropping under various fertilizer and manurial treatments. The inclusions of FYM in the treatment schedule improved the organic carbon status and available N, P, K and S in soil thereby, sustaining the soil health. In a long term experiment which was carried out for 12 years at four locations (Faizabad, Rewa, Raipur and Jabalpur) in rice-wheat cropping system indicated that productivity of rice-wheat system could not be sustained over years even with the application of highest level of NPK (120 kg N, 80 kg P_20_5 and 40 kg K_20 ha^{-1}) in semi-arid ecosystem and led to decline in available NPK and organic carbon status of the soil, while application of FYM had variable effect on the soil characteristics at different locations (Katyal *et al.,* 2003).

From multi-locations long-term fertilizer experiment conducted at Barrackpore, Ranchi and Akola by Manna *et al.* (2005) observed that the content of SOC significantly ($p < 0.05$) correlated with sustainable yield index and active fractions of SOC, viz., water soluble carbon, carbohydrates, soil microbial biomass carbon and nitrogen.

Selvi *et al.* (2005) noticed reduction in bulk density of soil with application of organics alone and in combination with inorganic.

Lal (2006) also reported that crop yields increased by 20–70 kg ha^{-1} for wheat, 10–50 kg ha^{-1} for rice, and 30–300 kg ha^{-1} for maize with every 1 Mg increase in SOC pool in the surface 15 cm layer. Increases in crop yields due to increase in SOC in some soils might result from increase in labile fraction of carbon. Increase in yield with increase in SOC has been reported for many crops including wheat, mustard, sunflower and groundnut.

The higher amount of exchangeable K in treatment where FYM was applied to both the crops may be due to the fact that FYM addition could increase the CEC of soil which was responsible for holding more amount of exchangeable-K and helped in the release of exchangeable-K from non exchangeable pool (Yaduvanshi and Swarup, 2006).

Gathala *et al.,* (2007) found that contents of bulk density and organic carbon in the soil significantly increased with the application of farm yard manure.

The application of balanced amounts of nutrients and manures improved the organic matter and MBC status of soils, which corresponded with higher enzyme activity. It has been reported that the increase in dehydrogenase activity and microbial biomass were proportional to the addition of number and amount of nutrients (Masto *et al.,* 2006). In the present study, a similar trend was also observed. According to Pancholy and Rice (1973), dehydrogenase activity is influenced more by the quality than by the quantity of organic matter incorporated into soil. Thus, the stronger effects of FYM or sulphur on dehydrogenase activity might be due to the more easily decomposable components of crop residues on the metabolism of soil microorganisms. The observation that dehydrogenase activity is less in influenced by mineral nitrogen fertilization is consistent with the studies of Marinari *et al.* (2000).

Mandal *et al.* (2007) showed that easily decomposable components of crop residues may have a strong effect on dehydrogenase activity and metabolism of soil microorganisms. The results obtained in this study indicate that almost 60 years of continual fertilization with mineral and organic fertilizers affected soil properties in different ways. While mineral fertilization and application of cattle slurry had no statistically significant effect on the most of monitored characteristics, FYM improved both the quantity and quality of soil organic matter. Moreover, addition of mineral NPK to compost and even to cattle slurry + straw increased the effect of these amendments on organic C and N content in soil and soil enzyme activity.

Manna *et al.,* (2007) observed that yield and its relationship with soil organic matter fractions in soyabean (Glycine max L.)-wheat (Triticum aestivum L.) cropping system under long-term fertilizer use, observed high correlation between biomass carbon (r= 0.825**) and biomass N (r= 0.865**) in an alfisol and also suggested that continuous use of NPK+FYM would sustain yield in a soybean-wheat system without deteriorating soil quality.

Mishra *et al.,* (2008) organic carbon, pH showed positively correlation in maize (r=0.77**) and (r=0.75**) and in wheat (r=0.63**) and (0.68**) with grain yield and nutrient uptake of NPK by maize and wheat.

Mishra *et al.,* (2008) continuous organic manure application or in combination with inorganic fertilizer, significantly influenced the grain yield, uptake of nutrients, organic carbon, Available N, P, K in soil, SMBC, SMBN, SMBP, water soluble carbon, carbohydrates over 100% NPK. Grain yield uptake of nutrients, SMBC, SMBN, SMBP, water soluble carbon, carbohydrates were significantly higher than 100% NPK applied treatment.

Katkar *et al.,* (2011) highly significant positive correlation of total productivity of biological parameters (soil Microbial biomass carbon (r=0.69**) and nitrogen (r=0.72**) and dehydrogenase activity (r=0.71**). This indicates that total productivity of sorghum-wheat grown in typic haplusteps was enhanced and controlled by these soil parameters.

It is evident that nutrient management practices have significant impact on the mineralizable organic carbon (MOC) as a measure of rate of soil respiration. it was observed that MOC increased with conjoint use of vermicompost, compost, FYM and mineral fertilizers which might be due to increased plant growth and biomass production including greater root biomass and microbial activity. This increases the percentage of easily decomposable organic matter and thus higher evolution of CO_2. The differences in the rate of C mineralization may be attributed to the presence of variable amounts of labile organic C accumulated in response to crop rotation. Therefore, balanced and integrated plant nutrition every year may contribute more labile C substrate to sustain the mineralization process. Similar results were reported by Basak *et al.* (2012) and Nayak *et al.* (2012) where they found that application of organic and mineral fertilizers increased the mineralizable carbon. Mineralization rate was higher in surface soil than sub-surface soil. This may be because of the presence of higher concentration of easily degradable organic carbon which led to a large growth in the microbial population in the surface soil.

From a field experiment conducted at IARI (New Delhi) Moharana *et al.* (2012) studied relationship between different fractions of SOC and yield of pearl millet and wheat. The results revealed that there existed a positive and significant relationship between yield of pearl millet and wheat with different fractions of SOC.

Verma *et al.* (2012) carried out an experiment at Palampur (Himachal Pradesh) to study the change in soil fertility status of maize-wheat system due to long-term use of chemical fertilizers and amendments in an Alfisols. The results revealed that application of lime in combination with NPK raised the soil pH to 6.2 from initial value of 5.5 as well as increased the status of organic carbon under 100% NPK + FYM treatments from initial value of 7.9 to 12.0 g kg^{-1}.They further concluded that the balanced use of fertilizers alone or conjoint use of inorganics with organics sustained the crop yield.

Kannan *et al.* (2013) carried out a field experiment at Manakkadavu (Pollachi) to study the effect of integrated nutrient management on soil fertility and revealed that application of recommended dose of inorganic fertilizer along with vermicompost @ 6 tonnes ha^{-1} improved soil fertility in terms of available N, P, K and organic carbon.

Mandal *et al.* (2013) in sandy loam soil of New Delhi reported a significant and positive relationship of wheat yield with SOC fractions in surface soil.

In silty loam soil of Northern Guinea Savanna (Nigeria), Nkechi *et al.* (2013) observed that cow dung alone or in combination with urea at the rate of 90 kg N ha^{-1} increased soil pH, organic carbon and total nitrogen. Cation exchange capacity increased by 26 per cent with application of cow dung while bulk density was reduced by 18 per cent and total porosity increased by 15 per cent.

Puli *et al.* (2013) studied the effect of long-term fertilization and manuring on soil pH and EC under sorghum-wheat cropping sequence in Vertisol of Akola (Maharashtra) and results indicated that soil pH decreased slightly in soil receiving continuous use of manure and fertilizer due to release of organic acids during decomposition of the organic compounds. They also found that electrical conductivity was highest in the treatment of super optimal dose of inorganic fertilizers (150 % NPK).

Tadesse *et al.* (2013) observed the improvement in plant available water in response to the addition of organic matter is due to improved soil structure and water stable aggregates, as well as moisture retention capacity by increasing the total number of storage pores.

Agarwal *et al.* (2014) studied the effect of continuous cropping and nutrient use on soil health and soil acidity under soybean- wheat cropping system in an acid Alfisol of Ranchi (Jharkhand). The results indicated that continuous application of nitrogen alone as urea reduced the soil pH by 0.8 unit in thirty eight years and also application of lime raised the soil pH by 0.8 unit whereas addition of FYM @ 15 t ha^{-1} stabilized the soil pH and maintained a higher soil organic carbon status.

Manjhi *et al.* (2014) conducted a long-term fertilizer experiment at Ranchi (Jharkhand) to study the effect of integrated nutrient managementon soil fertility status under maize-wheat cropping sequence and reported that application of chemical fertilizer along with organic manure significantly increased soil fertility status in terms of pH, organic carbon, available N, P, K, S and B as compared to its initial values after twenty eight years of cropping.

Sharma and Subehia (2014) studied the effect of long-term integrated nutrient management on soil properties under rice-wheat system in a *Typic Hapludalf.* The results revealed that organic carbon content increased from its initial value of 6.0 to 8.66 g kg^{-1}, CEC from 11.5 to 14.6 cmol(p^{+}) kg^{-1} and available phosphorus from 21.9 to 75.2 kg ha^{-1} through integrated use of organic and fertilizers for the last twenty years while the status of available N and K declined over the years in all the treatments.

Shen *et al.* (2014) in Haplic Calcisol soil of China found that Soil organic carbon significantly and positively correlated with Olsen-P and total P ($P<0.01$).

Simon and Czako (2014) found that dehydrogenase activity is only present in viable cells and reflects the total range of oxidative activity of soil microflora. Addition of NPK to straw combined with cattle slurry evidently increased dehydrogenase activity and straw decomposition compared to treatment without mineral NPK addition.

Sharma *et al.* (2013) reported that the conjunctive use of inorganic fertilizers and organic manure along with biofertilizers and micronutrients gave highest available N, P, K, S and Zn in soil as compared to other treatment combinations. Thus, integrated resource management improved the crop yields, produces quality grain as well as improved the soil fertility.

Tong *et al.* (2014) studied the relationship of organic carbon fractions with yield parameters in a red soil of China and found that significantly positive correlate between maize and wheat yields and all soil organic carbon fractions.

Long term balanced fertilization resulted in increased SOC and carbon sequestration compared to non-treated control. Increases in SOC resulted in improved soil physical properties such as CEC, pH, aggregate MWD, infiltration rate and cumulative infiltration. Integrated use of inorganic fertilizer along with organic fertilizer (100% NPK + FYM) had resulted in maximum infiltration rate, cumulative infiltration and aggregate MWD. Improved soil physical conditions and increase in SOC might have resulted in higher maize and wheat yields. Improvement in SOC and consequently, SOM also improved nutrient uptake of N, P and K significantly in all treatments compared to non-treated control. It can be concluded that balanced application of NPK fertilizers with FYM was best option for higher crop yields in maize–wheat rotation. The SOC pool was significantly correlated with grain yields of maize (R^2 = 0.80) and wheat (R^2 = 0.65). Although, the value for correlation coefficient (R^2) was higher for maize compared to wheat. Crop yields increased by 490 kg ha^{-1} for maize and 110 kg ha^{-1} for wheat with every 1 Mg increase in SOC pool in the 0–15 cm depth under 100% NPK + FYM compared to 100% NPK treatment (Brar *et al.*, 2015).

3. MATERIALS AND METHOD

A field study entitled “**Effect of Long Term Application of Fertilizer and Manure on Soil Organic Carbon Fractions under Maize-Wheat Cropping Sequence in *Haplustepts*”** was conducted at the Agronomy farm, Rajasthan College of Agriculture, Udaipur during 2013-14 and 2014-15. The details of experimental techniques, materials used and criteria adopted for treatment evaluation during the course of investigation are presented in this chapter.

3.1 Experimental Site:

The experimental site is a permanent manurial trial and its layout is on fixed site, at block B2, situated at 24°34N' latitude, 73°42E' longitude and 582.17 about mean sea level. The area comes under sub-humid southern plain (Zone-IVa) of Rajasthan.

3.2 Climate and Weather Conditions:

The climate of the region is subtropical, characterized by mild winters and distinct summers associated with high relative humidity particularly during the months of July to September. The mean annual rainfall of the region varies from 650 to 750 mm, most of which is received in rainy season from July to September. The mean maximum and minimum temperatures are 35.45°C and 17.41°C, respectively. The meteorological data recorded during the course of investigation are presented in Appendix-Ia & b and depleted in Fig. 3.1a & b and 3.2a & b.

3.3 Experimental Soil:

The long term fertilizer experiment was initiated in 1997-98; the composite soil sample was drawn from 0-15 cm depth prior to treatment application in order to ascertain initial fertility status and physico-chemical properties of the experimental soil. Perusal of data presented in Table 3.2 indicated that the soil of the experimental field was sandy clay loam in texture, non-saline and slightly alkaline in reaction. The macro and micronutrient analysis revealed that soil was medium in N, P, K, S and have sufficient level of DTPA extractable Fe, Mn, Zn and Cu.

Table 3.1: Initial physical and chemical characteristics of soil

Characteristics	Soil Content	References

A. Mechanical		
Sand (%)	35.3	International pipette method as described by Piper (1950)
Silt (%)	39.1	
Clay (%)	25.6	
Textural class	Sandy clay loam	Triangular diagram (Brady and Well, 2002)
B. Physical		
Bulk density (Mg m^{-3})	1.48	Core sampler method (Piper, 1950)
Particle density (Mg m^{-3})	2.61	
Porosity (%)	43%	
C. Chemical		
pH (1:2)	8.20	Richards (1954)
EC (1:2) (dS m-1 at 25ºC)	0.48	Richards (1954)
Organic carbon (g kg^{-1})	6.80	Walkley and Black (1947)
Available Nitrogen (kg ha-^{1})	360	Subbiah and Asija (1956)
Available phosphorus (kg ha-^{1})	22.4	Olsen et al. (1954)
Available potassium (kg ha-^{1})	671	Richards (1954)
Available Sulphur (mg kg^{-1})	22.4	Chopra and Kanwar (1976)
DTPA Zn (mg kg^{-1})	3.76	Lindsay and Norvell (1978)
DTPA Fe (mg kg^{-1})	2.52	Lindsay and Norvell (1978)
DTPA Mn (mg kg^{-1})	38.4	Lindsay and Norvell (1978)
DTPA Cu (mg kg^{-1})	3.12	Lindsay and Norvell (1978)

3.4 Cropping History:

On the experimental site, maize-wheat crop rotation followed previously since initiation of long term fertilizer experiment from *kharif* 1997.

Table 3.2: Treatment details :

Tr. No.	Treatment Details
T_1	Control
T_2	100% N of recommended dose to Maize-Wheat sequence
T_3	100% NP of recommended dose to Maize-Wheat sequence
T_4	100% NPK as per soil test
T_5	100% NPK+ Zn
T_6	100% NPK + S
T_7	100% NPK + Zn + S
T_8	100% NPK + Seed treatment with *Azotobacter*
T_9	100% NPK + FYM 10 t ha^{-1}
T_{10}	FYM 10 t ha^{-1} + 100% NPK (- NPK of FYM)
T_{11}	150% NPK of recommended dose to Maize-Wheat sequence
T_{12}	FYM 20 t ha^{-1} to Maize-Wheat sequence

Table 3.3 Recommended dose of Fertilizer (kg ha^{-1})

Crop	N	P_2O_5	K_2O	Zn	S
Maize (PEHM-2)	120	26	25	5	40
Wheat (Raj-4037)	120	26	25	0	0

Fertilizer Source : DAP, Urea, MOP, $ZnSO_4$, gypsum.

Table 3.4: Experimental details:

I.	Crop	Maize & Wheat
II.	Variety	Maize - PEHM-2 Wheat- Raj. 4037

III.	Initial year & Season	2013-14
IV.	Soil samples of Selected year:	(1) 1st year- 2013-14 (After harvest of wheat crop in maize-wheat cropping system) (2) 2nd year- 2014-15 (After harvest of wheat crop in maize-wheat cropping system)
V.	Seed rate	Maize - 20 kg ha^{-1} Wheat – 100 kg ha^{-1}
VI.	Experimental design	RBD
VII.	Treatment combinations	12
VIII.	Replications	4
IX.	Total number of plots	12 x 4 = 48
X.	Plot size	(a) Gross size 20 m x 9 m (b) Net size 18 m x 6.6m
XI	Crop geometry	Maize: (a) Row to row distance – 60 cm (b) Plant to plant distance – 30 cm Wheat: (a) Row to row distance – 22.5 cm
XII	Location	B_2, Agronomy farm ,RCA, Udaipur

3.5 COLLECTION, PREPARATION AND PRESERVATION OF SOIL SAMPLES

Soil samples were drawn from depth of 0-15 cm using core sampler after the harvest of wheat crop in maize-wheat rotation of the year 2013-14 and 2014-15 *i.e.* after 17 years of crop rotation. A part of the sample was preserved under refrigeration and used for analysis of microbiological properties and second part was air-dried, grounded, sieved through 2 mm sieve. Due care was taken to avoid external contamination and samples were stored for chemical analysis.

Table 3.5: Methods used for analysis of soil samples

S. No.	Item of analysis	Method	Reference
1.	pH	pH meter	Jackson, 1973
2.	EC	Conductivity meter	Richards, 1954
3.	Infiltration rate (cm hr^{-1})	Double ring infiltrometer	-
4.	Soil aggregate (mm)	Wet sieving method	Yoder,(1936)
5.	Bulk density (Mg m^{-3})	Core sampler method	
6.	Plant available water	-	Richards, 1954
7.	Organic carbon (%)	Walkley and Black method	Walkley, 1947
8.	Available nitrogen (kg ha^{-1})	Alkaline $KMnO_4$ method	Subbiah and Asija (1956)
9.	Available phosphorus (kg ha^{-1})	Extraction with 0.5 M $NaHCO_3$ at pH 8.5 and development of color with $SnCl_2$	Olsen *et al.* (1954)
10.	Available potassium (kg ha^{-1})	Estimation with 1 N ammonium acetate at pH 7.0 and determined by flame photometer	Richards, 1954
11.	Soil Microbial respiration	CO_2 evolution	Weaver *et al.* (1994)
12.	Microbial biomass C (µg g^{-1} soil)	Chloroform fumigation Extraction method	Vance *et al.* (1987)
13.	Microbial biomass N (µg g^{-1} soil)	Chloroform fumigation Extraction method	Brookes *et al.* (1985)
14.	Microbial biomass P (µg g^{-1} soil)	Chloroform fumigation method	Brookes *et al.* (1982)
15.	Dehydrogenase Activity	-	Cassida *et al.* (1964)
16.	Phosphatases Activity	-	Tabatabai (1982)
17.	Organic Carbon fractionation	-	Stevenson (1965)
18.	Carbon Mineralization	Rubber cork Method	Kukreja *et al.* (1991)

3.6 Soil Organic Carbon Fraction analysis methods:-

(A) Active Pools

(I) Soil Microbial Biomass Carbon: Soil microbial biomass carbon was analysed by Chloroform-Fumigation Incubation Method (Jenkinson and Powlson, 1976; Jenkinson and Ladd, 1981).

a. Fifty gm moist soil samples was taken, fumigate with chloroform (ethanol free) about 18 to 24 hours. Bring the soil samples from dessicators and expose for 2 hours to escape the chloroform from the systems. A fumigated soil of 10 g was placed in 50 ml beaker. Extract with 40 ml of 0.5 M K_2S0_4 through centrifuge at 350 rpm i.e. on rotary shaker for 30-40 minutes and filtered with whatman no. 42. Extract of 8 ml was placed in 150 ml flask with 2 ml of 0.07 N $K_2Cr_20_7$ solution and 70 mg of HgO and 15 ml of mixture of concentrated H_2S0_4 and H_3P0_4 (2:1). Keep for heating at 60 °C temperature on hot plate half an hour then cool it. Dilute with 20-25 ml distilled water. Add 3 to 4 drops of diphenylamine indicator and titrate against 0.01 N ferrous ammonium sulphate and note down the burette reading.

b. Same procedure was followed for non-fumigated soil.

c. SMBC= Fumigated C-Non fumigated C or divided with the help of Kc factor 0.45.

(II) Soil Microbial Biomass Nitrogen: Soil Microbial Biomass Nitrogen was analysed by Chloroform Fumigation Extraction Method (Brookes *et al.*, 1985)

a. For the determination of soil microbial biomass nitrogen (SMBN), in 5 gm of fumigated soil sample, 50 ml of 2 M KCl was added and shaken for half an hour and filtered added a pinch of MgO and 10 to 20 ml distilled water in 10 ml extract. The liberated NH_3 was absorbed in 20 ml of boric acid in 250 ml conical flask distillation process was done with the help of Kelplus instrument. Titration against 0.005 N H_2SO_4 (standardized) changed the colur of boric acid from purple to green which gives NH_4-N (Blank was run simultaneously). Same tube was cooled; a pinch of Devardas alloy and 10-20 ml distilled water was added. The NH_3evolved in this case was absorbed in 20 ml of 2 percent boric acid contained in 250 ml conical flask. Few drops of mixed indicator was added and titrated it against 0.005 N $H_2SO_4$and the volume used gave NO_3-N.

b. Same procedure was followed for non-fumigated soil.

c. SMBN= Fumigated N-Non fumigated N or divided with the help of Kn factor 0.54 (Average absorbance reading obtained from prepared solution of N of different concentrations Viz. 0, 1, 2, 3, 4 and 5 ppm).

(III) Soil Microbial Biomass Phosphorous: Soil Microbial Biomass Phosphorous was analysed by Chloroform-Fumigation Incubation Method (Brookes *et al.*,1982; Srivastava and Singh, 1988).

a. For determination of soil microbial biomass phosphorus (SMBP), in 2.5 gm of fumigated moist soil sample, 50 ml of 0.5 N $NaHCO_3$ solution and a pinch of activated charcoal was added and shaken for half an hour and filtered. To 5 ml extract one drop of p-nitrophenyl indicator, some drop of 7 N H_2SO_4, 4 ml reagent B was added and made the volume up to mark and noted down the reading on spectrophotometer (light yellow colour) at 780 nm wavelength.

b. Same procedure was followed for non-fumigated soil.

c. SMBP=Fumigated P-Non fumigated P or divided with the help of Kp factor 0.41 (Average absorbance reading obtained from prepared solution of P of different concentrations Viz. 0, 1,2,3.4 and 5 ppm).

(IV) Water Soluble Carbon: Water Soluble Carbon was analysed by Acid Extraction Method (Meloon and Sommcr's, 1996).

A soil of 5 gm was taken in 10 ml distilled water (1:2 ratios soil and water) in centrifuges for 30 minutes on 10000 rpm. Filter the supernatant aliquot. Soil extract of 5 ml was placed in digestion tube and treat with 5 ml of 0.07 N $K_2Cr_20_7$, 10 ml of 98 % H_2S0_4 and 5 ml of 88 % H_3P0_4. Samples are carefully mixed and digest at 150 ^{0} C for 30 minutes use by digestion block or heating block. After cool, samples are titrating with a solution of 0.01 N Ferrous Ammonium Sulphate in 0.4 M H_2S0_4. The indicator is prepare use 250 ml of N- Phenylanathrocamilic acid (100.2 mg) and Na_2C0_3 (107 mg) dissolve in 100 ml distilled water or use diphenylamine indicator (0.5 g + 100 ml H_2S0_4 + 20 ml distilled water). Colour changes from yellow to green.

(V) Water Soluble Carbohydrates: Water Soluble Carbohydrates was analysed by Hydralytic extraction with H_2S0_4 (Chebire and Mundie, 1966).

10 g of 2 mm sieved soil sample was treated with 50 ml of 12 M H_2SO_4 and shaken for 16 hrs. The suspension was diluted with1150 ml 0f water to make the acid 0.5 M and heated the mixture on water bath at 100°C for 5 hrs. The suspension was filtered with glass funnel and neutralized the filtrate to pH 6.8 with 5 ml of 6 M NaOH solution. Removed dark precipitate by centrifuging the samples at 1500 rpm for 10 min. and then filtered. To 5 ml aliquot, 10 ml of Anthrone solution was added

and shaken well. After 15 min, green colour appeared which was read on spectrophotometer at 625 nm wavelength.

(VI) Soil Dehydrogenase Activity: Soil Dehydrogenase Activity was analysed by Anthrone Extraction Method (Cassida *et al.,* 1964).

6 g of soil and a pinch of $CaCO_3$ was taken in test tube add 1 ml of 3 percent aqueous solution of TTC and 2.5 ml of distill water. After mixing, the sample incubated for 24 hrs at $37^{\circ}C$. 10 ml methanol was added and test tube was shaken. Filtered the suspension through a glass funnel plugged with absorbent cotton. Add methanol, until the reddish colour disappeared from the cotton plug. Dilute dto 100 ml volume with methanol. The intensity of red colour of TPF was measured using a spectrophotometer at a wavelength of 485 nm.

(VII) Carbon Mineralization: Carbon Mineralization was analysed by Rubber Cork Method (Kukreja *et al.,* 1991).

A soil of 100 gm was placed in 250 ml conical flask. Keep 10 ml 0.5 N NaOH in plastic tube and hanging in the conical flask and seal the conical flask mouth with adhesive and all to incubate for 10 days. Thereafter, expose it; put 2 N $BaCl_2$ solutions of 4 ml in NaOH solution of plastic tube in the presence of 1 drops of phenolphthalein indicator. Titrate with 0.5 N HCl till colour change from deep pink to colourless.

(B) Passive Pools

(I) HUMIC ACID (Stevenson, 1965):

The 10 grams of soil sample was taken in a polyethylene centrifuge bottle and 200 ml of 0.5 N NaOH was added; the mixture is shaken for 12 hours in a mechanical shaker and centrifuged at 3000 rpm for 15 minute. Dark colored supernatant liquid was filtered and the pH of the solution was adjusted to 1.0 with concentrated HCl. Additional 200 ml of 0.5 N NaOH added to the residual soil, shaken, centrifuged and filtered. The residue was dispersed in 200 ml distilled water, centrifuged and supernatant liquid added to the previous extracts and the pH adjusted to 1.0 with concentrated HCl and the humic acid was allowed to settle.

The supernatant liquid in the acidified extracts was fulvic acid. This siphoned off. The suspension was transferred to a polyethylene bottle and the humic acid centrifuged off at 3000 rpm for 15 minutes. Humic acid was redissolved in 0.5 N NaOH and reprecipitated with concentrated HCl; this purification was repeated several times. The supernatant liquid in each case was transferred to the original acid filtrate. Humic acid was washed with distilled water until free of chloride. The humic acid extracted was dried in a rotary evaporator and ground to a fine powder, this was weighed.

(II) FULVIC ACID (Stevenson 1965):

The acid extract collected in the humic acid preparation was fulvic acid. Adjust the pH of the solution to 4.8. The suspension was transferred to a polyethylene bottle and the fulvic acid centrifuged off at 3000 rpm for 15 minutes, the residue was weighed.

(III) HUMIN (Stevenson 1965):

The soil samples washed with 1N HCl weighing 10 gm was taken in a polyethylene centrifuge bottle and add 200 ml of 0.5 N NaOH. The mixture was shaken for 12 hours and centrifuged at 3000 rpm for 15 minute. Dark colored supernatant liquid was filtered and soil containing a portion of HA + FA was collected in moisture box for oven dry. Oven dry soil weight was taken after centrifuge and that was deduct from initial weight of soil (10 gm), it gives fractions of HA + FA in gm on 10 gm soil loss basis and that weight Difference was further deducted from per cent of soil organic matter, gives content of humin (gm).

3.7 STATISTICAL ANALYSIS

Statistical analysis was done as outlined by Panse and Sukhatme (1985). The data so generated during the course of present investigation were subjected to simple correlations and regression analysis (Steel and Torrie, 1980).

4. EXPERIMENTAL RESULT

The results of the field experiment entitled **"Effect of Long Term Application of Fertilizer and Manure on Soil Organic Carbon Fractions under Maize-Wheat Cropping Sequence in *Haplustepts*"** conducted during 2013-14 and 2014-15 at Instructional Farm, Rajasthan College of Agriculture, Udaipur are presented in this chapter. The data pertaining to the effect of different treatments on yield, soil organic fraction and soil properties were statistically analysed for test of significance of the results.

4.1 YIELD OF MAIZE AND WHEAT

The results pertaining to the grain and straw yield as influenced by different treatment combinations has been presented in Table 4.1 and 4.2 and depicted in Fig. 4.1 and 4.2.

4.1.1 Maize Yield

Data presented in Table 4.1 & Fig. 4.1 indicates that grain and straw yield of maize significantly varied under the treatments. The highest grain and straw yield obtained by integrated application of FYM with recommended dose of NPK during both the years of experimentation.

4.1.1.1 Grain Yield

The highest grain yields 4023 and 4033 kg ha^{-1} were recorded under 100% NPK + FYM 10 t ha^{-1} treatment (T_9) during 2013-14 and 2014-15, respectively (Table 4.1 & Fig. 4.1). It was followed by 3736 and 3630 kg ha^{-1} during 2013-14 and 3516 kg ha^{-1} during 2014-15, respectively and at par with 150% NPK (T_{11}) and 100% NPK + Zn + S (T_7) in both the year of experiment with T_9 treatment. The pooled analysis also revealed that this treatment gave highest yield and increased yield by 192.73 and 22.32 per cent as compare to control (1376 kg ha^{-1}) and recommended dose of fertilizer (3293 kg ha^{-1}).

4.1.1.2 Stover Yield

Data revealed (Table 4.1 & Fig. 4.1) that the highest stover yield 5330 and 5290 kg ha^{-1} was recorded under 100% NPK + FYM 10 t ha^{-1} treatment (T_9) during 2013-14 and 2014-15, respectively. It was at par with 150% NPK (T_{11}), 100%NPK + S (T_6), 100%NPK + Zn (T_5), 100% NPK + Seed treatment with *Azotobacter* (T_8), 100%NPK + Zn + S (T_7) and FYM 10 t ha^{-1} + 100% NPK (-NPK of FYM, T_{10}) during both the year, however only 150% NPK (T_{11}) and 100% NPK + Seed treatment with *Azotobacter* (T_8) were found at par in pooled analysis. The pooled analysis revealed 100% NPK + FYM 10 t ha^{-1} (T_9) gave 141.36 and 14.31 per cent higher yield as compare to control (2200 kg ha^{-1}) and recommended dose of fertilizer (4645 kg ha^{-1}).

4.1.2 Wheat Yield

An examination of data in Table 4.2 & Fig. 4.2 revealed that grain and straw yield of wheat significantly influenced by fertilizer treatments alone or in integration with manure. The highest grain and straw yield obtained by integrated application of 10 t FYM with recommended dose of NPK during both the years of experimentation.

4.1.2.1 Grain Yield

The perusal of data in Table 4.2 & Fig. 4.2 revealed that the highest grain yield 5007 and 4939 kg ha^{-1} was recorded under 100% NPK + FYM 10 t ha^{-1} treatment (T_9) during 2013-14 and 2014-15, respectively. It was at par with 150% NPK (T_{11}), FYM 10 t ha^{-1} + 100% NPK (-NPK of FYM, T_{10}), 100% NPK + Zn + S (T_7), 100%NPK + Zn (T_5), 100% NPK + Seed treatment with *Azotobactor* (T_8), and 100%NPK + S (T_6) in both the years. The highest mean grain yield 4973 kg ha^{-1} was obtained under 100% NPK + FYM 10 t ha^{-1} (T_9) treatment which followed by 4653, 4604 and 4600 kg ha^{-1} under 150% NPK (T_{11}), 100% NPK + Zn + S (T_7) and FYM 10 t ha^{-1} + 100% NPK (-NPK of FYM, T_{10}), respectively and found at par with T_9 in pooled analysis. This treatment *i.e.* 100% NPK + FYM 10 t ha^{-1} (T_9) gave 209.84 and 15.67 per cent higher yield as compare to control (1605 kg ha^{-1}) and recommended dose of fertilizer (4299 kg ha^{-1}).

4.1.2.2 Straw Yield

The data presented in Table 4.2 & Fig. 4.2 revealed that the highest grain yield 7170 and 7217 kg ha^{-1} was obtained under 100% NPK + FYM 10 t ha^{-1} treatment (T_9) during 2013-14 and 2014-15, respectively. It was at par with FYM 10 t ha-1 + 100% NPK (-NPK of FYM, T_{10}), 100% NPK + seed treatment with *Azotobacter* (T_8), 100% NPK + Zn + S (T_7), 100% NPK + Zn (T_5), 100% NPK + S (T_6), 150% NPK (T_{11}) and 100% NPK during both the year of experimentation and in pooled analysis. This treatment *i.e.* 100% NPK + FYM 10 t ha^{-1} (T_9) gave 213.46 and 12.82 per cent higher yield in pooled analysis as compare to control (2295 kg ha^{-1}) and recommended dose of fertilizer (6376 kg ha^{-1}).

4.2 PHYSICO-CHEMICAL PROPERTIES OF SOIL

An examination of data in Table 4.3 to 4.8 revealed that physico-chemical properties of soil significantly influenced by various treatments. Integrated application of 10 t FYM with recommended dose of NPK during both the year of experimentation improved the physico-chemical properties of soil as compared to control or recommended dose of NPK.

4.2.1 Bulk Density

Data presented in the Table 4.3 & Fig. 4.3 revealed that the bulk density varies from 1.32 to 1.44 Mg m^{-3} and 1.30 to 1.44 Mg m^{-3} during 2013-14 and 2014-15 under different treatments. The bulk density significantly decreased 1.32 and 1.30 Mg m^{-3} during 2013-14 and 2014-15, under FYM 20 t ha^{-1} application. This treatment was at par with 100% NPK + FYM 10 t ha^{-1} (T_9), FYM 10 t ha-1 + 100% NPK (-NPK of FYM) treatment (T_{10}) and 100% NPK + Zn + S (T_7) during 2013-14 and 100% NPK + FYM 10 t ha^{-1} (T_9) and FYM 10 t ha-1 + 100% NPK (-NPK of FYM) treatment (T_{10}) during 2014-15. The pooled data revels that application of FYM 20 t ha^{-1} gave lowest bulk density *i.e.* 1.31 Mg m^{-3} and at par with 100% NPK + FYM 10 t ha^{-1} (T_9). This treatment gave 9.02 and 7.09 per cent less bulk density as compare to control (1.44 Mg m^{-3}) and recommended dose of fertilizer (1.41 Mg m^{-3}).

4.2.2 Infiltration Rate

Data revealed (Table 4.3 & Fig. 4.3) that highest infiltration rate 0.923 and 0.939 cm ha^{-1} was recorded under FYM 20 t ha-1 treatment (T$_{12}$) during 2013-14 and 2014-15, respectively. It was at par with 100% NPK + FYM 10 t ha^{-1} (T$_{9}$), FYM 10 t ha-1 + 100% NPK (-NPK of FYM) treatment (T$_{10}$) and 100% NPK + Seed treatment with *Azotobactor* in both the year and in pooled analysis. The pooled analysis reveals that this treatment gave 43.23 and 4.37 per cent higher infiltration rate as compare to control (0.650 cm ha^{-1}) and recommended dose of fertilizer (0.892 cm ha^{-1})

4.2.3 Plant Available Water

It is apparent from the data (Table 4.4 & Fig. 4.3) that the highest plant available water 13.10 and 14.28 per cent was recorded under FYM 20 t ha^{-1} treatment (T$_{12}$) during 2013-14 and 2014-15, respectively. . It was at par with 100% NPK + FYM 10 t ha^{-1} (T$_{9}$) and FYM 10 t ha^{-1} + 100% NPK (-NPK of FYM) treatment (T$_{10}$) in both the year and only with 100% NPK + FYM 10 t ha^{-1} (T$_{9}$) treatment in pooled analysis. The pooled analysis reveals that plant available water was 19.25 and 25.02 per cent higher under application of FYM 20 t ha^{-1} (T$_{12}$) as compare to control (11.48 per cent) and recommended dose of fertilizer (10.95 per cent).

4.2.4 Soil Aggregate

Application of FYM 20 t ha^{-1} (T$_{12}$) significantly increased the soil aggregate to 62.97 and 65.50 per cent as compare to 50.05 and 50.19 per cent under control during 2013-14 and 2014-15, respectively (Table 4.4 & Fig. 4.3). The per cent soil aggregate at T$_{12}$ was at par with 100% NPK + FYM 10 t ha^{-1} treatment (T$_{9}$) in both the year of experiment. The pooled analysis reveals that application of FYM 20 t ha^{-1} (T$_{12}$) gave 28.17 and 16.73 per cent higher soil aggregate as compare to control (50.12 per cent) and recommended dose of fertilizer (55.03 per cent).

4.2.5 Soil pH and Electrical Conductivity

Data pertaining to soil pH and electrical conductivity presented in Table 4.5 & Fig. 4.4 showed application of chemical fertilizer alone or in combination with organic manures neither influenced to soil pH nor to electrical conductivity of soil in long term fertilizer experiment after completion of 17 year of experiment.

4.2.6 Available Nitrogen

The available nitrogen content varies from 246 to 419 kg ha^{-1} during 2013-14 and 2014-15 under different treatments of fertilizer application alone or in combination with FYM (Table 4.6 & Fig. 4.5). Critical perusal of data revealed that the highest available nitrogen 419 and 414 kg ha^{-1} was recorded under 100% NPK + FYM 10 t ha^{-1} treatment (T_9) during 2013-14 and 2014-15, respectively and significantly higher than other treatments. The pooled analysis also reveals that this treatment gave 63.77 and 17.30 per cent higher available nitrogen as compare to control (254 kg ha^{-1}) and recommended dose of fertilizer (344 kg ha^{-1}).

4.2.7 Available Phosphorus

The highest available phosphorus 27.54 and 29.97 kg ha^{-1} was recorded under 100% NPK + FYM 10 t ha^{-1} treatment (T_9) during 2013-14 and 2014-15, respectively (Table 4.6 & Fig. 4.5). It was closely followed by 27.52 and 29.33 kg ha^{-1}, respectively by application of 100% NPK + seed treatment with *Azotobactor* (T_8) in both the year. The pooled analysis reveals that this treatment gave 89.39 and 24.72 per cent higher available phosphorus as compared to control (15.18 kg ha^{-1}) and recommended dose of fertilizer (23.06 kg ha^{-1}).

4.2.8 Available Potassium

It is apparent from the data (Table 4.7 & Fig. 4.5) that the highest available potassium 614 and 600 kg ha^{-1} was recorded under 150% NPK treatment (T_{11}) during 2013-14 and 2014-15, respectively. It was at par with FYM 20 t ha^{-1} (T_{12}), FYM 10 t ha^{-1} + 100% NPK (-NPK of FYM, T_{10}), 100%NPK + FYM 10 t ha^{-1} (T_9) and 100% NPK + Zn (T_5) treatments during both the years and also in pooled analysis. The pooled analysis reveals that this treatment gave 22.37 and 11.37 per cent higher available potassium as compare to control (496 kg ha^{-1}) and recommended dose of fertilizer (545 kg ha^{-1}).

4.2.9 Organic Carbon

The data of organic carbon presented in Table 4.7 & Fig. 4.6 revealed that the highest organic carbon 0.896 and 0.902 per cent was recorded under FYM 20 t ha^{-1} treatment (T_{12}) and followed by 0.0851 and 0.0865 per cent with 100% NPK + FYM 10 t ha^{-1} treatment (T_9) during 2013-14 and 2014-15, respectively. And both these treatments were statistically at par. The pooled analysis reveals that application of FYM 20 t ha^{-1} (T_{12}) gave 71.56 and 24.34 per cent higher organic carbon content as compared to control (0.524 per cent) and recommended dose of fertilizer (0.723 per cent).

4.2.10 Microbial Respiration

The highest microbial respiration 65.81 and 68.82 mg CO_2 /100gm soil was recorded under FYM 20 t ha^{-1} treatment (T_{12}) during 2013-14 and 2014-15 (Table 4.8 & Fig. 4.7). The highest mean microbial respiration 67.32 mg CO_2 /100gm soil^{-1} was recorded with application of FYM 20 t (T_{12}) was at par with 100% NPK + FYM 10 t ha^{-1} (T_9), FYM 10 t ha^{-1} + 100% NPK (-NPK of FYM) treatment (T_{10}) and 100% NPK + Seed treatment with *Azotobacter* (T_8) treatments in pooled analysis. The pooled analysis reveals that this treatment with FYM 20 t ha^{-1} (T_{12}) application gave 39.49 and 23.21 per cent higher microbial respiration as compare to control (48.26 mg CO_2 /100gm soil) and recommended dose of fertilizer (54.64 mg CO_2 /100gm soil).

4.2.11 Phosphatase Activity

The perusal of data in Table 4.9 & Fig. 4.7 showed that acid as well alkaline phosphatase activity significantly influenced by treatments. The data revealed that the highest acid phosphatase activity 28.79 and 29.62 µg PNP g^{-1} hr^{-1} was recorded under 100% NPK + FYM 10 t ha^{-1} treatment (T_9) during 2013-14 and 2014-15, respectively. The acid phosphatise activity under 20 t ha^{-1} (T_{12}), FYM 10 t ha^{-1} + 100% NPK (-NPK of FYM, T_{10}) and 100% NPK + Zn + S (T_7) in 2013-14 and FYM 20 t ha^{-1} (T_{12}) and FYM 10 t ha^{-1} + 100% NPK (-NPK of FYM, T_{10}) in 2014-15 was statistically non-significant with 100% NPK + FYM 10 t ha^{-1} treatment. The pooled analysis reveals that this treatment gave 82.27 and 19.86 per cent higher acid phosphatase activity as compared to control (16.02 µg PNP g^{-1} hr^{-1}) and recommended dose of fertilizer (24.36 µg PNP g^{-1} hr^{-1}).

The highest alkaline phosphatase activity 215.42 and 217.19 µg PNP g^{-1} hr^{-1} was recorded under 100% NPK + FYM 10 t ha^{-1} treatment (T_9) during 2013-14 and 2014-15, respectively (Table 4.9 & Fig. 4.7). It was closely followed and at par with FYM 20 t ha^{-1} treatment (T_{12}), 209.15 and 210.69 µg PNP g^{-1} hr^{-1} during 2013-14 and 2014-15 and 209.92 µg PNP g^{-1} hr^{-1} in pooled analysis. The pooled analysis reveals that this treatment gave 64.13 and 14.52 per cent higher alkaline phosphatase activity as compare to control (131.78 µg PNP g^{-1} hr^{-1}) and recommended dose of fertilizer (188.87 µg PNP g^{-1} hr^{-1}).

4.3 SOIL ORGANIC MATTER FRACTION

4.3.1 ACTIVE POOLS

4.3.1.1 Soil Microbial Biomass Carbon

Data presented in the Table 4.10 & Fig. 4.8 revealed that the highest soil microbial biomass carbon (SMBC) 284 and 287 mg kg $^{-1}$ was obtained with treatment receiving FYM 20 t ha^{-1} (T_{12}) during 2013-14 and 2014-15. This treatment followed by T_{11} (274 & 278 mg kg^{-1}) and T_9 (277 & 281 mg kg^{-1}) treatments and these treatments were statistically at par. Application of FYM 20 kg ha^{-1} increases average SMBC by 73.28 and 37.02 per cent as compared to control (164 mg kg^{-1}) and recommended dose of fertilizer (208 mg kg^{-1}).

4.3.1.2 Soil Microbial Biomass Nitrogen

The highest soil microbial biomass nitrogen (SMBN) 40.54 and 40.21 mg kg^{-1} was recorded under 100% NPK + FYM 10 t ha^{-1} treatment (T_9) during 2013-14 and 2014-15, respectively (Table 4.10 & Fig. 4.8). It was closely followed and at par with FYM 10 t ha^{-1} + 100% NPK (-NPK of FYM, T_{10}), 38.67 and 38.59 mg kg^{-1} during 2013-14 and 2014-15. The pooled analysis reveals that this treatment gave 88.82 and 18.18 per cent higher soil microbial biomass nitrogen as compare to control (21.38 mg kg^{-1}) and recommended dose of fertilizer (34.16 mg kg^{-1}).

4.3.1.3 Soil Microbial Biomass Phosphorus

The data of soil microbial biomass phosphorus (SMBP) presented in Table 4.11 & Fig. 4.8 revealed that the highest soil microbial biomass phosphorus 6.13 and

6.18 mg kg^{-1} was recorded under 150% NPK (T_{11}) during 2013-14 and 2014-15, respectively. The pooled analysis reveals that application of 150% NPK (T_{11}) gave 99.68 and 18.27 per cent higher soil microbial biomass phosphorus as compared to control (3.08 mg kg^{-1}) and recommended dose of fertilizer (5.20 mg kg^{-1}).

4.3.1.4 Water Soluble Carbon

Data presented in the Table 4.11 & Fig. 4.8 revealed that the highest water soluble carbon (WSC) 85.16 and 88.61 mg kg $^{-1}$ was obtained with treatment receiving FYM 20 t ha^{-1} (T_{12}) during 2013-14 and 2014-15. This treatment followed by T_9 (83.79 & 86.20 mg kg^{-1}) and T_{10} (81.99 & 84.58 mg kg^{-1}) treatments and these treatments were maintain statistically at par. Application of FYM 20 kg ha^{-1} increases average WSC by 102.14 and 47.15 per cent as compared to control (42.98 mg kg^{-1}) and recommended dose of fertilizer (59.04 mg kg^{-1}).

4.3.1.5 Water Soluble Carbohydrate

It is apparent from the data (Table 4.12 & Fig. 4.8) that the highest water soluble carbohydrate (WSCH) 45.39 and 47.63 mg ka^{-1} was recorded under FYM 20 t ha^{-1} (T_{12}) during 2013-14 and 2014-15, respectively. It was at par with 100%NPK + FYM 10 t ha^{-1} (42.96 & 45.46 mg ka^{-1}) and 150% NPK (42.94 & 44.06 mg ka^{-1}) treatments during both the years. The pooled analysis reveals that this treatment gave 78.61 and 11.88 per cent higher water soluble carbohydrate as compare to control (26.04 mg ha^{-1}) and recommended dose of fertilizer (41.57 mg ha^{-1}).

4.3.1.6 Dehydrogenase Activity

The highest dehydrogenase activity (DHA) 6.56 and 5.54 mg TPF^{-1} $24hr^{-1}$ g^{-1} was recorded under 100% NPK + FYM 10 t ha^{-1} treatment (T_9) during 2013-14 and 2014-15, respectively (Table 4.12 & Fig. 4.8). It was closely followed by 6.47 and 5.46 mg TPF^{-1} $24hr^{-1}$ g^{-1}, respectively by application of FYM 20 t ha^{-1} (T_{12}) in both the year. The pooled analysis reveals that this treatment gave 67.13 and 25.26 per cent higher DHA as compared to control (3.62 mg TPF^{-1} $24hr^{-1}$ g^{-1}) and recommended dose of fertilizer (4.83 mg TPF^{-1} $24hr^{-1}$ g^{-1}).

4.3.1.7 Carbon Mineralization

Data presented in the Table 4.13 & Fig. 4.8 revealed that the highest carbon mineralization (CAR. MIN.) 36.59 and 38.25 mg CO_2-C kg^{-1} soil 24 hr^{-1} was obtained with treatment receiving FYM 20 t ha^{-1} (T_{12}) during 2013-14 and 2014-15. Application of FYM 20 kg ha^{-1} increases average carbon mineralization by 105.94 and 45.43 per cent as compared to control (18.77 mg CO_2-C kg^{-1} soil 24 hr^{-1}) and recommended dose of fertilizer (25.73 mg CO_2-C kg^{-1} soil 24 hr^{-1}).

4.3.2 PASSIVE POOLS

4.3.2.1 Humin

Data presented in the Table 4.14 & Fig. 4.9 revealed that the highest humin content 0.562 and 0.569 per cent was obtained with treatment receiving FYM 20 t ha^{-1} (T_{12}) during 2013-14 and 2014-15. This treatment followed by T_9 (0.548 & 0.557 per cent) treatment and these treatment were statistically at par. Application of FYM 20 kg ha^{-1} increases average humin content by 55.21 and 24.72 per cent as compared to control (0.364 per cent) and recommended dose of fertilizer (0.453 per cent).

4.3.2.2 Humic Acid

The highest humic acid 0.317 and 0.320 per cent was recorded under FYM 20 t ha^{-1} (T_{12}) during 2013-14 and 2014-15, respectively (Table 4.14 & Fig. 4.9). It was closely followed by 0.309 and 0.311 per cent, by application of 100% NPK + FYM 10 t ha^{-1} treatment (T_9) during 2013-14 and 2014-15, respectively. The pooled analysis reveals that FYM 20 t ha^{-1} (T_{12}) gave 38.26 and 16.05 per cent higher humic acid as compared to control (0.230 per cent) and recommended dose of fertilizer (0.274 per cent).

4.3.2.3 Fulvic Acid

It is apparent from the data (Table 4.15 & Fig. 4.9) that the highest fulvic acid 0.194 and 0.202 per cent was recorded under FYM 20 t ha^{-1} (T_{12}) during 2013-14 and 2014-15, respectively. It was at par with 100% NPK + FYM 10 t ha^{-1} (0.191 & 0.199 per cent) and FYM 10 t ha^{-1} + 100% NPK (-NPK of FYM) (0.189 & 0.197 per cent) treatments during both the years. The pooled analysis reveals that this treatment gave 112.90 and 65.00 per cent higher fulvic acid as compared to control (0.093 per cent) and recommended dose of fertilizer (0.120 per cent).

4.4 Correlation between Active pools of carbon and crop yield

Correlation between different active pools of carbon with grain and straw yield of maize and wheat were work out and values of correlation coefficient summarized in Table 4.16. The critical perusal of these values indicates that among different active pools CAR. MIN. have highest correlation with grain and straw yield of maize (r = 0.557 & 0.636**). SMBN and WSCH pools also have highly significantly correlation with grain and stover yield of maize. All other active carbon fractions also significantly influenced to yield of maize. However, highly significant and higher correlation 0.637** and 0.612** values were observed by WSCH followed by 0.608** and 0.511** with SMBN and 0.577** and 0.554** with CAR. MIN. fraction for wheat grain and straw, respectively. These results clearly indicate that all active fraction of carbon significantly correlated with yield of maize and wheat.**

4.5 Correlation between passive pools of carbon and yield

Correlation coefficient values were worked out between different passive pools of carbon with grain and straw yield of maize and wheat and summarized in Table 4.17. The perusal of data shows that among different fractions humin have only highly significant correlation with maize and wheat yield with correlation coefficient value >0.6. other fractions, *i.e.* humic acid and fulvic acid have not show any significant correlation with yield of maize and wheat except in between humic acid & grain yield of wheat *i.e.* 0.321*.

4.6 Correlation between active and passive pools of soil organic carbon

Correlation between active and passive pools of soil organic carbon were work out and summarized in Table 4.18. The perusal of data indicated that SMBN, WSC and Humin fraction positively correlated with all fractions. Among different pools correlation CAR. MIN. was found highly correlated with humin fraction (r = 0.893**). These results showed that most of carbon pools have significant positive correlation with each other.

4.7 Stepwise Regression:

Equations were worked out for explaining the total variation of maize and wheat yield with active and passive pools of carbon. These pools jointly explains 92, 99, 98 and 97 per cent variation in maize grain and stover yield and wheat grain and straw yield, respectively. These pools explain the highest 98.4 per cent variation in wheat grain and 99.6 per cent in maize stover yield.

Table: 4.1: Effect of fertilizer and manure on grain and stover yield of maize

Treatment	Grain yield (kg ha^{-1})			Stover yield (kg ha^{-1})		
	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled
T_1 = Control	1425	1327	1376	2210	2190	2200
T_2 = 100% N	2312	2169	2241	3470	3500	3485
T_3 = 100 NP	2929	2806	2867	4140	4090	4115
T_4 = 100% NPK	3366	3220	3293	4680	4610	4645
T_5 = 100% NPK + Zn	3508	3382	3445	4870	4790	4830
T_6 = 100%NPK + S	3413	3297	3355	4780	4730	4755
T_7 = 100% NPK+ Zn + S	3630	3516	3573	4820	4870	4845
T_8 = 100% NPK + Seed treatment with *Azotobacter*	3494	3402	3448	4850	4910	4880
T_9 = 100%NPK + FYM 10 t ha^{-1}	4023	4033	4028	5330	5290	5310
T_{10} = FYM 10 t ha^{-1} + 100% NPK (-NPK of FYM)	3466	3490	3478	4695	4650	4673
T_{11} = 150% NPK	3736	3605	3670	5230	5180	5205
T_{12} = FYM 20 t ha^{-1}	2374	2435	2404	3200	3160	3180
S.Em.±	160	185	122	225	232	161
C.D. (P = 0.05)	461	532	345	648	667	456

Table: 4.2: Effect of fertilizer and manure on grain and straw yield of wheat

Treatment	Grain yield (kg ha^{-1})			Straw yield (kg ha^{-1})		
	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled
T_1 = Control	1659	1552	1605	2280	2310	2295
T_2 = 100% N	3012	2915	2963	4395	4325	4360
T_3 = 100 NP	3582	3591	3586	5270	5324	5297
T_4 = 100% NPK	4329	4270	4299	6410	6342	6376
T_5 = 100% NPK + Zn	4512	4495	4503	6620	6588	6604
T_6 = 100% NPK+ S	4422	4393	4408	6500	6419	6460
T_7 = 100% NPK+ Zn + S	4617	4592	4604	6810	6755	6783
T_8 = 100% NPK + Seed treatment with *Azotobacter*	4438	4401	4420	6930	6885	6907
T_9 = 100% NPK + FYM 10 t ha^{-1}	5007	4939	4973	7170	7217	7194
T_{10} = FYM 10 t ha^{-1} + 100% NPK (-NPK of FYM)	4616	4585	4600	6980	7045	7013
T_{11} = 150% NPK	4667	4640	4653	6430	6378	6404
T_{12} = FYM 20 t ha^{-1}	3083	3077	3080	4460	4529	4494
S.Em.±	234	206	156	280	313	210
C.D. (P = 0.05)	674	592	440	807	901	594

Table: 4.3: Effect of fertilizer and manure on bulk density and infiltration rate after harvest of wheat crop

Treatment	BD (Mg m^{-3})	Infiltration Rate (cm hr^{-1})

	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled
T_1 = Control	1.44	1.44	1.44	0.648	0.651	0.650
T_2 = 100% N	1.40	1.40	1.40	0.668	0.654	0.661
T_3 = 100 NP	1.38	1.38	1.38	0.753	0.755	0.754
T_4 = 100% NPK	1.41	1.41	1.41	0.892	0.892	0.892
T_5 = 100% NPK + Zn	1.42	1.41	1.41	0.795	0.802	0.799
T_6 = 100% NPK+ S	1.39	1.39	1.39	0.834	0.836	0.835
T_7 = 100% NPK+ Zn + S	1.38	1.38	1.38	0.816	0.818	0.817
T_8 = 100% NPK + Seed treatment with *Azotobacter*	1.42	1.41	1.41	0.899	0.905	0.902
T_9 = 100% NPK + FYM 10 t ha^{-1}	1.36	1.34	1.35	0.917	0.924	0.920
T_{10} = FYM 10 t ha^{-1} + 100% NPK (-NPK of FYM)	1.36	1.35	1.36	0.913	0.915	0.914
T_{11} = 150% NPK	1.42	1.42	1.42	0.735	0.731	0.733
T_{12} = FYM 20 t ha^{-1}	1.32	1.30	1.31	0.923	0.939	0.931
S.Em.±	0.02	0.02	0.02	0.016	0.013	0.010
C.D. (P = 0.05)	0.06	0.06	0.04	0.045	0.037	0.029

Table: 4.4: Effect of fertilizer and manure on available water content and soil aggregate after harvest of wheat crop

Treatment	AWC (%)			Soil Aggregate (%)		
	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled
T_1 = Control	11.42	11.53	11.48	50.05	50.19	50.12
T_2 = 100% N	10.62	10.99	10.80	51.38	52.88	52.13
T_3 = 100 NP	11.19	11.24	11.21	51.66	53.14	52.40
T_4 = 100% NPK	10.85	11.04	10.95	54.28	55.78	55.03
T_5 = 100% NPK + Zn	11.49	11.79	11.64	54.30	55.80	55.05
T_6 = 100% NPK+ S	11.58	11.63	11.61	55.37	56.87	56.12
T_7 = 100% NPK+ Zn + S	11.64	11.67	11.65	56.10	57.60	56.85
T_8 = 100% NPK + Seed treatment with *Azotobacter*	11.36	12.34	11.85	56.73	58.23	57.48
T_9 = 100% NPK + FYM 10 t ha^{-1}	12.75	13.78	13.26	60.55	63.07	61.81
T_{10} = FYM 10 t ha^{-1} + 100% NPK (-NPK of FYM)	12.69	13.69	13.19	56.25	58.81	57.53
T_{11} = 150% NPK	10.73	10.85	10.79	55.80	57.33	56.57
T_{12} = FYM 20 t ha^{-1}	13.10	14.27	13.69	62.97	65.50	64.24
S.Em.±	0.26	0.24	0.18	0.85	1.04	0.67
C.D. (P = 0.05)	0.74	0.69	0.49	2.46	2.98	1.90

Table: 4.5: Effect of fertilizer and manure on pH and EC after harvest of wheat crop

Treatment	pH			EC (dSm^{-1})		
	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled
T_1 = Control	8.22	8.26	8.24	0.81	0.84	0.82
T2 = 100% N	8.26	8.25	8.25	0.80	0.83	0.82
T3 = 100 NP	8.25	8.23	8.24	0.83	0.86	0.85
T4 = 100% NPK	8.20	8.23	8.21	0.81	0.84	0.82
T5 = 100% NPK + Zn	8.18	8.20	8.19	0.83	0.85	0.84
T6 = 100% NPK+ S	8.19	8.19	8.19	0.81	0.84	0.83
T7 = 100% NPK+ Zn + S	8.18	8.19	8.19	0.83	0.85	0.84
T8 = 100% NPK + Seed treatment with *Azotobacter*	8.21	8.19	8.20	0.82	0.85	0.84
T9 = 100% NPK + FYM 10 t ha-1	8.16	8.18	8.17	0.80	0.83	0.81
T10 = FYM 10 t ha-1 + 100% NPK (-NPK of FYM)	8.21	8.23	8.22	0.82	0.84	0.83
T11 = 150% NPK	8.22	8.23	8.22	0.81	0.84	0.82
T12 = FYM 20 t ha-1	8.19	8.20	8.19	0.82	0.85	0.83
S.Em.±	0.03	0.02	0.02	0.01	0.01	0.01
C.D. (P = 0.05)	NS	NS	NS	NS	NS	NS

Table: 4.6: Effect of fertilizer and manure on available nitrogen and phosphorus after harvest of wheat crop

Treatment	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})

Table: 4.7: Effect of fertilizer and manure on available potassium and organic carbon after harvest of wheat crop

Treatment	K_2O (kg ha^{-1})			OC (%)		
	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled
T_1 = Control	256	252	254	15.29	15.08	15.18
T_2 = 100% N	246	265	255	15.83	15.25	15.54
T_3 = 100 NP	273	276	275	21.54	22.44	21.99
T_4 = 100% NPK	341	346	344	22.84	23.26	23.05
T_5 = 100% NPK + Zn	337	339	338	22.72	23.40	23.06
T_6 = 100% NPK+ S	339	341	340	22.93	24.13	23.53
T_7 = 100% NPK+ Zn + S	334	336	335	25.15	26.89	26.02
T_8 = 100% NPK + Seed treatment with *Azotobacter*	341	345	343	27.52	29.33	28.42
T_9 = 100% NPK + FYM 10 t ha^{-1}	419	414	416	27.54	29.97	28.75
T_{10} = FYM 10 t ha^{-1} + 100% NPK (-NPK of FYM)	396	402	399	23.40	25.76	24.58
T_{11} = 150% NPK	360	367	364	22.34	24.23	23.29
T_{12} = FYM 20 t ha^{-1}	293	302	298	25.94	26.60	26.27
S.Em.±	6	5	4	0.55	0.40	0.49
C.D. (P = 0.05)	17	15	11	1.58	1.15	1.51

T_1 = Control	497	494	496	0.524	0.523	0.524
T_2 = 100% N	492	480	486	0.637	0.632	0.635
T_3 = 100 NP	498	488	493	0.672	0.673	0.673
T_4 = 100% NPK	541	550	545	0.722	0.724	0.723
T_5 = 100% NPK + Zn	588	582	585	0.729	0.733	0.731
T_6 = 100% NPK+ S	569	555	562	0.717	0.722	0.720
T_7 = 100% NPK+ Zn + S	553	564	559	0.738	0.744	0.741
T_8 = 100% NPK + Seed treatment with *Azotobacter*	563	559	561	0.603	0.594	0.598
T_9 = 100% NPK + FYM 10 t ha^{-1}	590	587	588	0.851	0.865	0.858
T_{10} = FYM 10 t ha^{-1} + 100% NPK (-NPK of FYM)	598	595	597	0.845	0.851	0.848
T_{11} = 150% NPK	614	600	607	0.724	0.721	0.723
T_{12} = FYM 20 t ha^{-1}	599	586	593	0.896	0.902	0.899
S.Em.±	10.60	11.00	7.64	0.017	0.017	0.012
C.D. (P = 0.05)	30.53	31.68	21.588	0.049	0.050	0.034

Table: 4.8: Effect of fertilizer and manure on microbial respiration after harvest of wheat crop

Treatment	Microbial Respiration (mg CO_2/ 100gm soil)		
	2013-14	2014-15	Pooled
T_1 = Control	47.96	48.57	48.26

T_2 = 100% N	58.99	50.88	54.94
T_3 = 100 NP	57.27	51.27	54.27
T_4 = 100% NPK	56.06	53.23	54.64
T_5 = 100% NPK + Zn	55.95	55.35	55.65
T_6 = 100% NPK+ S	51.84	56.89	54.36
T_7 = 100% NPK+ Zn + S	49.55	56.91	53.23
T_8 = 100% NPK + Seed treatment with *Azotobacter*	62.48	59.46	60.97
T_9 = 100% NPK + FYM 10 t ha^{-1}	60.24	64.73	62.48
T_{10} = FYM 10 t ha^{-1} + 100% NPK (-NPK of FYM)	61.05	60.77	60.91
T_{11} = 150% NPK	56.40	56.09	56.25
T_{12} = FYM 20 t ha^{-1}	65.81	68.82	67.32
S.Em.±	1.08	0.91	2.28
C.D. (P = 0.05)	3.11	2.63	7.10

Table: 4.9: Effect of fertilizer and manure on phosphtase activity after harvest of wheat crop

Treatment	Acid Phosphatase (µg PNP g^{-1} hr^{-1})			Alkaline Phosphtase (µg PNP g^{-1} hr^{-1})		
	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled
T_1 = Control	15.24	16.79	16.02	133.75	129.82	131.78
T_2 = 100% N	21.76	22.54	22.15	152.89	155.74	154.31

T_3 = 100 NP	21.02	21.33	21.18	167.87	169.48	168.67
T_4 = 100% NPK	23.98	24.74	24.36	187.76	189.98	188.87
T_5 = 100% NPK + Zn	25.37	25.52	25.45	193.10	194.45	193.78
T_6 = 100% NPK+ S	25.86	26.39	26.12	198.57	201.67	200.12
T_7 = 100% NPK+ Zn + S	27.47	27.83	27.65	203.49	203.77	203.63
T_8 = 100% NPK + Seed treatment with *Azotobacter*	24.75	24.97	24.86	190.11	192.35	191.23
T_9 = 100% NPK + FYM 10 t ha^{-1}	28.79	29.62	29.20	215.42	217.19	216.30
T_{10} = FYM 10 t ha^{-1} + 100% NPK (-NPK of FYM)	27.75	28.19	27.97	212.98	213.72	213.35
T_{11} = 150% NPK	25.28	26.55	25.91	190.55	191.31	190.93
T_{12} = FYM 20 t ha^{-1}	27.88	28.27	28.07	209.15	210.69	209.92
S.Em.±	0.57	0.41	0.35	3.09	4.38	2.68
C.D. (P = 0.05)	1.65	1.18	0.99	8.89	12.61	7.57

Table: 4.14: Effect of fertilizer and manure on humin and humic acid after harvest of wheat crop

Treatment	HUMIN (%)			HUMIC (%)		
	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled
T_1 = Control	0.361	0.368	0.364	0.229	0.231	0.230
T_2 = 100% N	0.383	0.388	0.385	0.242	0.244	0.243
T_3 = 100 NP	0.445	0.452	0.448	0.252	0.256	0.254

T_4 = 100% NPK	0.451	0.454	0.453	0.272	0.277	0.274
T_5 = 100% NPK + Zn	0.448	0.453	0.451	0.264	0.266	0.265
T_6 = 100% NPK+ S	0.448	0.454	0.451	0.264	0.268	0.266
T_7 = 100% NPK+ Zn + S	0.459	0.463	0.461	0.266	0.269	0.267
T_8 = 100% NPK + Seed treatment with *Azotobacter*	0.472	0.476	0.474	0.285	0.289	0.287
T_9 = 100% NPK + FYM 10 t ha^{-1}	0.548	0.557	0.553	0.309	0.311	0.310
T_{10} = FYM 10 t ha^{-1} + 100% NPK (-NPK of FYM)	0.505	0.511	0.508	0.297	0.299	0.298
T_{11} = 150% NPK	0.501	0.507	0.504	0.293	0.298	0.296
T_{12} = FYM 20 t ha^{-1}	0.562	0.569	0.565	0.317	0.320	0.318
S.Em.±	0.007	0.007	0.005	0.003	0.003	0.002
C.D. (P = 0.05)	0.020	0.020	0.014	0.009	0.010	0.007

Table: 4.15: Effect of fertilizer and manure on fulvic acid after harvest of wheat crop

Treatment	FULVIC (%)		
	2013-14	2014-15	Pooled
T_1 = Control	0.091	0.096	0.093
T_2 = 100% N	0.099	0.103	0.101
T_3 = 100 NP	0.113	0.117	0.115
T_4 = 100% NPK	0.119	0.121	0.120

T_5 = 100% NPK + Zn	0.125	0.128	0.127
T_6 = 100% NPK+ S	0.125	0.131	0.128
T_7 = 100% NPK+ Zn + S	0.124	0.131	0.128
T_8 = 100% NPK + Seed treatment with *Azotobacter*	0.161	0.169	0.165
T_9 = 100% NPK + FYM 10 t ha^{-1}	0.191	0.199	0.195
T_{10} = FYM 10 t ha^{-1} + 100% NPK (-NPK of FYM)	0.189	0.197	0.193
T_{11} = 150% NPK	0.165	0.152	0.158
T_{12} = FYM 20 t ha^{-1}	0.194	0.202	0.198
S.Em.±	0.002	0.003	0.002
C.D. (P = 0.05)	0.007	0.010	0.006

Table: 4.10: Effect of fertilizer and manure on soil microbial biomass carbon (SMBC) and soil microbial biomass nitrogen (SMBN) after harvest of wheat crop

Treatment	SMBC (mg kg^{-1})			SMBN (mg kg^{-1})		
	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled
T_1 = Control	164	165	164	21.44	21.33	21.38
T_2 = 100% N	174	175	174	31.82	32.39	32.10
T_3 = 100 NP	181	185	183	26.15	27.44	26.79
T_4 = 100% NPK	207	209	208	34.72	33.60	34.16
T_5 = 100% NPK + Zn	225	224	224	34.21	34.39	34.30

T_6 = 100% NPK+ S	192	194	193	38.23	36.63	37.43
T_7 = 100% NPK+ Zn + S	241	241	241	34.73	33.96	34.35
T_8 = 100% NPK + Seed treatment with *Azotobacter*	247	248	247	35.92	35.77	35.84
T_9 = 100% NPK + FYM 10 t ha^{-1}	277	281	279	40.54	40.21	40.37
T_{10} = FYM 10 t ha^{-1} + 100% NPK (-NPK of FYM)	274	278	276	38.67	38.59	38.63
T_{11} = 150% NPK	258	257	257	36.11	35.94	36.03
T_{12} = FYM 20 t ha^{-1}	284	287	285	33.85	32.99	33.42
S.Em.±	4.78	4.40	3.00	0.73	0.75	0.52
C.D. (P = 0.05)	13.8	12.7	9.17	2.11	2.16	1.48

Table: 4.11: Effect of Fertilizer and manure on soil microbial biomass phosphorus (SMBP) and water soluble carbon (WSC) after harvest of wheat crop

Treatment	SMBP (mg kg^{-1})			WSC (mg kg^{-1})		
	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled
T_1 = Control	3.08	3.09	3.08	42.94	43.02	42.98
T_2 = 100% N	3.19	3.15	3.17	52.22	54.71	53.46
T_3 = 100 NP	4.17	4.22	4.19	54.26	56.67	55.46
T_4 = 100% NPK	5.19	5.21	5.20	57.86	60.23	59.04
T_5 = 100% NPK + Zn	3.55	3.58	3.56	60.04	62.49	61.27
T_6 = 100% NPK+ S	4.12	4.15	4.14	59.68	62.12	60.90
T_7 = 100% NPK+ Zn + S	3.64	3.67	3.65	61.12	63.38	62.25
T_8 = 100% NPK + Seed treatment with *Azotobacter*	4.10	4.12	4.11	64.15	66.56	65.35
T_9 = 100% NPK + FYM 10 t ha^{-1}	4.84	4.89	4.86	83.79	86.20	84.99
T_{10} = FYM 10 t ha^{-1} + 100% NPK (-NPK of FYM)	4.29	4.33	4.31	81.99	84.58	83.28
T_{11} = 150% NPK	6.13	6.18	6.15	74.99	77.28	76.13
T_{12} = FYM 20 t ha^{-1}	5.23	5.29	5.26	85.16	88.61	86.88
S.Em.±	0.08	0.08	0.06	1.23	1.41	0.94
C.D. (P = 0.05)	0.24	0.23	0.16	3.53	4.07	2.64

Table: 4.12: Effect of fertilizer and manure on water soluble carbohydrate (WSCH) and dehydrogenase activity (DHA) after of harvest wheat crop

Treatment	WSCH (mg kg^{-1})			DHA (TPF^{-1} $24ha^{-1}$ g^{-1} soil)		
	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled
T_1 = Control	25.87	26.20	26.04	4.14	3.09	3.62
T_2 = 100% N	31.51	32.98	32.24	4.24	3.30	3.77
T_3 = 100 NP	33.66	35.61	34.63	5.36	4.33	4.85
T_4 = 100% NPK	39.61	43.54	41.57	5.33	4.33	4.83
T_5 = 100% NPK + Zn	41.18	42.41	41.79	5.44	4.42	4.93
T_6 = 100% NPK+ S	40.91	43.70	42.31	5.41	4.40	4.90
T_7 = 100% NPK+ Zn + S	41.67	44.38	43.02	5.42	4.41	4.92
T_8 = 100% NPK + Seed treatment with *Azotobacter*	39.89	42.38	41.13	5.50	4.54	5.02
T_9 = 100% NPK + FYM 10 t ha^{-1}	42.96	45.46	44.21	6.56	5.54	6.05
T_{10} = FYM 10 t ha^{-1} + 100% NPK (-NPK of FYM)	42.23	44.53	43.38	5.72	4.63	5.17
T_{11} = 150% NPK	42.94	44.06	43.50	5.77	4.76	5.27
T_{12} = FYM 20 t ha^{-1}	45.39	47.63	46.51	6.47	5.46	5.96
S.Em.±	0.96	0.98	0.69	0.08	0.08	0.06
C.D. (P = 0.05)	2.76	2.82	1.94	0.24	0.23	0.16

Table: 4.13: Effect of fertilizer and manure on carbon mineralization after harvest of wheat crop

Treatment	Carbon Mineralization (mg CO_2–C kg^{-1} soil 24 hr^{-1})		
	2013-14	2014-15	Pooled
T_1 = Control	18.49	19.04	18.77
T_2 = 100% N	21.72	23.69	22.71
T_3 = 100 NP	23.56	25.34	24.45
T_4 = 100% NPK	24.31	27.14	25.73
T_5 = 100% NPK + Zn	18.57	19.23	18.90
T_6 = 100% NPK+ S	19.92	21.55	20.74
T_7 = 100% NPK+ Zn + S	19.76	21.03	20.40
T_8 = 100% NPK + Seed treatment with *Azotobacter*	24.88	27.84	26.36
T_9 = 100% NPK + FYM 10 t ha^{-1}	32.56	33.63	33.09
T_{10} = FYM 10 t ha^{-1} + 100% NPK (-NPK of FYM)	33.61	35.49	34.55
T_{11} = 150% NPK	19.52	20.39	19.95
T_{12} = FYM 20 t ha^{-1}	36.59	38.25	37.42
S.Em.±	0.46	0.43	0.31
C.D. (P = 0.05)	1.31	1.24	0.88

Table 4.16: Correlation co-efficient between active pools of organic carbon and yield

Active pools	Maize yield		Wheat yield	
	Grain	Stover	Grain	Straw
SMBC	0.421*	0.384*	0.488**	0.390*
SMBN	0.520**	0.491**	0.608**	0.511**
SMBP	0.430*	0.331*	0.310*	0.294
WSC	0.425*	0.424*	0.426*	0.336*
WSCH	0.507**	0.471**	0.637**	0.612**
DHA	0.360*	0.364*	0.314*	0.255
CAR. MIN.	0.557**	0.636**	0.577**	0.554**

* Significant, ** highly significant

Table 4.17: Correlation co-efficient between passive pools of organic carbon and yield

Passive pools	Maize		Wheat	
	Grain	Stover	Grain	Straw
HUMIC ACID	0.191	0.273	0.321*	0.196
FULVIC ACID	0.088	0.166	0.201	0.075
HUMIN	0.605**	0.613**	0.632**	0.600**

* Significant, ** highly significant

Table 4.18: Correlation coefficient between active and passive pools of organic carbon

	SMBC	SMBN	SMBP	WSC	WSCH	DHA	CAR. MIN.	H.A.	F.A.	HUMIN
SMBC	1.000									
SMBN	0.829**	1.000								
SMBP	0.608*	0.813**	1.000							
WSC	0.776**	0.790**	0.695*	1.000						
WSCH	0.568	0.637*	0.456	0.631*	1.000					
DHA	0.552	0.751**	0.810**	0.892**	0.594*	1.000				
CAR. MIN.	0.554	0.825**	0.809**	0.619*	0.633*	0.744**	1.000			
H.A.	0.727**	0.779**	0.541	0.710**	0.498	0.631*	0.674*	1.000		
F.A.	0.701*	0.653*	0.407	0.695*	0.402	0.582*	0.494	0.952**	1.000	
HUMIN	0.729**	0.827**	0.739**	0.606*	0.666*	0.600*	0.893**	0.776**	0.634*	1.000

Table 4.19: Regression equation between crop yield and active and passive pools of organic carbon

Dependent variables	**Regression equation**	**R^2**
MGY	$Y= -1027 - 0.787(\text{SMBC}) + 34.83(\text{SMBN}) - 34.44(\text{SMBP}) + 8.96(\text{WSC}) - 4.35(\text{WSCH}) - 0.10(\text{DHA}) - 5.15(\text{CAR.MIN}) - 3.03(\text{HA}) + 0.89(\text{FA}) + 80.46(\text{HUMIN})$	0.926
MSY	$Y= 2270 - 1.15(\text{SMBC}) + 53.51(\text{SMBN}) - 111.99(\text{SMBP}) + 22.33(\text{WSC}) - 13.69(\text{WSCH}) - 0.823(\text{DHA}) + 11.17(\text{CAR.MIN}) - 6.125(\text{HA}) + 1.159(\text{FA}) +144.8(\text{HUMIN})$	0.996
WGY	$Y= 2403 - 4.378(\text{SMBC}) + 299.4(\text{SMBN}) - 298.5(\text{SMBP}) + 43.82(\text{WSC}) -16.15(\text{WSCH}) + 0.423(\text{DHA}) - 22.59(\text{CAR.MIN}) -14.29(\text{HA}) - 3.556(\text{FA}) + 418.7(\text{HUMIN})$	0.984
WSY	$Y= 2374 - 6.630(\text{SMBC}) + 332.2(\text{SMBN}) - 308.8(\text{SMBP}) + 65.64(\text{WSC}) - 13.61(\text{WSCH}) - 21.83(\text{DHA}) - 11.04(\text{CAR.MIN}) - 25.13(\text{HA}) + 17.59(\text{FA}) + 534.7(\text{HUMIN})$	0.978

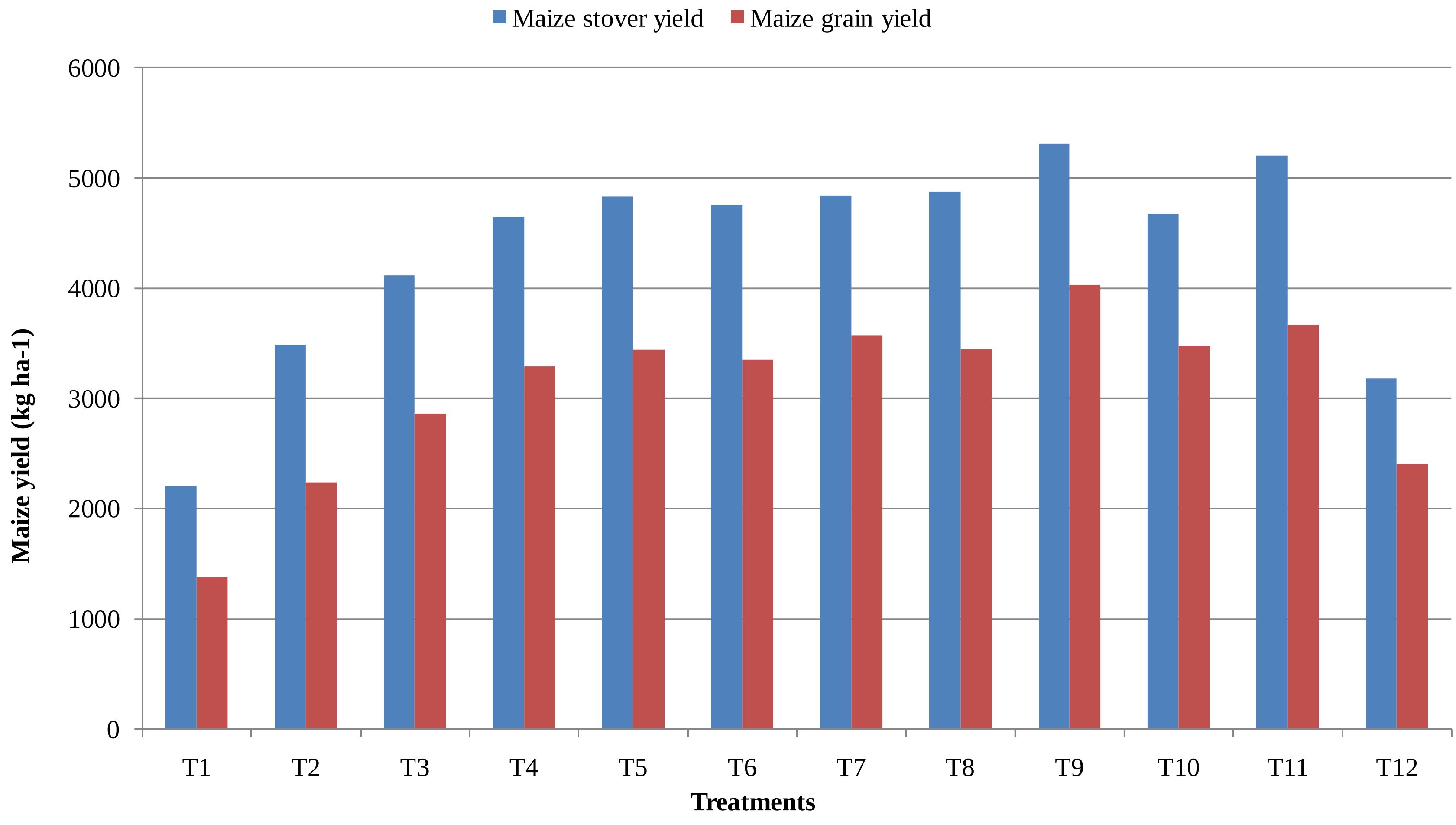

Figure 4.1: Effect of manure and fertilizer on yield of maize

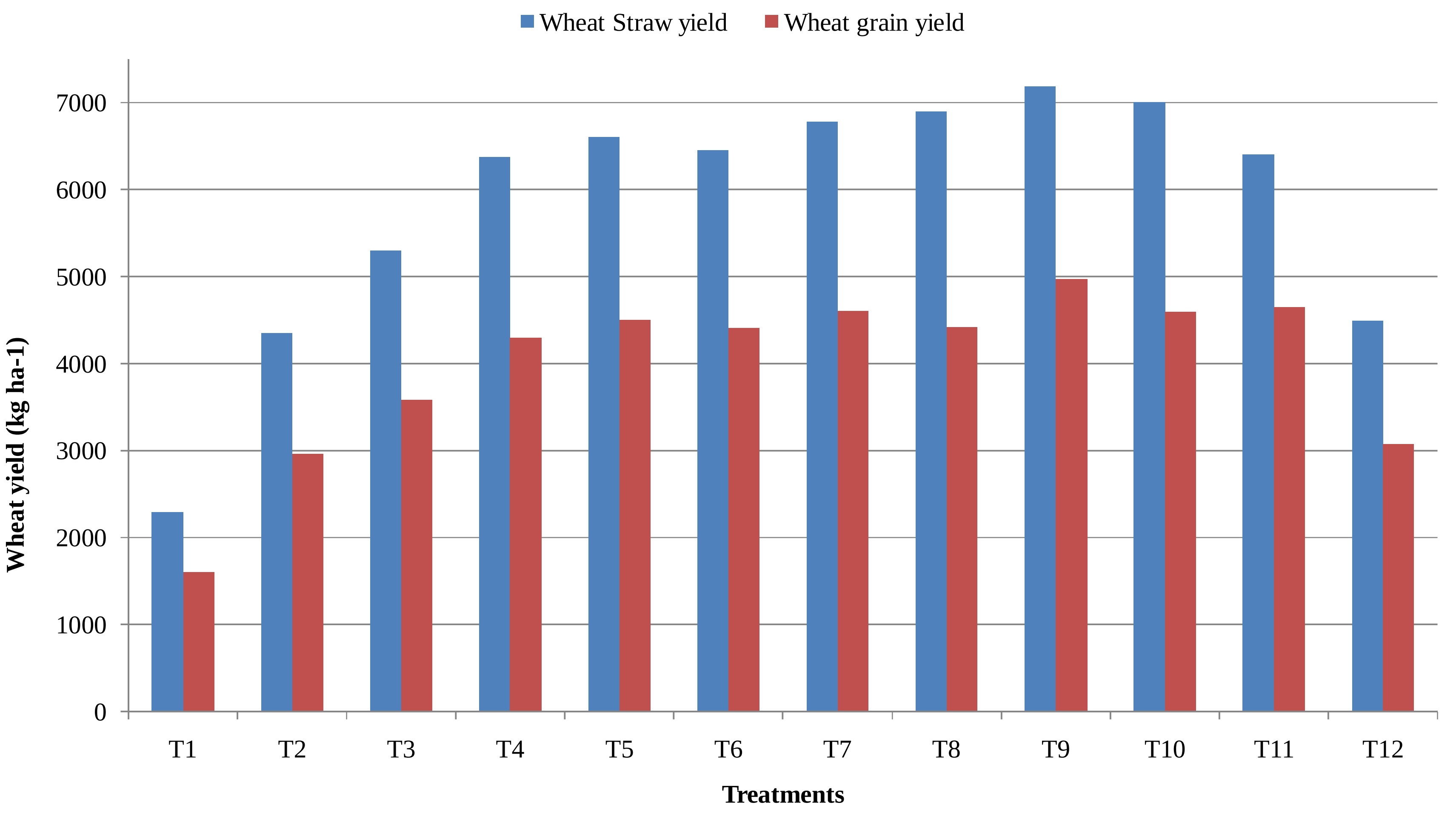

Figure 4.2: Effect of manure and fertilizer on yield of wheat

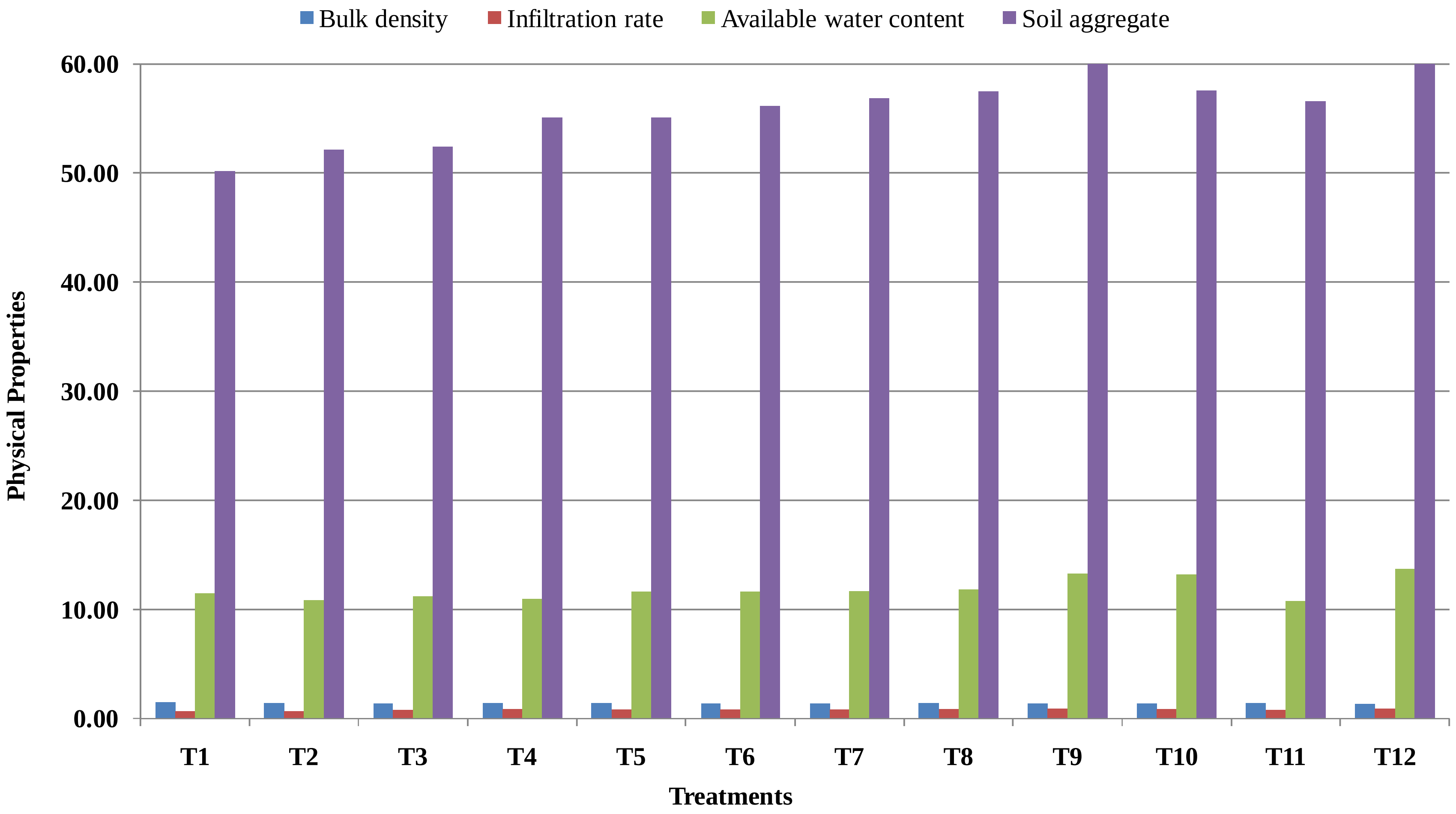

Figure 4.3: Effect of manure and fertilizer on physical properties of soil

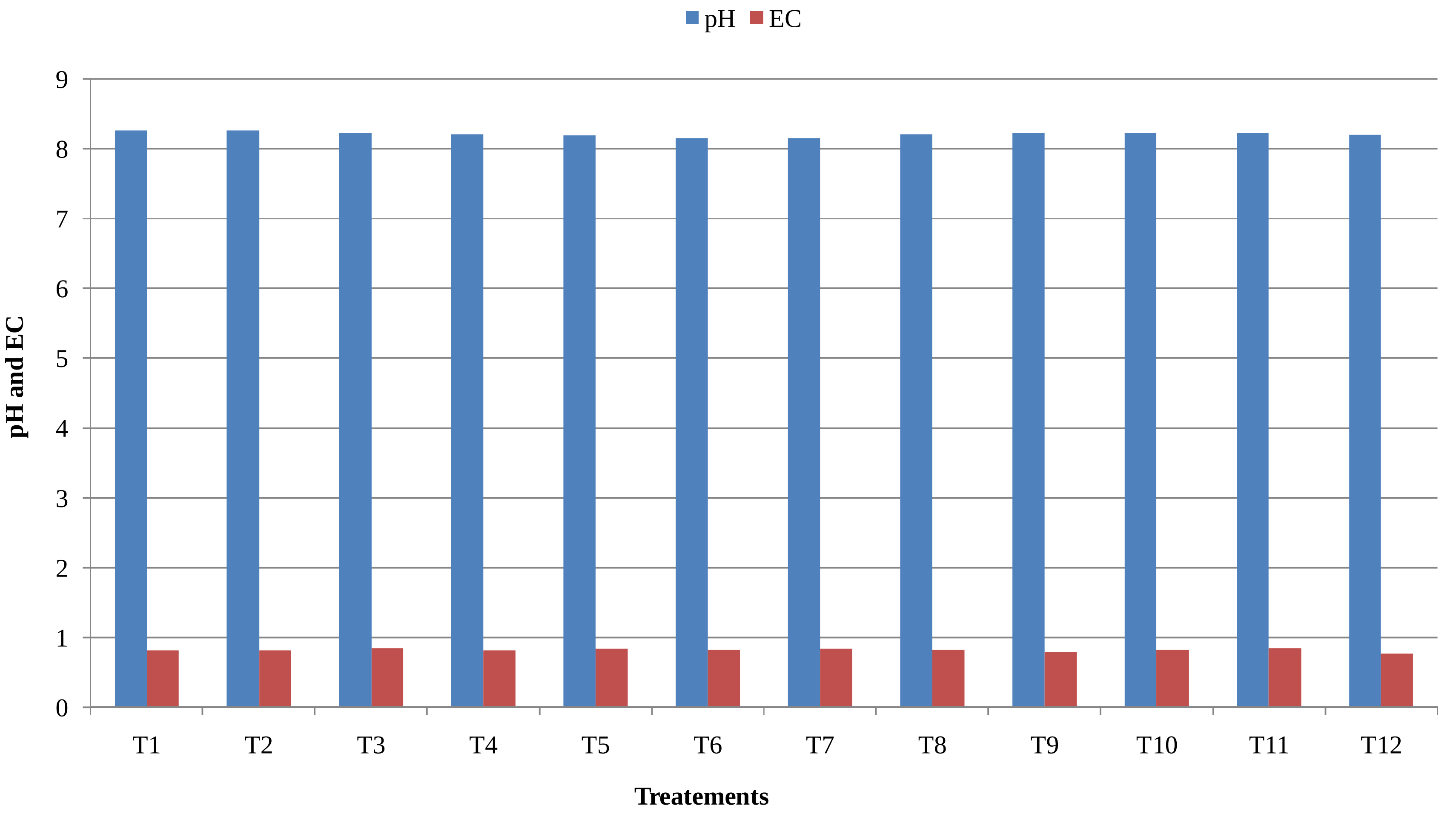

Figure 4.4: Effect of manure and fertilizer on pH and EC

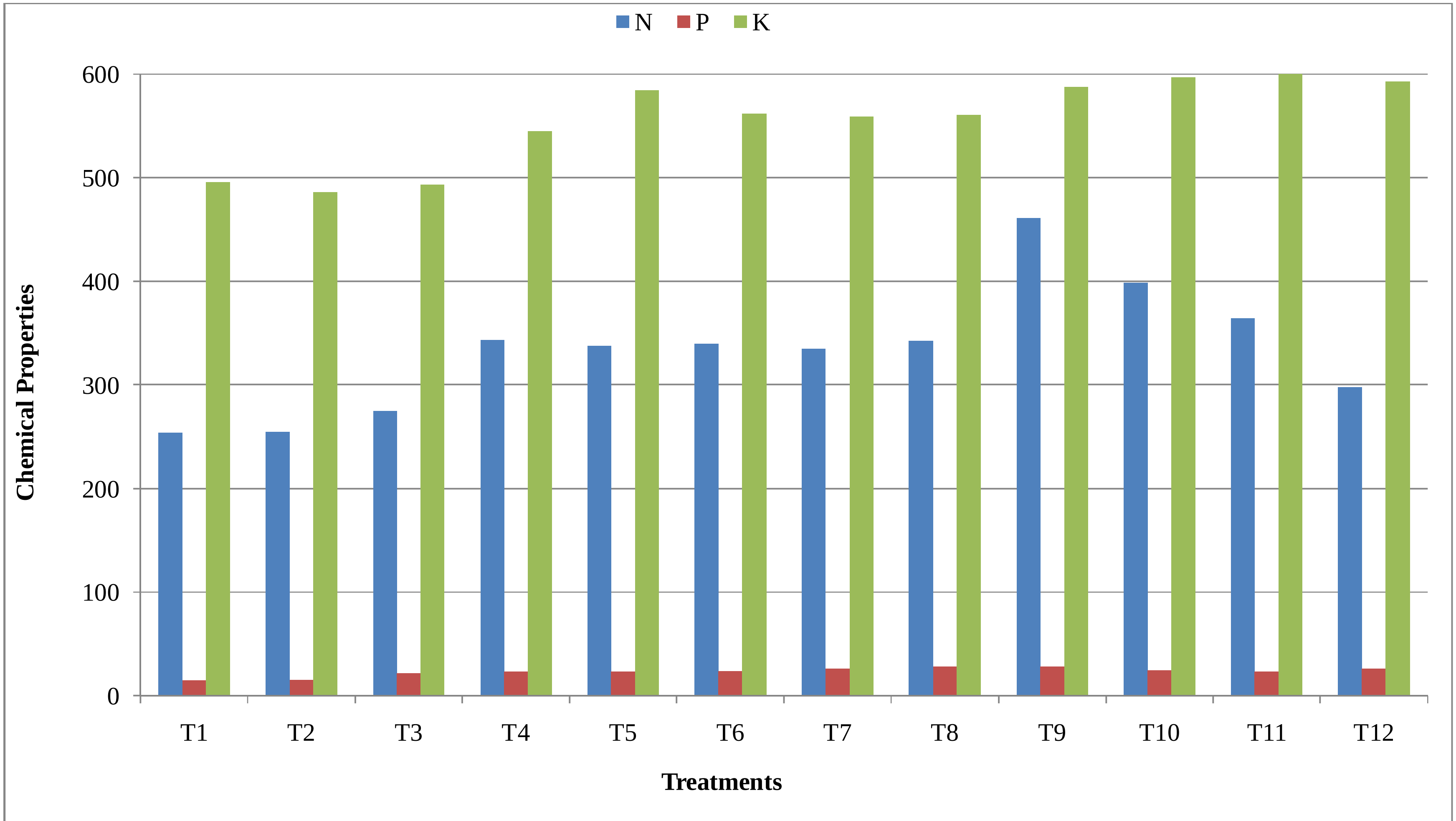

Figure 4.5: Effect of manure and fertilizer on chemical properties of soil

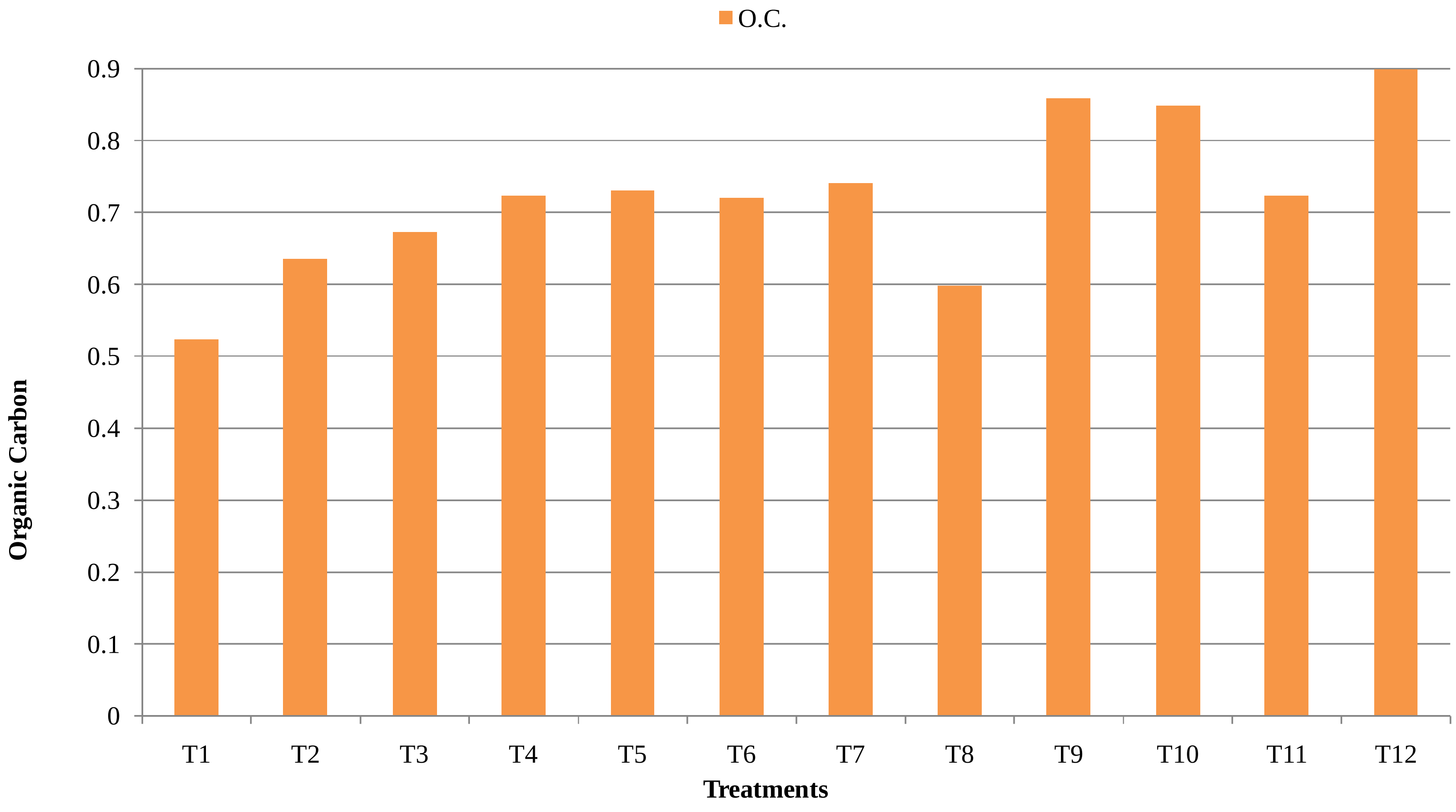

Figure 4.6: Effect of manure and fertilizer on chemical properties of soil

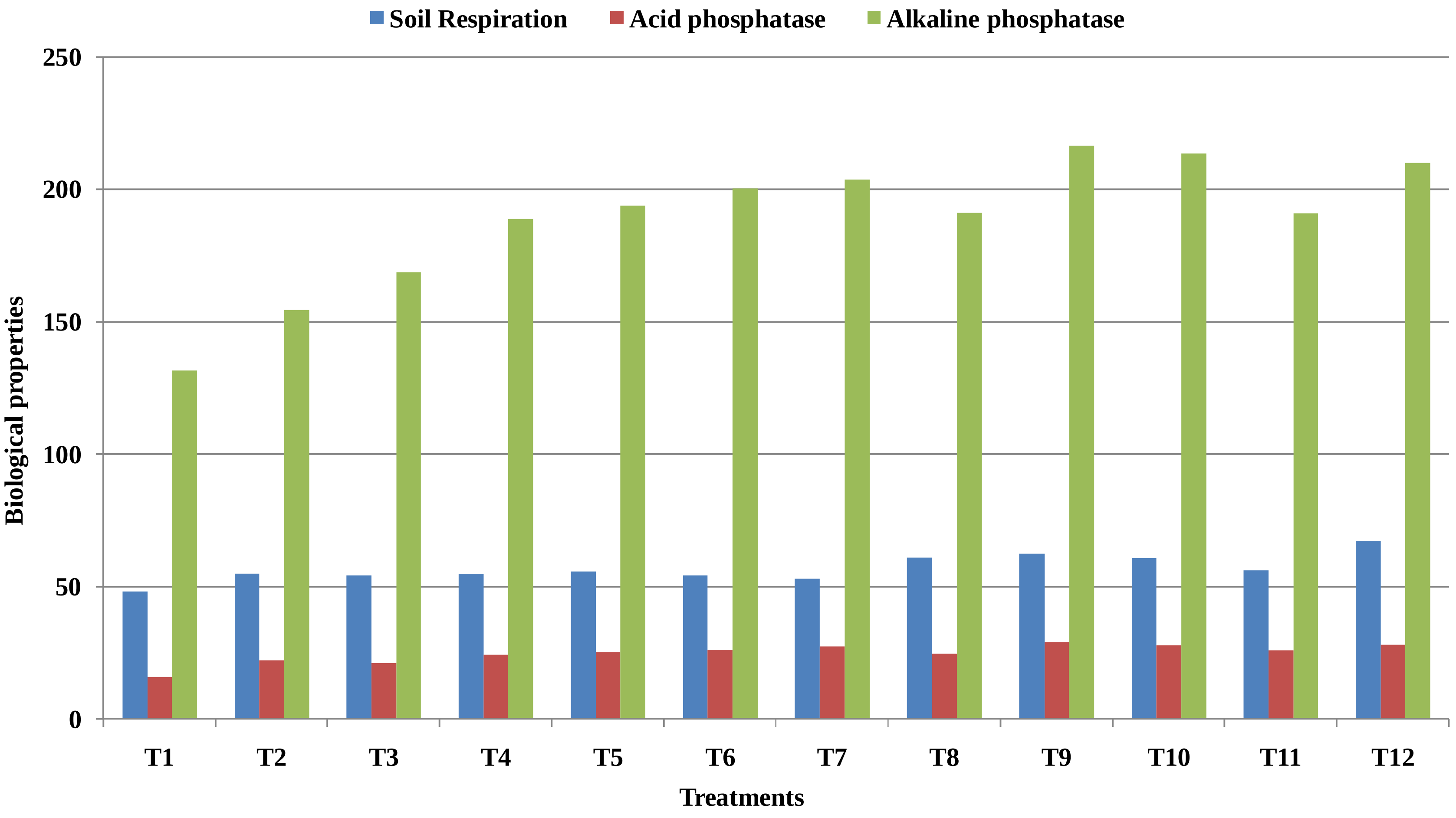

Figure 4.7: Effect of manure and fertilizer on biological properties of soil

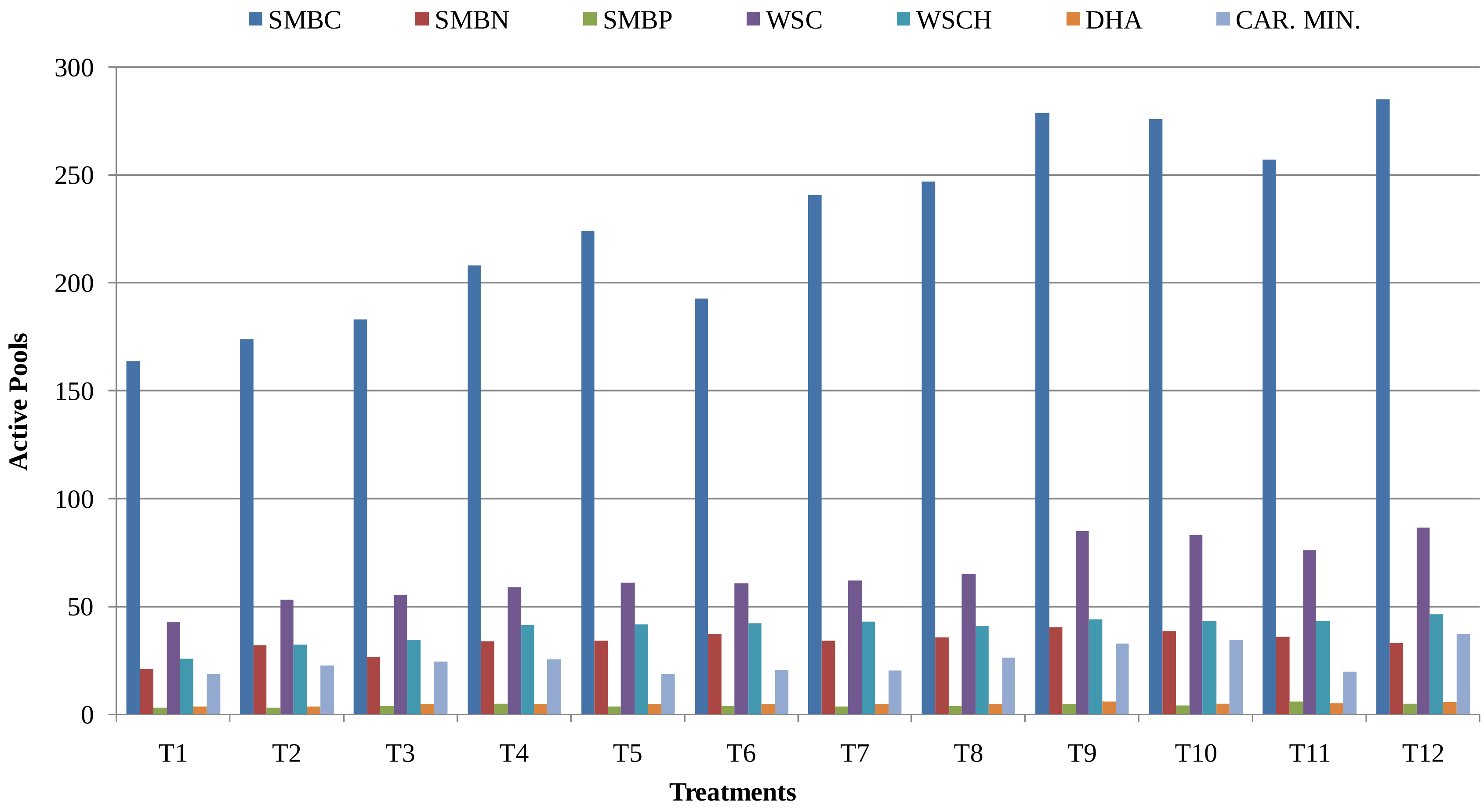

Figure 4.8: Effect of manure and fertilizer on active pools of organic carbon

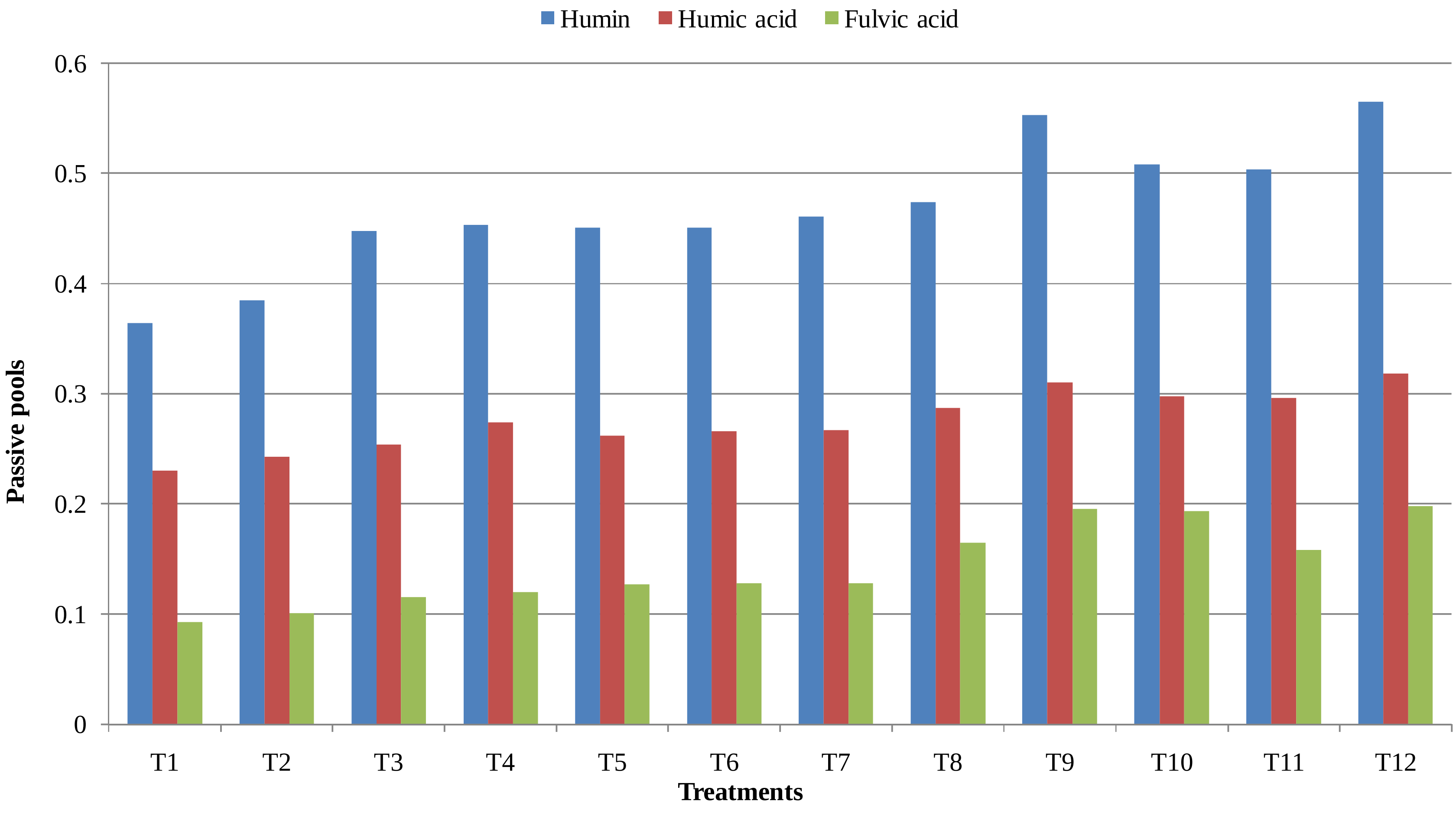

Figure 4.9: Effect of manure and fertilizer on passive pools of organic carbon

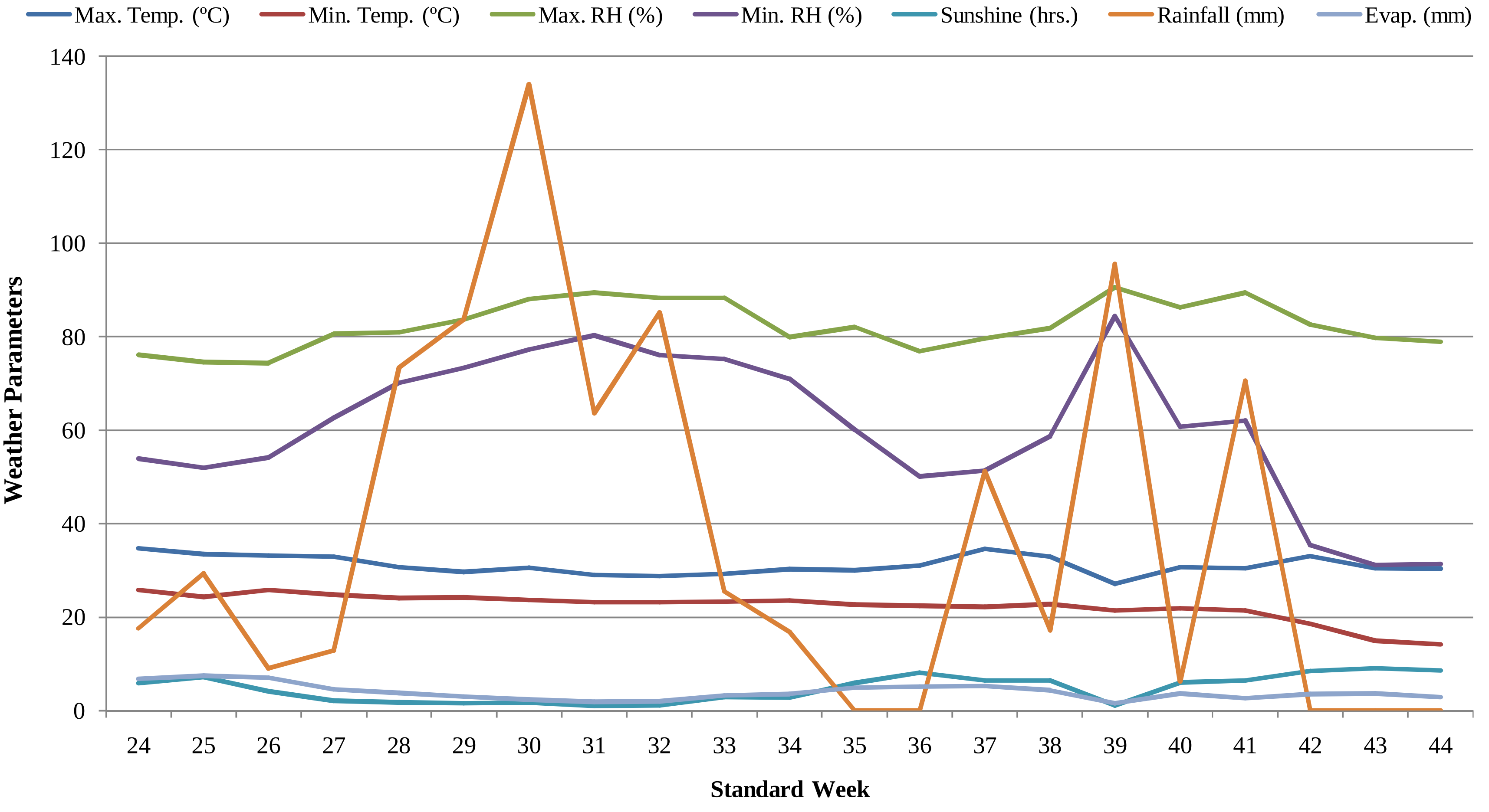

Fig. 3.1a Mean weekly weather parameters during the *Kharif* season (2013-14)

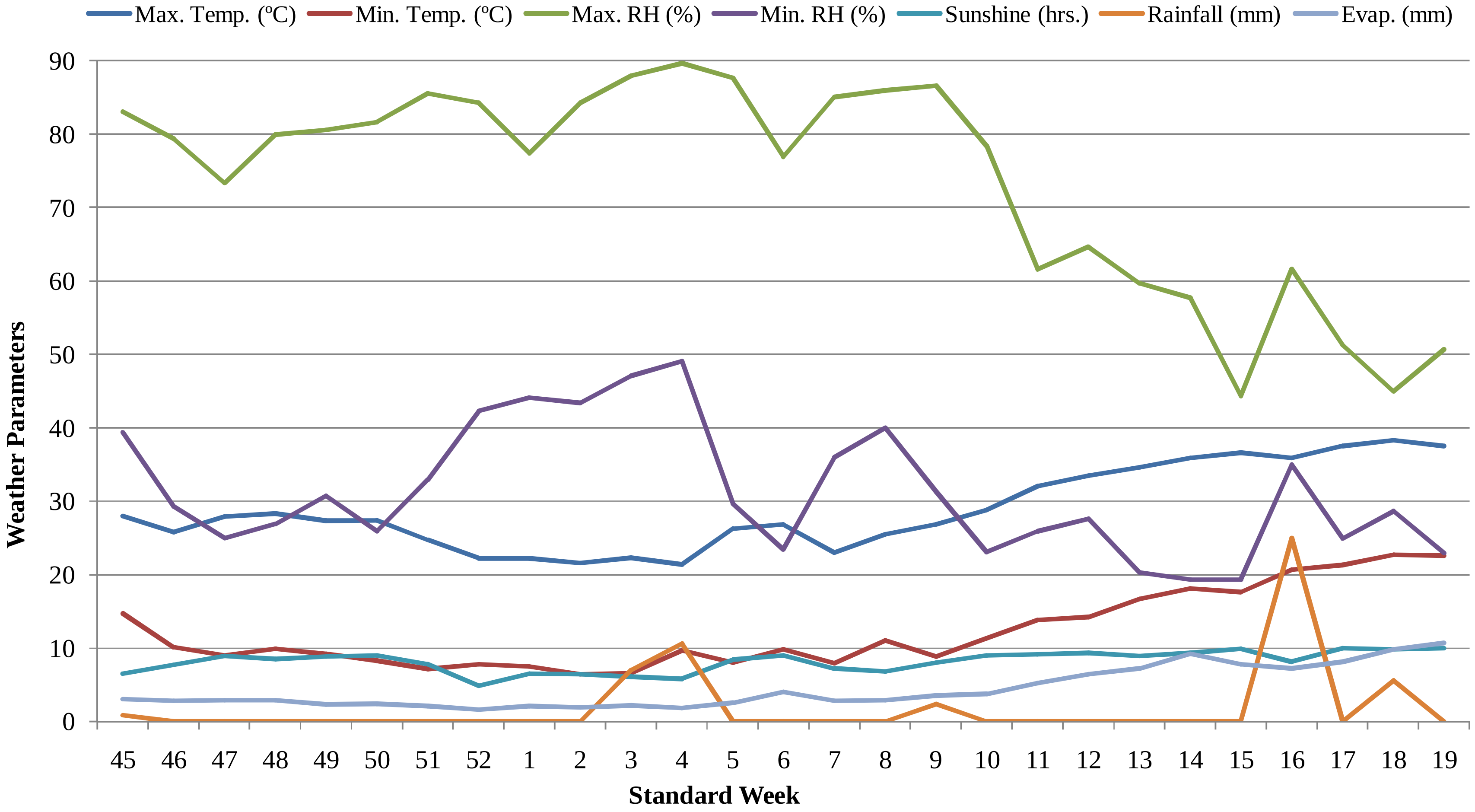

Fig. 3.1b Mean weekly weather parameters during the *Rabi* season (2013-14)

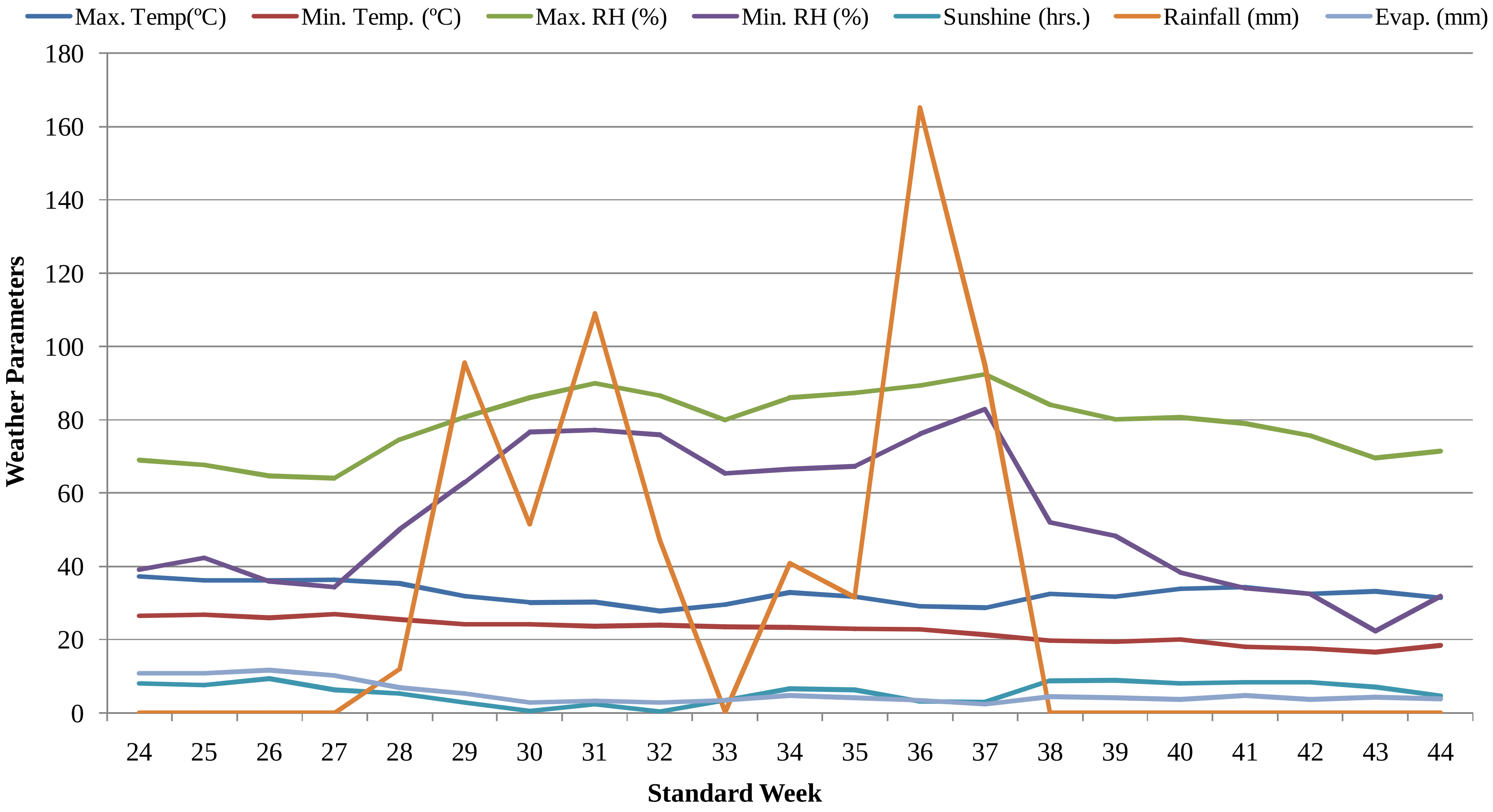

Fig. 3.2a Mean weekly weather parameters during the *Kharif* season (2014-15)

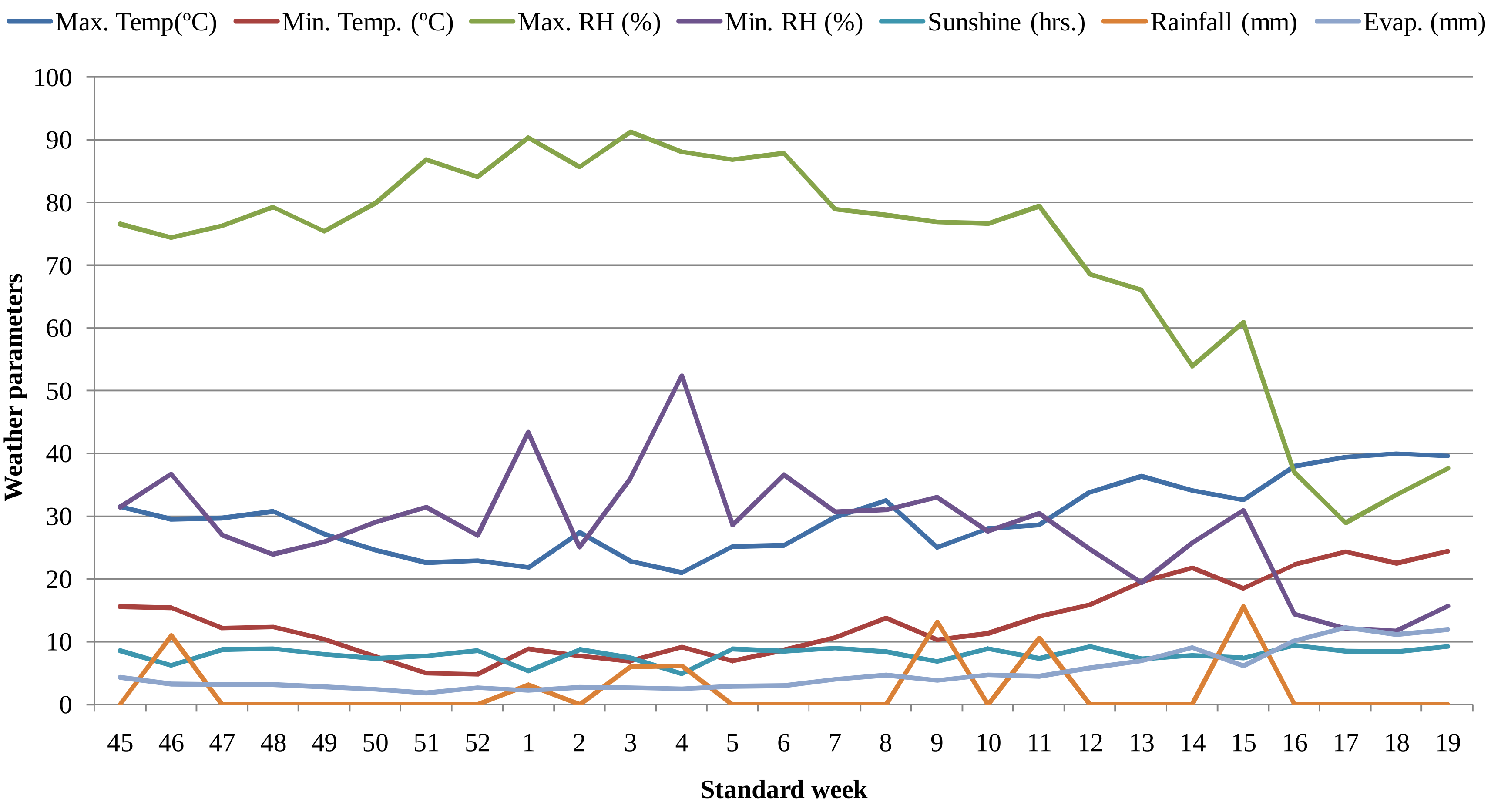

Fig. 3.2b Mean weekly weather parameters during the *Rabi* season (2014-15)

5. DISCUSSION

5.1 Effect of treatment on yield

The application of fertilizer and manure invariably recorded the highest grain and stover yield of maize. Almost similar trend was observed for grain and straw yield of wheat. The combined application of organic and inorganic fertilizers in continuous manner, might have sustained the crop yield. Lal (2006) reported that increases in crop yields due to increase in SOC in some soils might result from increase in labile fraction of carbon. Increase in yield with increase in SOC has been reported for many crops including wheat, mustard, sunflower and groundnut. Brar *et al.* (2015) also reported that better crop yields of maize and wheat with balanced application of organic manure and inorganic fertilizers may be attributed to improvements in soil physical properties along with sufficient supply of nutrients from FYM and inorganic fertilizers. The improved SOC concentration continuously from the initial level of 2.03 g kg^{-1} to 5.20 g kg^{-1} with application of FYM over 36 years might have also responsible for higher yields in treatments receiving FYM. Increases in yield due to inorganic and organic fertilizers have been reported by many other researchers. Application of manure and retention of crop residues increased soil moisture, SOC and improved yields of pearl millet (*Pennisetum typhoides*) by 0.1–0.2 Mg ha^{-1} in Rajasthan, India. The advantage of organic manures is quite obvious, as these provide a steady supply of nutrients leading better growth of plants. Moreover, the increased availability of P and K in addition to other plant nutrients released by the organic manures might have contributed in enhancing the yield-attributes. The positive impact of availability of individual plant nutrients and humic substances from manure and balanced supplement of nitrogen through inorganic fertilizers might have induced cell division, expansion of cell wall, meristematic activity, photosynthetic efficiency and regulation of water intake into the cells, resulting in the enhancement of yield parameters. Improvement in yield due to combined application of inorganic fertilizer and organic manure might be attributed to control release of nutrients in the soil through mineralization of organic manure which might have facilitated better crop growth (Sharma *et al.,* 2013). These results were confirmed by Mishra *et al.,* (2008), and Verma *et al.* (2012).

5.2 Effect of treatment on soil physico-chemical properties

The lowest bulk density was recorded with FYM application as compare to other treatments. Lowering of bulk density might be due higher organic carbon, more pore space and soil aggregation. Sheeba and Kumarswamy (2001) observed a decrease in bulk density with increase in organic matter content. Selvi *et al.* (2005) and Nkechi *et al.* (2013) also noticed reduction in bulk density of soil with application of organics alone and in combination with inorganic.

Continuous application of organics alone and in combination with inorganic fertilizer significantly increased the infiltration rate of soil over control treatment. The increase in infiltration rate might be due to addition of organic matter content and subsequent increase in porosity of soil. Similar results were reported by Brar *et al.* (2015).

The maximum plant available water was observed under the application of organic manure. The improvement in plant available water in response to the addition of organic matter is due to improved soil structure and water stable aggregates, as well as moisture retention capacity by increasing the total number of storage pores (Tadesse *et al.*, 2013).

Soil organic matter is the major binding agent and aggregation is hierarchical in which primary particles and clay domains are cemented together. Application of farm yard manure alone or in combination with chemical fertilizers significantly increased soil particles aggregation of soil after harvest of wheat crop. The initial status of soil organic carbon is also high. Brar *et al.* (2015) also noticed increase in water stable aggregation due to application of organic manure to the soil.

Application of recommended dose of fertilizer with FYM and super optimal dose of fertilizer registered maximum content of available N after the harvest of wheat crop. The reason might be due to the additional supply of N through recommended dose of NPK and contribution of additional N through super optimal dose of fertilizer and contribution of additional N through FYM in above two treatments. These results are in agreement with those of Kannan *et al.* (2013) and Manjhi *et al.* (2014).

Application of 100% NPK + FYM 10t ha^{-1} resulted in an increase in available phosphorus content of soil over control. This increase in available phosphorus might be due to decomposition of organic matter accompanied by the release of appreciable quantities of carbon dioxide, organic acids, which play an important role in increasing the phosphate availability. These findings are in line with findings of Tiwari *et al.* (2002), Kannan *et al.* (2013) and Manjhi *et al.* (2014).

Increase in available K status of soil by application of K has also been reported by Yaduvanshi and anand swarup (2006). The enhanced status of K could be attributed to the higher amount of K being add in super optimal dose of fertilizer (Kannan *et al.,* 2013).

Higher values of organic carbon content of the soil were found in the treatments receiving farmyard manure alone or in combination with chemical fertilizers as compared to those treatments receiving chemical fertilizers alone. Application of FYM alone or in combination with chemical fertilizers increased soil organic carbon content after harvest of wheat crop. Reason attributed is the direct incorporation of organic matter, better root growth and more plant residues addition after harvest of crops. These findings are in agreement with the observations of Kumar and Yadav (1993), Katyal *et al*. (2003), Kannan *et al.* (2013) and Brar *et al.* (2015).

Microbial respiration gives an overall picture of activity of biota of soil microbial population which is better maintained under the influence of application of organic manures. Higher population of various groups of microorganisms under the influence of chemical fertilizers, organics and integrated nutrient management have also been reported by earlier workers (Basak *et al.*, 2012 and Nayak *et al.,* 2012) results are in line with these reports.

The maximum phosphatase activity was found under the application of recommended dose of fertilizer with FYM. The acid phosphatase activity was much lower than alkaline phosphatase activity, irrespective of the treatments, which may be due to the alkaline reaction of the soil. Earlier studies also proved that phosphatase activity was strongly influenced by soil pH (Manna *et al.,* 2005, Mandal *et al*., 2007 and Simon and Czako, 2014).

5.3 Effect of treatment on active pool of soil organic carbon

5.3.1 Soil Microbial Biomass Carbon (SMBC)

The soil microbial biomass acts as the transformation agent of the organic carbon in the soil. As such, the biomass is both a source and sink of the carbon, nitrogen and phosphorus content in the organic carbon. It is the center of majority of biological activity in soil and therefore, the knowledge of the soil microbial biomass carbon is essential. Soil and crop management practices can greatly influences soil biological activity through their effect on quantity and quality of organic carbon added to soil. Use of FYM alone or in combination with chemical fertilizers significantly increased soil microbial biomass carbon (SMBC). The supply of additional mineralizable and readily hydrolysable carbon due to organic manure application might have resulted in higher microbial activity in return higher soil microbial biomass carbon. Many other workers (Kumari *et al.,* 2011, Venkatesh *et al*., 2013, Mandal *et al.,* 2013 and Tamilselvi *et al.,* 2015) have also shown marked build up in microbial biomass carbon in soil receiving manure.

5.3.2 Soil Microbial Biomass Nitrogen (SMBN)

Application of FYM in combination with inorganic fertilizers resulted in significantly higher soil microbial biomass nitrogen (SMBN) content as compared to the rest of treatments. High soil carbon content, more root proliferation and additional supply of N by FYM to microorganism might be responsible for increasing the level of SMBN. FYM is not only rich in C but also in N and other macro and micronutrients. But the availability of nutrients to the crop from FYM is generally lower than N from inorganic fertilizer because of the slow release of organically bound N and volatilization of NH_3 from the manure especially in calcareous soil (Beauchamp, 1983). Therefore, a combined application of FYM and fertilizer in the present study apparently provided supply of nutrients in balanced proportion which was reflected in terms of increased amounts of microbial biomass N. other alternate amendments, *viz.,* $ZnSO_4$ fertilizer application produced similar effect on microbial biomass N as the that of NPK. In control, there was reduction in biomass N from that observed with optimal NPK for both crops (Maize and wheat). With increase in fertilizer level from 100 to 150 % there was a significant increase in biomass N over control. Ghoshal and Singh (1995) reported 27 % increase in biomass N in the fertilizer treated plots in tropical dry land conditions. Mohanty *et al*. (2013), Manna *et al.* (2013) and Katkar *et al.* (2011) also found that the highest content of microbial biomass nitrogen was observed in NPK + FYM treated soil.

5.3.3 Soil Microbial Biomass Phosphorus (SMBP)

Continuous application of chemical fertilizers either alone or in combination with FYM increased the soil microbial biomass phosphorus (SMBP) content as compared to zero fertilized plots. Integrated use of organic and inorganic significantly increased the crop productivity and thereby provided substrates essential for microbial growth and activity which are probably responsible for this increase in SMBP. The low content in control plot could be due to no addition of any external input into the soil over the years and thereby poor crop productivity. Low content of SMBP in 100 % N alone was observed. Reason attributed is the reduction/ death of microbial cells due to absence of any phosphate substrate. The addition of higher levels of phosphorus through external source might have influenced the metabolism of microorganisms, which is probably responsible for higher levels of SMBP. Similar elevation in SMBP with the application of super-optimal dose of NPK and the rise in content of SMBP were also reported Verma and Mathur (2009).

5.3.4 Water Soluble Carbon (WSC)

Water soluble carbon is considered as most mobile from of SOC and is immediate organic substrate for microorganism. It is realized from microbial activity, root exudation and leaching of organic carbon. Highest water soluble carbon was observed in treatment receiving FYM alone followed by treatment with continuous addition of FYM in association with 100% NPK fertilizers whereas the lowest content was found in controlled treatment in both the crop. The newly humified organic carbon through FYM addition might have sustained higher amount of WSC in sole FYM treatment whereas higher amount of water soluble carbon in the 100% NPK + FYM @ 10 t ha^{-1} might be due to its origin and root exudates and lysates and its presence in soil solution. The results are in agreement with Yagi *et al.*, (2005) who attributed the same to the priming effect of the application of inorganic N or fresh organic material to the soil which stimulates the microbial activity and mineralization of N forms present in SOC helping thereby in decomposition of SOC with rapid release of WSC fraction. These results were confirmed by Verma and Mathur (2009).

5.3.5 Water soluble carbohydrates

Carbohydrates comprise one of the major groups of naturally occurring organic molecules. The carbohydrate material in soil occurs as: a) Free sugars in the soil solution, b) Complex polysaccharides which can be extracted and separated from other organic constitutes and c) Polymeric molecules of various sizes and shapes which are so strongly attached to clay and humic colloids that cannot be easily isolated and purified (Stevenson, 1982). The higher water soluble carbon was observed in treatment FYM 20 t ha^{-1}. Water soluble carbohydrates serves as source and sink for mineral nutrients and organic substrates in a short – term and as a catalyst for conversion of plant nutrients from over a longer period and there for influence crop productivity and nutrient cycling (Kumari *et al*., 2013). Verma and Mathur (2009) and Manna *et al.* (2013) also found that the highest content of water soluble carbohydrate was observed in FYM treated plot along with inorganic fertilizer.

5.3.6 Dehydrogenase Activity

All biological reactions in soil are catalyzed by enzymes. Soil enzyme activities are believed to indicate the extent of specific processes in soil and in some cases act as indicators of soil fertility. Biological oxidation of organic compounds is generally a dehydrogenation process and there are many dehydrogenases that carry out the following reactions. Highest dehydrogenase activity was observed in combined application of FYM with inorganic fertilizer followed by FYM alone. The results are in line with the findings reported by (Bhattacharyya *et al.,* 2008). Where in observed 4-5 folds increase in dehydrogenase activity due to farmyard manure application along with NPK. The addition of farmyard manure couple with mineral fertilization exerted a stimulating influence on preponderance of bacteria (Mandal *et al.,* 2007). Verma and Mathur (2007) and Katkar *et al*., (2011) also found the similar results.

5.3.7 Carbon mineralization

The results indicated that maximum carbon mineralization occurred in the treatment receiving FYM alone. The amount of mineralized CO_2–C increased with the application of increasing level of FYM fertilizers from FYM 10 t ha^{-1} +100 % NPK-NPK of FYM and 100% NPK+ FYM 10 t ha^{-1}. The reason attributed is that this might be due to the regular addition of manure, which enhanced the water soluble fraction carbon and acted as an important source of bio-energy as compared to inorganic alone. (Salinas *et al.,* 1997).

5.4 Effect of treatment on passive pool of soil organic carbon

5.4.1 Humin

Humin is the most resistant fraction of SOC and its contribution is the largest among other fraction. The highest concentration of humin was observed in the treatment FYM 20 t ha^{-1} followed by treatment 100% NPK + FYM 10 t ha^{-1}. Continuous addition of organic and inorganic treatments noticed increased content over control. The reason might be due to better and improved soil physical parameters and conductive environment for its fraction. The increase in the concentration of mineralization owing to the higher temperature of surface soil in tropical regions (Santhy *et al*., 2001).

5.4.2 Humic Acid (HA)

Humic acid (HA) is one of the important fractions of SOC whose improvement tells in nutrient restoration and transformation in soil for higher yields. Humic acid content increased in soil with the application of fertilizer and FYM. The highest concentration of humic acid was recorded under treatment FYM 20 t ha^{-1}, followed by treatment 100% NPK + FYM 10 t ha^{-1} which could be due to improved soil physical parameters and a conductive environment for the formation of humic acid (Santhy *et al.,* 2001). Srilatha *et al.* (2013) also reported that the content of humic acid increased with increased levels of fertilizer application over control, respectively and higher content of humic acid and fulvic acid were recorded under 100% NPK+FYM followed by 150% NPK and in fallow treatment.

5.4.3 Fulvic Acid (FA)

Fulvic acid is a part of organic carbon which is soluble in alkali and remains in solution when the humic acid is precipitated with acid. It is low molecular weight chemical and it is less complex in structure compared to humic acid and supposed to be more related to soil fertility. Fulvic acid, although primarily considered to be humic acid precursor, may be humic acid degradation product as well. It is probable that fulvic acid can be adsorbed in to clay, but the size of their molecules suggests that forces of attraction would be less than those for larger humic acid constituents. Fulvic acid content of soils of different treatments was highest in treatment FYM 20 t ha^{-1} followed by treatment 100% NPK+FYM 10 t ha^{-1}. Similar trend was reported by (Santhy *et al.,* 2001)

5.5 Correlation between soil organic carbon pools

The soil microbial biomass carbon fraction ascribed highly significant positive relationship with wheat grain yield, maize grain yield, soil microbial biomass nitrogen, water soluble carbon, humic acid, Humin and significant positive relationship with soil microbial biomass phosphorus and fulvic acid. The results of present investigation are in line with the finding of Thakre and Ravankar (2004) and Santhy (1999).

The soil microbial biomass nitrogen fraction ascribed highly significant positive relationship with wheat grain yield, wheat straw yield, maize grain yield, soil microbial biomass phosphorus, dehydrogenase activity, carbon mineralization, humic acid, humin and significant positive relationship with water soluble carbohydrates and fulvic acid. These observations are in close conformity to those obtained by Vance *et al.* (1987).

The soil microbial biomass phosphorus fraction ascribed highly significant positive relationship with maize grain yield and significant positive relationship with wheat grain yield, dehydrogenase activity, carbon mineralization and humin.

The Water soluble carbon fraction ascribed significant positive relationship with maize grain yield, maize stover yield and wheat grain yield. The water soluble carbon highly significantly correlated with dehydrogenase activity and humic acid, While it show significant positive relationship with WSCO, carbon mineralization, fulvic acid and humin.

The Water Soluble Carbohydrates fraction ascribed highly significant positive relationship with maize grain yield, wheat grain yield, wheat straw yield. The water soluble carbohydrate significantly correlated with dehydrogenase activity, carbon mineralization and humin.

The dehydrogenase activity fraction ascribed significant positive relationship with maize grain yield, maize stover yield, carbon mineralization and significant positive relationship with humic acid, fulvic acid and humin.

The carbon mineralization fraction ascribed highly significant positive relationship with maize stover yield, wheat grain yield, humin and significant positive relationship with maize grain yield, wheat straw yield and humic acid. Verma and Mathur (2007) show relationship among active pools of soil organic matter and C/N, SMBC, SMBN, SMBP. The C/N ratio was highly and significantly correlated with soil microbial biomass carbon (SMBC), soil microbial biomass nitrogen (SMBN), water soluble carbon (WSC), water soluble carbohydrates (WS-CHO) and dehydrogenase activity (DHA) under maize crop.

The humic acid fraction ascribed highly significant positive relationship with maize grain and stover yield and wheat straw yield, fulvic acid and humin and significant positive relationship with wheat grain yield.

The fulvic acid fraction maize grain and stover yield, wheat grain and straw yield observed non-significant. The fulvic acid significant correlated with humin.

The humin fraction ascribed highly significant positive relationship with maize grain and stover yield, wheat grain yield and straw yield.

5.6 LTFE-Pooled Stepwise Regression

Soil microbial biomass carbon followed by soil microbial biomass nitrogen, soil microbial biomass phosphorus, water soluble carbon, water soluble carbohydrates, soil dehydrogenase activity, humic acid fulvic acid and Humin explained jointly the variation in maize grain and stover yield, wheat grain and straw yield yield up to 92, 99, 98 and 97 per cent to the maximum extent. Brar *et al.* (2015) reported that the SOC pool was significantly correlated with grain yields of maize (R^2 = 0.80) and wheat (R^2 = 0.65). Although, the value for correlation coefficient (R^2) was higher for maize compared to wheat. Crop yields increased by 490 kg ha^{-1} for maize and 110 kg ha^{-1} for wheat with every 1 Mg increase in SOC pool in the 0–15 cm depth under 100% NPK + FYM compared to 100% NPK treatment.

6. SUMMARY AND CONCLUSION

Salient findings emerging out of the field experiment are presented in preceding chapter are summarized as follows:

1. The combined application of organic and inorganic fertilizers in continuous manner, might have sustain the crop yield of both the crop.
2. The application of farm yard manure significantly decrease the bulk density and increase the infiltration rate, available water content and soil aggregate.
3. The highest available nitrogen and phosphorus observed under the combined application of fertilizer and manure and highest available potassium under the application of super optimal dose.
4. The soil organic carbon and soil microbial respiration significantly increased under the application of organic manure.
5. The combined application of manure and fertilizer increased the acid and alkaline phosphatase activity of the soil.
6. The passive pools *viz.* humin, humic acid and fulvic acid of soil organic carbon increased under the application of organic manure.
7. The maximum content of soil microbial biomass carbon, water soluble carbon, water soluble carbohydrate and carbon mineralization were registered under application of farm yard manure in LTFE soils. The combined application of fertilizer and manure increased the soil microbial biomass nitrogen and dehydrogenase activity but the highest soil microbial phosphorus was observed under the application of super optimal dose of fertilizer.
8. The significant positive correlation between active organic carbon pools and yield of maize and wheat was observed. However, among passive pools only humin have significant correlation with yield of maize and wheat.
9. SMBN, WSC and humin pool of organic carbon positively correlated with all other pools.

10. The variation of 92, 99, 98 and 97 percent in maize grain, maize stover, wheat grain and wheat straw yield was explained jointly different organic carbon fractions studied.

Conclusion:

The study concluded that the maximum yield of maize and wheat crop obtained under the combined application of organic manure and fertilizer. Available N, P and K in soil also increased significantly under this treatment. Application of 20 t ha^{-1} FYM improved the physico-chemical and biological properties of soil.
Long term application of FYM alone or in combination with chemical fertilizer improved active and passive pools of soil organic carbon *i.e.* soil microbial carbon, water soluble carbon, water soluble carbohydrate, carbon mineralization humin, humic acid and fulvic acid in the maize-wheat cropping sequence. Correlation studies revealed that active and passive pools of soil organic matter helps in nutrient restoration. Different carbon fraction explain 92, 99, 99 and 98 percent variation in maize grain, maize stover, wheat grain and wheat straw yield.

Application of chemical fertilizers alone could not sustain the soil fertility status and productivity. Thus, integrated nutrient management in maize-wheat cropping system effective for sustainability of yield under the long term continuous application of fertilizer and manure.

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Effect of Long Term Application of Fertilizer and Manure on Soil Organic Carbon Fractions under Maize-Wheat Cropping Sequence in *Haplustepts*

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Research Scholar Major Advisor

ABSTRACT

A field experiment entitled **"Effect of Long Term Application of Fertilizer and Manure on Soil Organic Carbon Fractions under Maize-Wheat Cropping Sequence in *Haplustepts*"** was conducted at the Agronomy farm, Rajasthan College of Agriculture, Udaipur during 2013-14 and 2014-15 with the objectives to work out the effect of long term application of fertilizer and manure under maize-wheat cropping sequence on active and passive fraction of soil organic matter (SOM) and to establish relationship between these fractions of soil organic carbon and maize and wheat yield in *Haplustepts*.

The soil of the experimental field was sandy clay loam in texture, non-saline and slightly alkaline in reaction. The macro and micronutrient analysis revealed that soil was medium in N (360 kg ha^{-1}) and P (22.4 kg ha^{-1}), high in K_2O (671 kg ha^{-1}) and have sufficient level of DTPA extractable Fe, Mn, Zn and Cu. The experiment consisted of 12 treatment combinations *viz.,* T_1-Control, T_2-100%N, T_3-100%NP, T_4-100%NPK*, T_5-100%NPK+Zn, T_6-100%NPK+S, T_7-100%NPK+Zn+S, T_8-100%NPK+Seed treatment with *Azotobacter,* T_9-1000%NPK+ FYM 10 t ha^{-1}, T_{10}-FYM 10 t ha^{-1} +100%NPK (-NPK of FYM), T_{11}-150%NPK and T_{12}-FYM 20 t ha^{-1} with four replications in a randomized block design.

The results of the present investigation revealed that the maximum yield of maize and wheat crop in terms of grain, straw are obtained under the combined application of organic manure and fertilizer (100% NPK + 10 t ha^{-1} FYM). Available N, P and K in soil also increased significantly under this treatment.

Application of 20 t ha^{-1} FYM improved the physico-chemical and biological properties of soil *viz.* bulk density, infiltration rate, soil aggregate, plant available water, organic carbon, soil microbial respiration. The application of farm yard manure also increased the active and passive soil organic carbon fractions *i.e.* soil microbial carbon, water soluble carbon, water soluble carbohydrate, carbon mineralization humin, humic acid and fulvic acid.

The results of present study indicated that application of FYM alone and in combination with chemical fertilizer improved soil physico-chemical properties and available nutrient status. The soil organic matter pools were noticeably higher in plots dressed with organic manure and integrated use of fertilizer and manure (100% NPK + FYM) as compared to inorganic fertilizers (100% NPK).

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Appendix X: Correlation between organic carbon pools and maize grain yield

	d.f.	SS	MS	F	Sig.
Regression	10	6073977.756	607397.776	8.768	.257[a]
Residual	1	69274.152	69274.152		
Total	11	6143251.908			

	Coefficients	Std. Error	T Stat	Sig.
Intercept	-7724.775	3987.038	-1.937	.303
Humin	-36607.832	29605.439	-1.237	.433
Humic	55981.514	24062.981	2.326	.258
Fulvic	-55654.875	20129.086	-2.765	.221
SMBC	.921	12.047	.076	.951
SMBN	-9.745	93.342	-.104	.934
SMBP	-739.853	392.812	-1.883	.311
WSC	85.211	79.320	1.074	.477
WSCH	54.832	85.533	.641	.637
DHA	2794.843	1318.982	2.119	.281
CAR. MIN.	87.017	53.001	1.642	.348

Summary Output

	Regression	Statistics	
	Multiple R	0.924	
	R Square	0.926	
	Adjusted R	0.989	
	Standard E	0.876	

Appendix XI: Correlation between organic carbon pools and maize stover yield

	d.f.	SS	MS	F	Sig.
Regression	10	9317105.378	931710.538	3.841	.379[a]
Residual	1	242548.776	242548.776		
Total	11	9559654.154			

	Coefficients	Std. Error	t Stat	Sig

Intercept	-9959.545	7460.438	-1.335	.409
Humin	-34867.974	55396.897	-.629	.642
Humic	70919.831	45025.999	1.575	.360
Fulvic	-66942.506	37665.003	-1.777	.326
SMBC	-.905	22.541	-.040	.974
SMBN	18.721	174.660	.107	.932
SMBP	-866.465	735.020	-1.179	.448
WSC	79.936	148.421	.539	.685
WSCH	51.507	160.048	.322	.802
DHA	2913.155	2468.043	1.180	.447
CAR. MIN.	89.831	99.174	.906	.531

Summary Output

	Regression	Statistics
	Multiple R	0.987
	R Square	0.996
	Adjusted R	0.721
	Standard E	92.49241

Appendix -XII: Correlation between organic carbon pools and wheat grain yield

	d.f.	SS	MS	F	Sig.
Regression	10	1.042E7	1042008.512	5.677	.316[a]
Residual	1	183560.196	183560.196		
Total	11	1.060E7			

	Coefficient	Std. Error	t Stat	Sig.
Intercept	-9888.822	6490.139	-1.524	.370
Humin	-50063.829	48192.023	-1.039	.488
Humic	74760.317	39169.955	1.909	.307
Fulvic	-72799.225	32766.323	-2.222	.269
SMBC	-2.730	19.610	-.139	.912

SMBN	-30.723	151.944	-.202	.873
SMBP	-1023.587	639.424	-1.601	.355
WSC	125.134	129.117	.969	.510
WSCH	125.407	139.232	.901	.533
DHA	3400.721	2147.052	1.584	.359
CAR. MIN.	123.878	86.276	1.436	.387

Summary Output

	Regression	Statistics
	Multiple R	0.991
	R Square	0.984
	Adjusted R	0.810
	Standard E	28.43926

Appendix- XIII: Correlation between organic carbon pools and wheat straw yield

	d.f.	SS	MS	F	Sig.
Regression	10	2.307E7	2306666.421	3.834	.379[a]
Residual	1	601669.374	601669.374		
Total	11	2.367E7			

	Coefficient	Std. Error	t Stat	Sig.
Intercept	-16371.691	11750.158	-1.393	.396
Humin	-78652.153	87249.882	-.901	.533
Humic	126913.416	70915.760	1.790	.324
Fulvic	-110026.104	59322.222	-1.855	.315
SMBC	-7.983	35.503	-.225	.859
SMBN	-85.575	275.088	-.311	.808
SMBP	-1824.103	1157.653	-1.576	.360
WSC	170.938	233.762	.731	.598

WSCH	250.279	252.074	.993	.502
DHA	5065.056	3887.158	1.303	.417
CAR. MIN.	240.831	156.199	1.542	.366

Summary Output

Regression	Statistics
Multiple R	0.987
R Square	0.978
Adjusted R	0.720
Standard E	75.67350