

**LONG-TERM EFFECTS OF ORGANIC
MANURES AND FERTILIZERS ON SOIL
ORGANIC CARBON POOLS AND NITROGEN
FRACTIONS**

By
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CERTIFICATE – I

This is to certify that this thesis entitled, **“Long-term effects of organic manures and fertilizers on soil organic carbon pools and nitrogen fractions”** submitted for the degree of **“Doctor of Philosophy”** in the subject of **soil science** to the Chaudhary Charan Singh Haryana Agricultural University, Hisar, is a bonafide research work carried out by **Mr. Kumara, B. H.** under my supervision and that no part of this thesis has been submitted for any other degree.

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

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CERTIFICATE – II

This is to certify that this thesis entitled **“Long-term effects of organic manures and fertilizers on soil organic carbon pools and nitrogen fractions”** submitted by **Mr. Kumara, B. H.** to the Chaudhary Charan Singh Haryana Agricultural University, Hisar, in partial fulfillment of the requirements for the degree of **“Doctor of Philosophy”** in the subject of **Soil Science** has been approved by the Student’s Advisory Committee after an oral examination on the same, in collaboration with an external examiner.

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CHAPTER-I

INTRODUCTION

“Soil quality is how well soil does what we want it to do” (Alan and Richard, 2006) long-term experiments are considered as valuable tools to understand the complex interaction involving soils, plants, climate and management practice and their effects on soil health and crop productivity. Long-term monitoring allows both the identification of current changes in the soil and prediction of future changes. Long-term experiments are valuable tools for determining yield trend, understanding changes in yield, estimating nutrient dynamics, and assessing system sustainability. The complex problems of soil fertility management can be monitored by conducting long-term field experiments as it takes time for the crops, crop rotation, fertilizers and manures to have a measurable effect on soil fertility. Long-term fertilization is a key to sustainable crop production and maintenance of soil health, long-term application of organic manures and fertilizer, which advocates the combined and optimum use of all available nutrients, is the key component of soil health enhancement.

The green revolution technologies involving greater use of synthetic agrochemicals such as fertilizers and pesticides with adoption of nutrient-responsive, high-yielding varieties of crops have boosted the production output per hectare in most of the crops. However, during the last decades, increase in production has slowed down and in some crops there are indications of decline in growth of productivity and production. There have been several reports from the farmers that they have to use higher quantities of fertilizers each year to obtain the same yield level as obtained in previous year. The probable reason for this type of behavior in yield pattern of crops is decline in organic matter content, imbalanced use of fertilizers, extra mining of nutrients, low use of organic manures and deficiency of secondary and micronutrients. The use of organic manures with chemical fertilizers may be an effective alternate approach for further improving levels of the crop yields and sustaining soil health.

The loss of soil fertility, in many developing countries, due to continuous nutrient depletion by crops without adequate replenishment poses an immediate threat to food and environmental securities. There is a need to revive the age-old practice of application of organic manures to maintain soil fertility and also to supplement many essential plant nutrients for crop productivity. Organic manures are an important component of soil influencing a number of constraints linked with crop productivity. Amount of soil organic matter in most arid, semi-arid and sub-tropical soils is relatively low yet its influence on soil properties is of great significance. The increase in soil organic matter in agricultural soils has become a major issue on the past years because more than 70 % of terrestrial C stocks involved in the active C cycle as stored in the soil whereas only around about 30 % are bound

in the vegetation. Currently, the CO₂ contraction in atmosphere is 400 ppm, which equals to 824.7 qt C (IPCC, 2007). The use of inorganic fertilizers in combination with organic manures has been found more advantageous than either of them on their own for sustainable agriculture for long-term basis (Narwal and Antil 2005). Integrated nutrient management could be followed for enhancing crop productivity of intensive cropping systems, nutrient availability, biological properties and soil carbon pools for long-term (Moharana *et al.* 2012). Sequestered soil organic carbon (SOC) with a relatively long turnover time, is returned to the recalcitrant soil pool, thus decreasing the rate of accumulation of atmospheric CO₂ concentration. Diversified cropping systems with better management substantially improved SOC in semiarid-tropical soils of India (Manna *et al.* 2006).

Enhancing SOC pool through humification of biomass is an important strategy to offset fossil fuel emissions, improve soil quality, increase and sustain agronomic productivity. Increasing SOC pool requires soil available nutrient such as NPK and S, without which the C rich biomass cannot be converted into humus. Thus achieving global SOC sequestration potential of 0.6 to 1.2 Gt C per year would require annual supply of 4 to 7 Gt of biomass, 0.05 to 0.10 Gt of N, 0.01 to 0.02 Gt of P and 0.009 to 0.0017 Gt of S (Lal, 2006). SOC concentration in soil depends on the availability of C provided through biomass and other building blocks comprising of essential elements. Assuming that soil humus has C: N ratio of 12:1, C: P ratio of 50:1 (Himes, 1998).

Nitrogen has been made increasingly available, resulting in its extensive use however the major concern has been its disproportionate use by the farmers resulting in nutrient imbalance irrespective of crops or soils. This has manifested in several nutritional usages and has affected soil fertility and productivity. Inorganic forms of soil nitrogen constitute 2 to 6 per cent of the total N implying that a major portion is found in the organic combination. All these forms constitute an extremely dynamic system influenced by physical and chemical processes, in the soil system (Savant and De Datta, 1982). A major portion of the soil nitrogen was in organic combination, which was acid hydrolysable constituting 62 to 87 per cent of the total soil nitrogen and the major organic - N hydrolysable fractions were the amino-acids, hydrolysable NH₄⁺ - N and amino sugars and the balance were referred to as unidentified N (Stevenson, 1982). Hydrolysable ammonical nitrogen is also one of the major constituent of soil organic nitrogen, derived from the decomposition of amides, amino sugar, amino acids, fixed ammonical nitrogen on the clay minerals and some N containing minerals (Bremner, 1960).

Long-term experiments on the integrated nutrient management (farmyard manure (FYM) and fertilizer N); and various combinations of organic manures and fertilizers were established in 1967 and 1995, respectively, under pearl millet-wheat cropping sequence. In this experiment, basic data on soil physical properties (Khanna *et al.* 1975; Singh, 1991),

different forms of N (Sethi *et al.* 1976; Sagwal, 1981), nutrient depletion due to continuous cropping in soil without addition of manure (Rahul and Shukla, 1979; Sagwal, 1981; Gupta *et al.* 1996; Chaudhary and Narwal, 2005; Rohtash kumar, 2006; Antil and Narwal, 2007; Antil *et al.* 2011), periodical mineralization of NPK (Gupta *et al.* 1988), uptake of nutrients (Rahul and Shukla, 1979; Gupta *et al.* 1992; Rohtash kumar, 2006; Chaudhary, 2002; Narwal and Antil, 2005; Chaudhary and Narwal, 2005), yield (Gupta *et al.* 1999, 2003; Antil, 2009), fractions of organic C pools (Ranjan laik, 2002); P fractions (Antil *et al.* 1985), fractions of K, Zn and Cu (Rohtash kumar, 2006), fractions of S, Fe and Mn (Ramanjaneya Reddy, 2005) and N balance in soil (Narwal *et al.* 2010; Antil *et al.* 2011) have been reported previously. In another long-term experiment, effect of various combination of organic manures and fertilizers (established in 1995) have been reported previously on various soil properties and available nutrients status of soil (Antil and Mandeep, 2007).

In this above background of research, researchers have provided valuable information on impact of long-term adoption of nutrient systems with varying sources, types and combinations of plant nutrients on soil fertility and productivity. Therefore, there is need for studying at present situation of both sets of long-term experiments due to the climatological changes and continuous intensive cropping sequences. Hence, a study was undertaken on **"long-term effects of organic manures and fertilizers on soil organic carbon pools and nitrogen fractions"** with the following objectives:

1. To study the impact of modes and levels of FYM and fertilizer N; and various combinations of organic manures and fertilizers on wheat yield and nutrient uptake.
2. To study the impact of modes and levels of FYM and fertilizer N; and various combinations of organic manures and fertilizers on soil organic carbon pools and N fractions.
3. To study the impact of various combinations of organic manures and fertilizers on periodic changes in organic C, available N and P content of the soil during the growing period of wheat.

CHAPTER-II

REVIEW OF LITERATURE

Soil organic carbon (SOC) is simultaneously a source and sinks for nutrients and plays a vital role in soil fertility maintenance. Inorganic forms of soil nitrogen (N) constitute 2 to 6 per cent of the total N implying that a major portion is found in the organic forms. The use of inorganic fertilizers in combination with organic manures has been found more advantageous than either of them on their own for sustainable agriculture for long-term basis (Narwal and Antil 2005; Antil *et al.*, 2011). Continuous application of organic manures alone or in conjunction with NP fertilizers for 10 years decreased the soil pH and reverse trend was observed in case of EC, organic C content, and their application also increased the available N, P, K and DTPA extractable Zn, Fe, Mn and Cu content of soil (Antil and Mandeep, 2007). Application of FYM increased the organic C, macro and micronutrient content of soil (Chaudhary & Narwal, 2005); organic C pools (Ranjan laik, 2002) and N balance in soil (Antil *et al.*, 2011). The limited recent reviews related to the present investigation are given under the following headings.

- 2.1 Long-term experiments for sustainable use
- 2.2 Carbon pools.
- 2.3 Nitrogen fractions
- 2.4 Periodical transformations of major plant available nutrients in soil
- 2.5 Correlations between soil organic C pools and N fractions
- 2.6 Organic manures effects on crops yield, uptake of nutrients and soil properties

2.1 Long-term experiments for sustainable use

J. B. Lawes and J. H. Gilbert started nine long-term experiments between 1843 and 1856 but one of these was discontinued in 1878. Even after the death of Lawes in 1900, the eight remaining experiments were continued more or less as originally planned; these are called the 'Rothamsted Classical Experiments'. The main objectives was to measure the effects of inorganic compounds containing N, P, K, Na and Mg elements known to occur in considerable amounts in crops and FYM on crop yields but their separate actions as plant foods had not been studied systematically. The effects of these inorganic fertilizers alone and in various combinations were compared with those of FYM and mustard cake in most of the experiments. These experiments are being continued for more than 150 years and yielded most valuable information for adoption of an efficient approach for managing the crops and cropping systems. Growing of same crop year after year on the same land was considered as bad farming in the nineteenth century, but it has now become an established practice for

growing cereal. It has added emphasis on the urgency and priority of these experiments, as the information emerging from these studies has led to many timely interventions in agronomic practices. After 1957 several of the classical experiments were modified to evaluate the residual effects of the annually repeated dressings of different combinations of nutrients. These experiments are continuously providing the most valuable information for changes in strategy and policy to enhance productivity without adverse effect on environment.

In the beginning of this century, based on Rothamsted model, in India also a series of long-term fertilizer experiments were established at different locations in the country. These were at Kanpur, Uttar Pradesh (1905); Pusa, Bihar (1908); and at Coimbatore, Tamil Nadu (1909). Later on more long-term fertilizer experiments were established with more heavily fertilized crop such as sugarcane at Sahajahanpur (Uttar Pradesh) 1935; Padegaon (Maharashtra) 1939; Indore (Madhya Pradesh) 1947; Muzaffarnagar (Uttar Pradesh) 1947; and at Anaka Palle (Andhra Pradesh) 1950 and on cereal based cropping system at Ranchi (Jharkhand) 1956; and at Hisar (Haryana) 1967. Unfortunately, some of these experiments were either discontinued or seriously altered, as they were found inadequate in respect of the statistical requirement pertaining to the design of experiment or suffered from some management problems. However, the experiments at Coimbatore, Ranchi and Hisar are still continuing.

During the late sixties high yielding varieties (HYV) were introduced which later on proved to be the main pillar of green revolution. Intensification of agriculture under irrigated conditions resulted in acceleration of nutrient mining from soil to harness the potential of the HYV for long-term. Under this situation, it has become imperative to maintain supply of the nutrients in sufficient quantity through external use of fertilizers. Within short period, monitoring of soil fertility has failed to supply the nutrient on soil basis. The long-term application of fertilizer alone to soil has resulted in the deterioration of soil health, thereby culminating in environmental pollution and stagnation in crop productivity. Hence, integrated use of both inorganic and organic source of plant nutrients is the only way to maintain and improve the nutrient status of soil.

2.2 Carbon pools

Arid and semi-arid ecosystems are a key terrestrial biome, covering 41% of the Earth's land surface and supporting over 38% of the total global population (Reynolds *et al.*, 2007). Biological soils play key functional roles in arid and semi-arid worldwide, where they are a prevalent biotic component (Maestre *et al.*, 2011). SOC is the second largest carbon pool on the surface of the earth after the oceans (Swift, 2001) and the possibility of increasing the OC content of the soil through changing agronomic management practices may play a role in combating climate change (Lal, 2002). Organic matter (OM) acts as the storehouse of essential nutrients and source or sink to atmospheric CO₂ (Lal, 2002). An increase in SOC

levels is directly linked to the amount and quantity of organic residues return to the soils (Mandal *et al.*, 2007). Indicated by higher microbial biomass and elevated soil respiration (Sparling *et al.*, 2003). The soil solution concentration of N, P, S and several micronutrients are intimately related to organic fraction in soil (Havlin *et al.*, 2005). Soils control the C cycle in these soils by fixing atmospheric C through photosynthesis (Belnap *et al.*, 2004), by contributing to soil CO₂ efflux (Castillo-Monroy *et al.*, 2011). Key processes of the N cycle (Belnap, 2004), mineralization-depolymerization (Castillo-Monroy *et al.*, 2010). Dissolved organic carbon (DOC) is an important component of C cycling (Kalbitz *et al.*, 2000; Royer *et al.*, 2007; Pan *et al.*, 2010). Although DOC represents only a small part of C pools, it appears to be involved in many processes, such as the biogeochemistry of N and P (Kalbitz *et al.*, 2000), microbial decomposer activities (Peichl *et al.*, 2007). Light fraction carbon (LFC) is associated with non aggregated soil and it is not ready losing from any tillage practices, and it easily accumulated in microbial biomass compared to other C fractions (David *et al.*, 2006). DOC dynamics appear to be independent of N inputs (Kalbitz *et al.*, 2000). It is possible to detect changes in microbial biomass long before changes in total organic C (Sparling *et al.*, 1994). Light fraction acts as a transitory pool of organic matter between fresh residues and humified organic matter and permit assessment of the effects of decomposition on soil fertility, residue persistence and organisms (Gregorich and Janzen, 1996).

The effect of various manures on the concentration of heavy fraction C (HFC) in surface layer was almost similar to that of LFC content (Mahapatra *et al.*, 2007; Lu and Yin, 2006). The average concentration of particulate organic C, DOC and microbial biomass carbon (MBC) in organic manure plus inorganic fertilizer treatments (NP+S and NP+FYM) in 0–60 cm depth were increased by 64.9–91.9%, 42.5–56.9%, and 74.7–99.4%, respectively, over the chemical fertilizers treatment. The particulate organic C, MBC and DOC concentrations increased linearly with increasing SOC content. These results indicate that long-term additions of organic manure have the most beneficial effects in building C pools among the investigated types of fertilization (Liu *et al.*, 2013). Although quantity and quality of dissolved organic matter may change seasonally, management or treatment effects would likely remain. Recent studies conducted in arable soils (Embacher *et al.*, 2007, 2008) demonstrated that quality of dissolved organic matter was highly related to soil and management associated factors rather than seasonality. Long-term application of NPK+FYM maintained or improved SOC content over initial level. Further fractions of SOC viz., particulate organic C, water-soluble C and soil MBC (Liu *et al.*, 2013). Manna *et al.* (2005) examined that the potential impact of continuous cultivation of crops in rotation, and fertilizer and manure application on yield trends and SOC storage. Labile SOC, total N and stable SOC increased with polyphenols in fine sand and clay + silt fractions, which indicates a positive

response of polyphenols on C sequestration and N accumulation owing to reduced decomposition and chemical immobilization, respectively (Seneviratne *et al.*, 2009).

The low SOC content is due to the low shoot and root growth of crops and natural vegetation, the rapid turnover rates of organic material as a result of high soil temperatures and fauna activity particularly termites and the low soil clay content. There is increasing evidence that dissolved organic matter is highly related to SOC sequestration and nutrient cycling in wetlands, peat lands, and managed ecosystems (Freeman *et al.*, 2001, Zibilske and Bradford, 2007, Yao *et al.*, 2009). Case study clearly demonstrated that the active restoration can enhance soil carbon sequestration, nutrients availability, and the capability of SOC sequestration is regulated by the soil nutrients supply (Gong *et al.*, 2013). Soil biochemical coupling mechanisms between SOC and nutrients resulting from soil weathering, roots transferring, and decomposing of plant tissues and residues (Reich and Oleksyn, 2004; Townsend *et al.*, 2007). The recalcitrant C: total OC, and recalcitrant N: total N ratios are regarded as indicators of global OC and N quality (Rovira and Vallejo, 2002). Kundu *et al.* (2007) reported that the concentration of SOC increased 40 and 70% in the NPK + FYM-treated plots as compared to NPK ($43.1 \text{ Mg C ha}^{-1}$) and unfertilized control plots ($35.5 \text{ Mg C ha}^{-1}$), respectively.

The increase in soil C in surface soil accounted for 24.9, 28.3 and 7.0 % of the carbon added through FYM, pressmud and green manure, respectively (Sekhon *et al.*, 2009). Mixed application of organic and inorganic fertilizers is a compromise between food security and soil carbon sequestration (Cai and Qin, 2006). Balanced application of inorganic fertilizers maintains soil productivity and even slightly increase SOC content along with increased crop yields (Kanchikerimath and Singh, 2001; Shen *et al.*, 2004). It is essential to restore degraded soils through enhancing the soil organic pool and improving the below-ground environment for food security. In this situation, the maintenances of soil organic pools are a major challenge in tropical climates (Lal, 2009). Temperature and rainfall are important factors controlling soil organic matter turnover and understanding how these parameters affect SOC stocks (Haddix *et al.*, 2011). Understanding the temperature sensitivity of SOC decomposition is challenging because soil organic matter is composed of many different compounds with different inherent kinetic properties (Davidson and Janssen, 2006). The results indicated 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 (Manjaiah and Singh, 2001). Aulakh *et al.* (2001) reported that incorporation of cereals (rice or wheat) residues of higher C: N ratios resulted in more C sequestration into soil organic matter than that with green manure. Cereals residues and FYM have been reported to have a higher humification coefficient than green manure and lead to greater carbon sequestration in soil (Yadvinder-Singh *et al.*, 2004). The balanced application

of NPK can increase the production of root biomass and stubble, which may increase soil organic carbon (Regmi *et al.*, 2002). Daniele *et al.* (2013) suggested that alterations in the different fractions of SOM are more effective in indicating changes in soil use than total soil organic matter content. Continuous application of organic manure alone or in combination with inorganic fertilizer enriched the soil with total OC (Geeta Kumari *et al.*, 2011). The active pools generally contribute about 10-20 % towards total soil organic matters, whereas the stable or passive pools have 50-90 % contribution towards total soil organic matters (Brady and Weil, 2002).

SOC represents a major reservoir of potentially mineralizable C that contains more C than the atmosphere and the terrestrial biomass combined (Amundson, 2001). Substrate available regulates the activity, growth and community structure of the microbiota and thus C sequestration and nutrient turnover in ecosystems (Engelking *et al.*, 2007). Sodhi *et al.* (2009) concluded that soils can be rehabilitated and can sustain the soil C and N levels with the continuous application of rice straw compost either alone or in combination with inorganic fertilizer. This will also help in controlling the rising levels of atmospheric CO₂. Saha *et al.* (2011) reported that the SOC in surface soils significantly decreased by 27 % in forest and 45 % in agricultural land. Huang *et al.* (2008) reported that SOC is recognized to consist of various fractions varying in degree of decomposition, recalcitrance and turnover rate. Tan *et al.*, (2007) concluded that the dynamics of SOC with change in land use and management can better be explained by the way C is allocated in different fractions of soil organic matter. The C input of plants into the soil is in form of residues (Poll *et al.*, 2010) and rhizodeposition which are decomposed microorganisms (Wichern *et al.*, 2007).

2.3 Nitrogen fractions

N is a critical element in many aspects of agricultural production and the environment. The amount of potentially mineralizable N plays a large role in the soil, specifically in assessing needs for N applications as fertilizer to agricultural land to maximize crop yields (Schomberg *et al.*, 2009). As proteins represent approximately 10% of the total dry mass of plant roots and shoots, their input into soil via root turnover and leaf litter fall represents the biggest single N input into most terrestrial ecosystems (Jones *et al.*, 2005). The effect of amendment history and crop rotation on the tested measures of N availability demonstrates the impact of these management practices on a wide range of N fractions from readily available to more stable fractions in the soil. These N fractions include soluble or exchangeable mineral N, microbial biomass N, soluble organic-N, amino sugar N, α amino-N, and hydrolyzable unidentified N fractions (Mulvaney *et al.*, 2006; Greenfield, 2001). Inorganic forms of soil N constitute 2 to 6 per cent of the total N implying that a major portion is found in the organic combination. However, it is this inorganic N which is available for direct uptake by plants (Black, 1968). The inorganic N present in the soil is in the form of

NH_4^+ - N, NO_3^- - N, NO_2^- - N and non-exchangeable ammonical N fixed on to the clay particles. All these forms constitute an extremely dynamic system influenced by physical and chemical processes, in the soil system (Savant and De Datta, 1982).

A major portion of the soil N was in organic combination, which was acid hydrolysable constituting 62 to 87 per cent of the total soil N and the major organic-N hydrolysable fractions were the amino-acids, hydrolysable NH_4^+ -N and amino sugars and the balance were referred to as unidentified N (Stevenson, 1982). Due to current concerns over food security and climate change, there is an increasing need to develop more sustainable agricultural systems. In this context, there is a requirement to better understand the cycling of N in plant-soil systems. Most N enters soil as protein or other biological polymers, which need to be cleaved extracellular before they are available for uptake by microorganisms or plants (Jan *et al.*, 2009; Schimel and Bennett, 2004; Weintraub and Schimel, 2005). The fractions of SOC and soil organic N are widely used as surrogate measures for evaluating soil fertility (von Lutzow *et al.*, 2000; Freixo *et al.*, 2002). Dissolved organic N loss from agricultural soils occurs mainly in the form of recalcitrant compounds rather than in the form of labile low molecular weight dissolved organic N (e.g. oligopeptides and amino acids), and that although nitrate was bioavailable, it was not a preferred N form for the C-limited microbial biomass (Abaas *et al.*, 2012). Amino acids, amino sugars constitute one of the major components of the mineralizable N pool in soil (Mengel, 1996). The behaviour of amino acids and peptides in soils has received a lot of attention in recent years due to their proposed role in plant nutrition (Jamtgard *et al.*, 2010; Hill *et al.*, 2011). Reliable prediction of optimum fertilizer N requirement of a particular crop in a particular field condition requires an estimate of the amount of N made available to the crop by mineralization (Glinding and Powlson, 1995)

The percentage of all forms of N in total N was high in clay soil, moderate in loam soil and low in sand soil. It has been estimated that amino sugars contribute between 5 and 12% of total soil organic N making it a significant reservoir of both C and N in soil (Knicker, 2011). Continuous application of mineral fertilizers, alone or in combination with organic manures for 7 years, led to a marked increase in total N, hydrolysable N (amino acid-N, amino sugar-N, ammonia-N, hydrolysable unknown-N) and non-hydrolysable N compared with their original status of soil (Sekhon *et al.*, 2011). The easily hydrolysable fractions, in particular, amino acid-N, amino sugar-N, amine-N and hydrolysable ammonical-N have also been found to be the most active N pools and the major source of N potentially available to plants (Khan *et al.*, 2001). The N fractions can provide an assessment of soil organic N changes induced by management such as cropping system and inorganic and organic fertilization (Wander *et al.*, 2007). Additional N provided by organic fertilization was primarily concentrated into amino acid-N, hydrolysable-N, hydrolysable unknown-N and

non-hydrolysable-N (Huang *et al.*, 2009). Long-term addition of either fertilizer alone or in combination with FYM not only led to an improvement in organic N fractions in soil profile, but also contributed to N mineralization (Reddy *et al.*, 2003). Historically amended soil reduced the availability of recently added N relative to the non amended soil. This reduction occurred in the active pool N for mineralizing manure and in the slow pool N for Fertilizers (Mallory and Griffin, 2007).

2.4 Periodical transformations of major nutrients in soil

Long-term addition of either fertilizer alone or in combination with FYM not only led to an improvement in organic N fractions in soil profile, but also contributed to N mineralization (Reddy *et al.*, 2003). The amount and quantity of C in agricultural soil has changed rapidly as a result of farming, fertilization and irrigation (Alvarez, 2005). Soil enzymes (intracellular and extracellular) are the mediators and catalysts of biochemical processes important in soil functioning, such as nutrient mineralization and cycling, and decomposition and formation of stable soil organic matter. Johann *et al.* (2004) studied that plots which received either prepared or non-prepared FYM (30 Mg ha⁻¹ year⁻¹) had significantly increased soil pH, P and K concentrations, and microbial biomass. However, after 100 days, decomposition was significantly faster in plots which received completely prepared FYM than in plots which received no FYM. Yadav *et al.* (2000) analyzed that the yield trends and effect of fertilizer NPK application, alone or in combination with FYM, green manure or wheat crop residue incorporation, on the changes in SOC and available NPK contents. SOC represents a major reservoir of potentially mineralizable C that contains more C than the atmosphere and the terrestrial biomass combined (Amundson, 2001). Substrate available regulates the activity, growth and community structure of the microbiota and thus C sequestration and nutrient turnover in ecosystems (Engelking *et al.*, 2007). The organic C, available N, P and K contents of soil decreased from its initial values after 37 cycles of pearl millet-wheat cropping system due to continuous cropping without FYM and N (Antil *et al.*, 2011). However, continuous application of FYM for a period of 37 years increased EC, CEC, organic C, available macro and micronutrients content of soil (Antil and Narwal, 2007).

2.5 Correlations between soil organic C and N fractions

SOC plays an important role in soil physicochemical and biological properties (Johnston, 1986; Stevenson, 1986; Reeves, 1997). Currently, increasing attention has been paid to the effects of soil organic C fractions on soil quality indicators of physical, chemical, and biological properties under different soil management regimes (Campbell *et al.*, 1999; Chan *et al.*, 2002). Particulate organic C has recently been shown to be a sensitive indicator of soil management effects on SOC (Elliott *et al.*, 1994). This fraction is considered to represent the slow pool of SOC with an intermediate turnover time between the active and passive pools (Parton *et al.*, 1987). Bremner, (1967) revealed that the composition and status of N

fractions were key indicators of soil N fertility. Diverse agroecosystems differed in the chemical composition of dissolved organic matter and the differences could be correlated with soil peroxidase activity and soil C and N mineralization (Lei *et al.*, 2010). Relationships among different soil organic C pools, soil enzyme activity, and soil C decomposition also have been studied by Carreiro *et al.*, 2000; Saiya-Cork *et al.*, 2002; Waldrop *et al.*, 2004; Sinsabaugh *et al.*, 2005; Stursova *et al.*, 2006; Zeglin *et al.*, 2007; Keeler *et al.*, 2009. Mandal *et al.* (2007) conducted a field experiment to investigate the effect of six long-term (34-year) fertilizer and FYM treatments and stepwise regressions have revealed that grain yield of wheat was significantly associated with mineralizable N at tillering ($R^2 = 0.80$), MBC at flowering ($R^2 = 0.90$) and alkaline phosphatase activity ($R^2 = 0.70$) at dough stages of wheat growth. Sharifi *et al.* (2007) reported that total organic C and N represent long-term changes in potentially mineralizable N and were almost as effective in predicting potentially mineralizable N as the other indices ($r^2 = 0.60$ and 0.67 , respectively). Goyal *et al.* (1993) studied that microbial biomass C was positively correlated with soil organic C and ranged from 1.8 % to 2.2 % of organic C after 12 months of farmyard manure applications. Ding *et al.* (2012) studied that the positive relationship between C sequestration and organic manure input indicates that the soil has not reached its maximum capacity of C sequestration.

2.6 Organic manures effects on crops yield, uptake of nutrients and soil properties

Soil of world's agro ecosystem are depleted of their SOC stock by 25-75 % depending on climate, soil type, and historic management, magnitude of this loss may be 10-50 Mg C ha⁻¹ (Lal, 2011). Soils with severe depletion of their SOC stocks have their low agronomic yield and low use efficiency of added input (Srinivasarao *et al.* 2012). Addition of organic manure increases microbial activity in the soil (Marschner, 1995), which may increase the organic matter contents in soils. Furthermore, in these treatments, significant amount of organic matter was added, which increased the content of organic matter (Agbede *et al.*, 2008). Marschner, (1995) and Walker *et al.*, 2004) observed that significant changes in soil pH on addition of organic manure owing to organic matter oxidation and release of CO₂ in the soil. Cavigelli and Thien, (2004) also found increased bioavailability of P in soils by addition of organic matter. Phosphorus is relatively immobile nutrient in soil and diffusion is the major process controlling its movement. Hence indirectly soil moisture regulates soil P mobility (Marschner, 1995).

Addition of organic manure increased soil moisture contents (Boateng *et al.*, 2006), which may be the reason of improved P availability in soil. These indicated that organic manure application with or without chemical fertilizers played the most significant role in enhancing soil organic C and N quantity and quality in the paddy field studied (Huang *et al.*, 2009). In most south Asian countries, degradation of soil organic matter, soil structure and associated nutrient supply are major factors for yield decline in intensive cereal based

cropping system (Ladha *et al.*, 2003; Mulvaney *et al.*, 2009). Applications of FYM can increase soil organic matter and improve soil physical fertility (Blair *et al.* 2006). Majority of organic C sequestered due to C inputs was accumulated and stabilized in recalcitrant C pool. In general, organic manure combined with inorganic fertilizer exerted greater influence on topsoil C storage and crop yield than chemical fertilizer alone (Ding *et al.*, 2012). The decrease in soil organic matter and or in organic matter pools, however, has been reported to be the major cause of yield decline particularly in plots receiving imbalanced use of NPK fertilizers (Manna *et al.*, 2006). Labile fractions of soil organic matter such as MBC, DOC and hot water extractable C can respond rapidly to change in C supply (Ellerbrok *et al.*, 2005). Application of organic manure, either alone or in combination with mineral fertilizers, is more effective in increasing soil organic matter and its fractions than mineral fertilizers alone (Wu *et al.*, 2004; Yang *et al.*, 2005; Blair *et al.*, 2006; Rudrappa *et al.*, 2006; Purakayastha *et al.*, 2008). Active restoration of SOC, available N, P and K observed differences between restoration and control are consistent with previous studies indicating that restoration results in C gains (Huang *et al.*, 2012) and nutrient availabilities (Liu *et al.*, 2011). The research in soil ecological restoration impacts on soil nutrients (Paul *et al.*, 2010; Liu *et al.*, 2011; Xie *et al.*, 2012). Soil nutrients may act as a limiting factor impeding SOC accumulation (Moorhead and Sinsabaugh, 2006; Li *et al.*, 2009).

FYM and green manure and pressmud can be a potential supplier of plant available N in a rice-wheat cropping system (Yadvinder-Singh *et al.*, 2008). Studies by Bhandari *et al.* (2002) and Regmi *et al.* (2002) attributed the reduced productivity of the rice-wheat system, inter alia. to declining soil organic matter and decreased soil fertility. Golakiya *et al.*, (2006) reported that during the year 1980 and 2000, the FYM at 25 Mg ha⁻¹ treatment improved SOC content (0.45 and 0.66 %) as compared to that of NP (0.36 and 0.60 %), ½ NP+K (0.36 and 0.54 %), ½ NP (0.30 and 0.40 %) and control (0.30 and 0.36 %). Sehken *et al.* (2006) reported that the total annual productivity (rice plus wheat grain yield) was significantly affected by organic amendments and followed the order: FYM>green manure>pressmud>burnt rice husk. Among the organic manures treatments, highest total N, P and K uptake by rice crop was observed with FYM, followed green manure and pressmud. Steve *et al.* (2010) reported that poultry litter was comparable with inorganic fertilizer in terms of increasing soil available-P and forage yield, and the timing of application made no difference. Organic manures may increase soil fertility and thus the crop production potential possibly by changes in soils physical and chemical properties including nutrient bioavailability, soil structure, water holding capacity, cation exchange capacity, soil pH, microbial community & activity etc. (Walker *et al.*, 2004; Clemente and Bernal, 2006; Agbede *et al.*, 2008; Muhammad and Khattak, 2009).

Improved yields of various crops have been reported by addition of organic manures (Usman *et al.*, 2003; Khaliq *et al.*, 2004; Muhammad and Khattak, 2009). Combined application organic and synthetic nutrient sources, particularly poultry manure at 2.5 t ha⁻¹ in combination of mineral fertilizer 200-150-125 NPK ha⁻¹ not only improved maize growth and yield but also the fertility status of soil (Habib *et al.*, 2012). The application of organic materials to soil has been reported to enhance crop yield depending upon agro-ecological setting and rates of amendments applied (Schlecht *et al.*, 2006). Poultry manure in combination with synthetic fertilizers increased mineral N content of soils and maize yield compared to inorganic fertilizers alone (Ayuke *et al.*, 2004). Patil *et al.* (2013) reported that pressmud can be used for soil application or seed treatment to make basic nutrients readily available and enhance soil fertility. Ghulam *et al.* (2010) studied that the addition of pressmud increased the available P, S, K, Fe, Mn, Zn and Cu content in soil in addition to increase in total porosity of soil and other hand, there was small increase in EC, and small decrease in bulk density and pH of the soil as a result of increasing levels of pressmud application.

Pressmud is a good source of organic matter, NPK and important micronutrients and has established its importance in improving fertility, productivity and other physical properties of agricultural soils (Rangaraj *et al.*, 2007) and (Kumar and Verma, 2002). Parthasarathi, (2006) reported that the application of fresh pressmud with increased microbial population and activity to the soil support better improvement of soil fertility. Li *et al.* (2007) concluded that chemical fertilizers in paddy fields with high fertility might degrade soil biological properties and biochemical function, resulting in deterioration of soil biological quality. N, P and K uptake of maize plant was increased significantly by increasing level of N up to 140 kg N⁻¹ fed (Hanan *et al.*, 2008). SOC represents a major reservoir of potentially mineralizable C that contains more C than the atmosphere and the terrestrial biomass combined (Amundson, 2001). Substrate available regulates the activity, growth and community structure of the microbiota and thus C sequestration and nutrient turnover in ecosystems (Engelking *et al.*, 2007).

CHAPTER-III

MATERIAL AND METHODS

The present investigation was undertaken to study the "long-term effects of organic manures and fertilizers on soil organic carbon pools and nitrogen fractions". The details of the materials and methods used and procedures followed in various experiments are described in this chapter.

3.1 Experimental Details

3.1.1 Climate and Weather conditions

The climate of the region is subtropical to semiarid with an average rainfall of 2010, 2011 and 2012 around 774.9 mm, 543.7 mm and 501.4 mm respectively (Fig. IIIa). Approximately 90 % of this is received from South-West monsoon between the months of May and October. The mean monthly maximum temperature was lowest in January and increased in May months. Similarly, mean monthly minimum temperature was lowest in January and highest in July months in irrespective of the years (Fig. IIIB and IIIC)

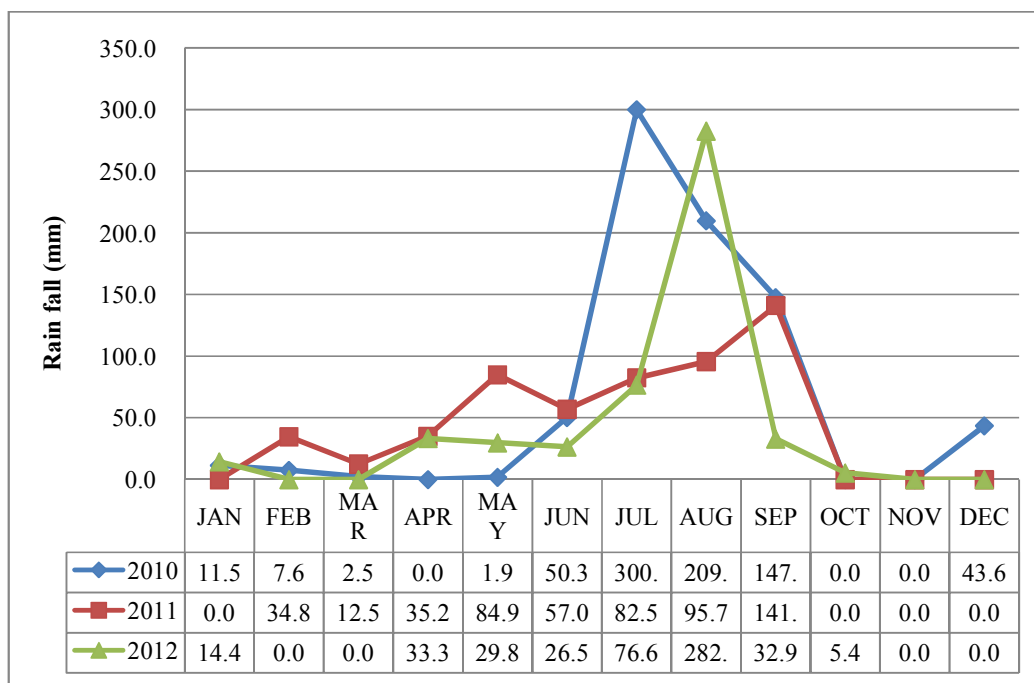


Fig. III a. Monthly mean rain fall of experiment site during 2010, 2011 and 2012

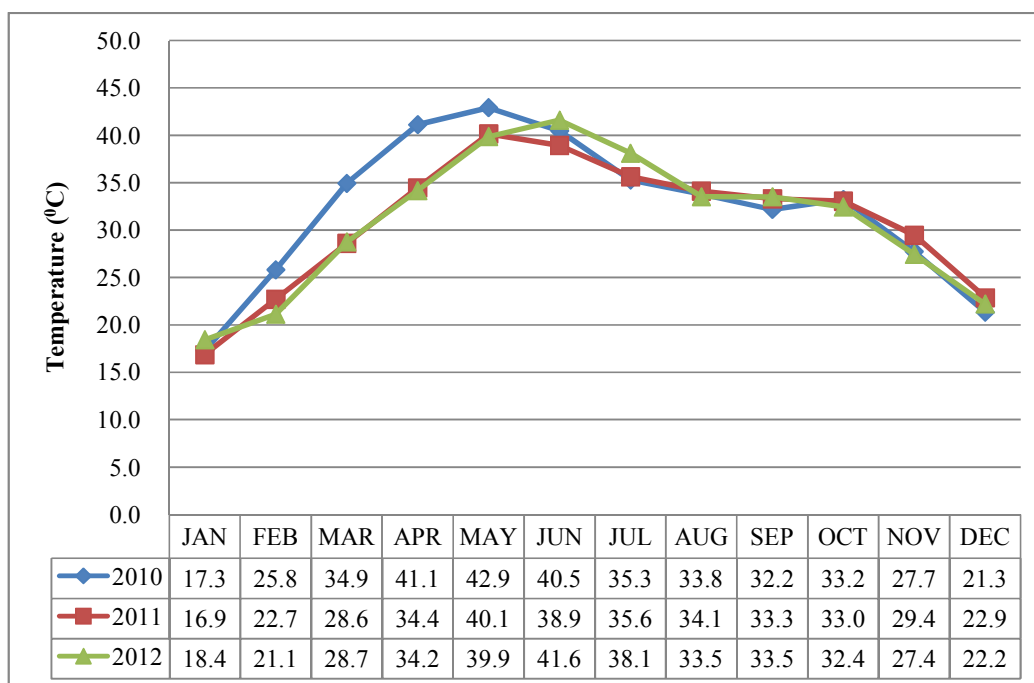


Fig. III b: Monthly means maximum Temperature ($^{\circ}\text{C}$) of experiment site during 2010, 2011 and 2012

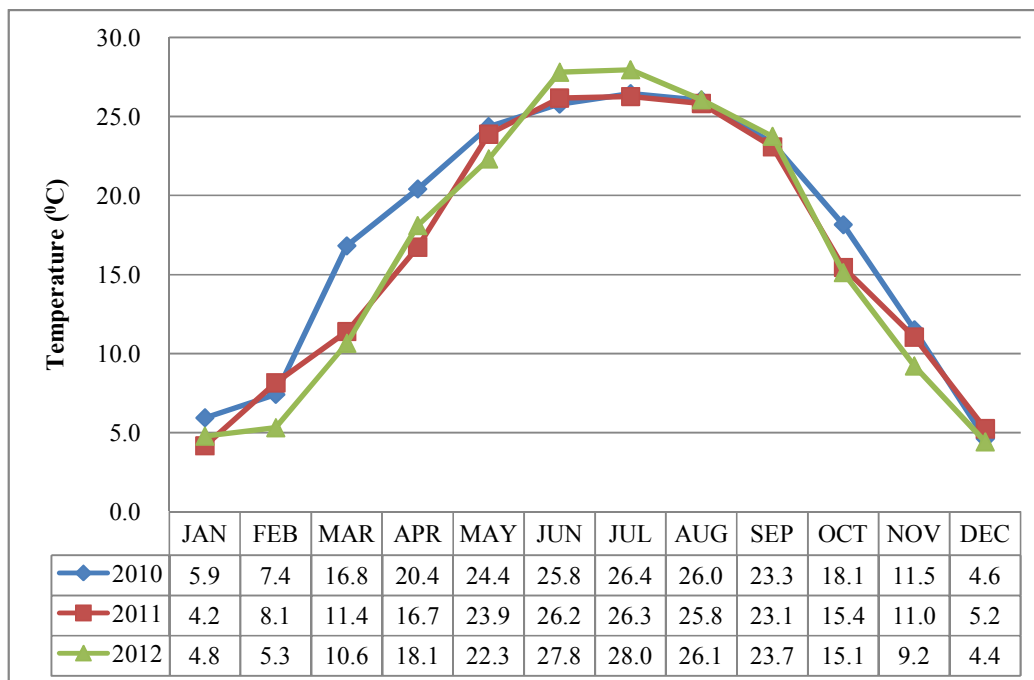


Fig. III c: Monthly means minimum Temperature ($^{\circ}\text{C}$) of experiment site during 2010, 2011 and 2012

EXPERIMENT: I

A long-term field experiment initiated in October, 1967 on a soil coarse, loamy, Typic Ustochrept soil at CCS Haryana Agricultural University, has been running at the research farm of the Department of Soil science was selected, to study the impact the modes and levels of FYM and fertilizer N on yield, uptake of N, soil organic carbon pools and organic N fractions under pearl millet-wheat cropping system. The experimental site is located between 29.16° N latitude and 75.75° E longitude with a mean annual precipitation of 443 mm. The physico-chemical properties of the surface soil (0-15 cm) analyzed at the start of the experiment is presented in Table III B. The experimental treatment consisted of 3 levels of FYM (15, 30 and 45 Mg ha⁻¹ till 2007-08) and 5, 10 and 15 Mg ha⁻¹ from 2008-09 onwards); there modes of application: every kharif crop (summer season), in every rabi crop (winter season) and in both (kharif and rabi) the crops. An absolute control without application of FYM in any of the seasons was maintained as control. These 10 treatments (3 FYM levels X 3 modes of application + 1 FYM control) were allocated in the main plots and each main plot was subdivided into two sub-plots receiving fertilizer N at 0 and 120 kg N ha⁻¹ in each season through urea using split plot design. All the treatments were replicated four times; each sub-plot measuring 10 X 6 m. FYM was incorporated in the top 15-20 cm layer 3 to 4 weeks before sowing crops. FYM was analyzed and the mean values of chemical composition applied during summer and winter, 2011 is given in Table IIIB. N was applied in two equal split i.e. half at sowing and rest 25-30 days after sowing. Both the crops were irrigated with canal water. No chemical fertilizers other than urea have been applied to any treatment since the inception of the experiment. The crops, pearl millet in summer and wheat in winter, were sown. Both crops were harvested at about 2-5 cm above ground level and harvested crop was removed and the roots and stubbles were incorporated. The grain yields of both the crops were recorded. The grain and straw samples of both the crops were analyzed for N, P and K.

3.2 Soil Sampling and Analysis

3.2.1 Collection and preparation of soil samples

The surface (0-15 cm) soil samples from each treatment were collected using a 5 cm diameter auger after harvesting of wheat in May, 2011. Five cores samples collected from each treatment plots were mixed through and a composite sample was taken. Soil samples were air dried, grounded and sieved (2mm) for analysis. The pH, EC, organic C, available macro (N, P and K) and micronutrients (Zn, Mn, Fe and Cu); organic C pools and different fractions of N were analyzed in the soil samples.

3.2.2 Organic Matter Pools Analysis

3.2.2.1 Dissolved Organic Carbons (DOC)

Fifty ml of deionized water was added into 10 g of soil and shaken in horizontal shake for one hour. Then it was subjected to centrifuge for 30 minutes at 8000 rpm. The solution was filtered through Whatman no. 1 filter paper and filtrate was collected and stored in the freezer until analysis. Dissolved organic carbon was determined by dichromate acid oxidation method (Ciavitta *et al.*, 1989).

3.2.2.2 Microbial Biomass Carbon (MBC)

Microbial biomass was determined by the Chloroform (CHCl_3) fumigation method proposed by Vance *et al.* (1987). Each moist soil sample (approx. 20 g on oven dry basis) was fumigated with ethanol free CHCl_3 for 24 hours. Following fumigant removal, the soil was extracted with 0.5 M K_2SO_4 (1: 4, soil: solution ratio) by shaking for 30 minutes on an oscillator shaker. It was then filtered through Whatman no. 42 filter paper. The non-fumigated portions were extracted similarly at the time of fumigation commenced. All results are expressed on an oven dry basis (105 °C, 24 h). Biomass carbon is the difference between the extracted carbon in fumigated and non-fumigated soil.

3.2.2.3 Light and Heavy Organic Matter Fractions

Light fraction soil organic matter in soil samples was isolated by densimetric method modified by Janzen *et al.* (1992). The represented soil samples (10 g) of coarsely ground soil (<2 mm) were dispersed with a NaI solution (40 ml) having specific gravity of 1.70 g cm^{-3} . Suspensions were allowed to equilibrate for 48 hours before removing suspended material i.e. light fraction by vacuum. This process was repeated twice for complete recovery of light fraction (LF) in the solution. The unsuspended material represented heavy fraction (HF). The LF and HF was washed with three successive aliquots each of 0.01 M CaCl_2 and distilled water, dried, ground and analyzed for total carbon by dichromate digestion of modified Walkley and Black's rapid titration method as described by Nelson and Sommers (1996). Different organic C pools were determined by following the flow chart as outlined in Fig. III d.

3.2.3 Organic Nitrogen Fractions

Different nitrogen fractions Viz. acid insoluble-N, hydrolysable NH_3 -N, amino acid-N, amino sugar-N, hydrolysable unknown-N and total hydrolysable-N were determined as per fractionation procedure given by Stevenson (1996). The details are given below:

3.2.3.1 Preparation of soil Hydrolyzate

Twenty gram of soil was taken in distillation flask, to which 2-3 drops of octyl alcohol and 20 ml of M HCl were added before refluxing it for 6 hours on constant low heat (80°C) on a soxhlet by placing it on crushed ice. The final volume was made to 100 ml with distilled water without neutralizing the sample to avoid precipitation with 5 M NaOH. The hydrolyzate was then stored in freezer for determination of different forms of organic

nitrogen. The neutralization of the hydrolyzate was done at the time of estimation of different organic nitrogen fractions on kjeldahl distillation unit.

3.2.3.2 Acid-Insoluble Nitrogen (Non-Hydrolyzable N)

This form of nitrogen is obtained by the difference between total soil N and total hydrolysable N.

3.2.3.3 Hydrolysable NH_3 -N

After adding approximately 0.5 gm of MgO to 10 ml of hydrolysate and calculated amount of 5 M NaOH for neutralization, the kjeldahl flask was connected to the steam distillation apparatus. The amount of ammonia-N was determined as described in section 3.2.3.7

3.2.3.4 Amino acid-N

In five ml of the hydrolysate, 1 ml of 0.5 M NaOH was added in 100 ml digestion flask and heated in boiling water bath until the volume of the sample was reduced to 2 to 3 ml after cooling the flask, 500 mg of citric acid and 100 mg of ninhydrin was added, and the flask was again placed in a vigorously boiling water bath. After cooling, 1.25 g of the phosphate-borate buffer mixture and 10 ml of the deionized water was added. Finally after adding one ml more than the required amount of 5 M NaOH for neutralization, the flask was immediately connected to the steam distillation apparatus and quantified as described in section 3.2.3.7

3.2.3.5 Amino sugar-N

This form of N was taken as the difference between the amounts of N recovered in ammonia + amino sugar-N and ammonia-N fractions.

3.2.3.6 Hydrolysable unknown-N

This form of N was taken as the difference between total hydrolysate N and the N accounted for as (NH_3 + amino acid + amino sugar-N).

3.2.3.7 Total hydrolysable-N

Five ml of hydrolyzate was placed in a 100 ml distillation flask. After adding 0.5 g of K_2SO_4 catalyst mixture and 2 ml of concentrated H_2SO_4 , the flask was cautiously heated on a water bath until the mixture cleared. After digestion, the flask was allowed cooling and 10 ml of distilled water was added. Total hydrolyzate N was determined by stream distillation after adding 10 ml of 10 M NaOH and distillate was collected in 4 % boric acid indicator solution and its amount was determined by titration with 0.005 N H_2SO_4 .

Organic N fractions were determined by following the flow chart as mentioned in Fig. IIIe

3.3 Plant Analysis

3.3.1 Collection, Preparation and Analysis of Plant Samples

The grain and straw samples of both pearl millet and wheat crops were collected from each plot at physiological maturity and dried in hot air oven at 65 °C for 3 days. Grain and

straw samples were ground in Willey mill and stored in paper bags for further chemical analysis. Dried and ground grain and straw samples were digested in a diacid mixture of H_2SO_4 and HClO_4 (4: 1).

EXPERIMENT: II

An ongoing long-term field experiment with pearl millet-wheat cropping sequence which was established in 1995 on a coarse loamy, Typic Ustochrept soil at CCS Haryana Agricultural University, Hisar, India was selected to study the effect of various combinations of organic manures and fertilizers on yield, uptake of N, soil organic carbon pools, organic N fractions and periodic mineralization of C, N and P in soil. The soil was classified as coarse loamy, Typic Ustochrept. The site is located between 29.16°N latitude and 75.75°E longitude in the northwest part of India. The climate of the experimental area is semi arid with a mean annual precipitation of 443 mm and mean annual temperature of 248 °C. The physical-chemical properties of the surface soil (0-15 cm) analyzed at the start of the experiment are presented in Table IIIB. The average nutrient composition of FYM, poultry manure and pressmud applied in the experiment during 2011 are given in Table IIIA. All the organic manure contained about 20 % moisture. The experiment was laid out with the following treatments. The experiment was laid out with the following treatments in a randomized block design with three replications; T₁: 75 kg N + 30 Kg P₂O₅ ha⁻¹, T₂: 150 kg N + 60 Kg P₂O₅ ha⁻¹, T₃: 15 Mg FYM ha⁻¹, T₄: 15 Mg FYM + 150 kg N ha⁻¹, T₅: 15 Mg FYM + 150 kg N ha⁻¹ + 30 Kg P₂O₅ ha⁻¹, T₆: 5 Mg poultry manure ha⁻¹, T₇: 5 Mg poultry manure + 75 kg N ha⁻¹, T₈: 7.5 Mg pressmud ha⁻¹, T₉: 7.5 Mg pressmud + 75 kg N + 30 Kg P₂O₅ ha⁻¹, T₁₀: 7.5 Mg pressmud + 150 kg N + 30 Kg P₂O₅ ha⁻¹. FYM, poultry manure and pressmud were applied once a year in winter at time of wheat planting. The plots are of 24 X 5 m in size. Both crops were harvested at about 2-3 cm above ground level and the grain and straw yield of both the crops were recorded. Grain and straw samples of both the crops were analyzed for N, P and K.

3.4 Collection of soil samples:

Soil samples were collected from 0-15, 15-30 and 30-45 cm depths after harvesting of wheat in May 2011. Five cores collected from each treatment plot were mixed thoroughly and a composite sample was taken. Soil samples were air-dried, ground, and sieved (2 mm) for analysis. Soil samples were analyzed for pH, EC, organic C, available macro (N, P and K) and micronutrients (Zn, Mn, Fe and Cu) different organic C pools and organic N fractions.

Determination of **organic carbon pools** (dissolved organic carbon, microbial biomass carbon, and light and heavy carbon fractions), **organic nitrogen fractions** (acid insoluble-N, hydrolysable NH₃-N, amino acid-N, amino sugar-N, hydrolysable unknown-N and total hydrolysable-N) and **plant analysis** was followed above the same procedures as in the experiment I.

3.5 Periodic mineralization of C, N and P in soil.

The soil organic C and available N, P and K were determined by following standard methods are mentioned in Table IIIC. The collection of soil samples for periodic mineralization of C, N, P and K in the surface soil during wheat growth was done at 24 days interval from the date of sowing up to 120 days, which may represent the maximum vegetative growth of crop.

3.6 Statistical Analysis

The data obtained under various studies was subjected to statistical analysis for significance using OPSTAT software

Table III A. Average composition of FYM, Poultry Manure and Pressmud

Nutrient (Total)	FYM	Poultry Manure	Pressmud
C (%)	38.1	22.8	38.0
N (%)	1.18	2.55	3.10
P (%)	0.60	1.80	0.90
K (%)	1.92	1.15	0.80
Zn (mg kg ⁻¹)	53.0	100.3	115.0
Mn (mg kg ⁻¹)	26.3	56.7	61.5
Cu (mg kg ⁻¹)	224.5	15.0	14.5
Fe (mg kg ⁻¹)	2211.0	550.0	460.7

Table III B. Physicochemical properties of the soil at the start of the experiment.

Property	Experiment-I	Experiment-II
pH (1:2)	8.2	8.1
Organic C (%)	0.42	0.39
CaCO ₃ (%)	1.12	1.00
Available N (mg kg ⁻¹)	100.0	98.0
Available P (mg kg ⁻¹)	13.0	12.6
Available K (mg kg ⁻¹)	249.0	217.0

Table III C. Methods followed for soil, plant and organic manures analysis

Parameter	Method	Reference
Soil Analysis		
pH (1:2::Soil: water suspension)	Potentiometric method	Jackson, 1973
EC (1:2::Soil: water suspension)	Conductometric method	Jackson, 1973
Organic C	Wet oxidation method	Walkey and Black, 1934
Available N	Alkaline potassium permanganate method	Subbaiah and Asija, 1956
Available P ₂ O ₅	Bray's and Olsen's extraction and Colorimetry	Jackson, 1973
Available K ₂ O	NH ₄ OAC extraction and Flame photometry	Jackson, 1973
DTPA extractable Fe, Mn, Zn and Cu	Atomic absorption spectrophotometry	Lindsay and Norvell, 1978
Plant and manures analysis		
Nitrogen	Kjeldahl digestion & distillation	Piper, 1966
Phosphorus	Diacid digestion and vanadomolybdate & Colorimetry	Piper, 1966
Potassium	Diacid digestion Flame Photometry	Piper, 1966

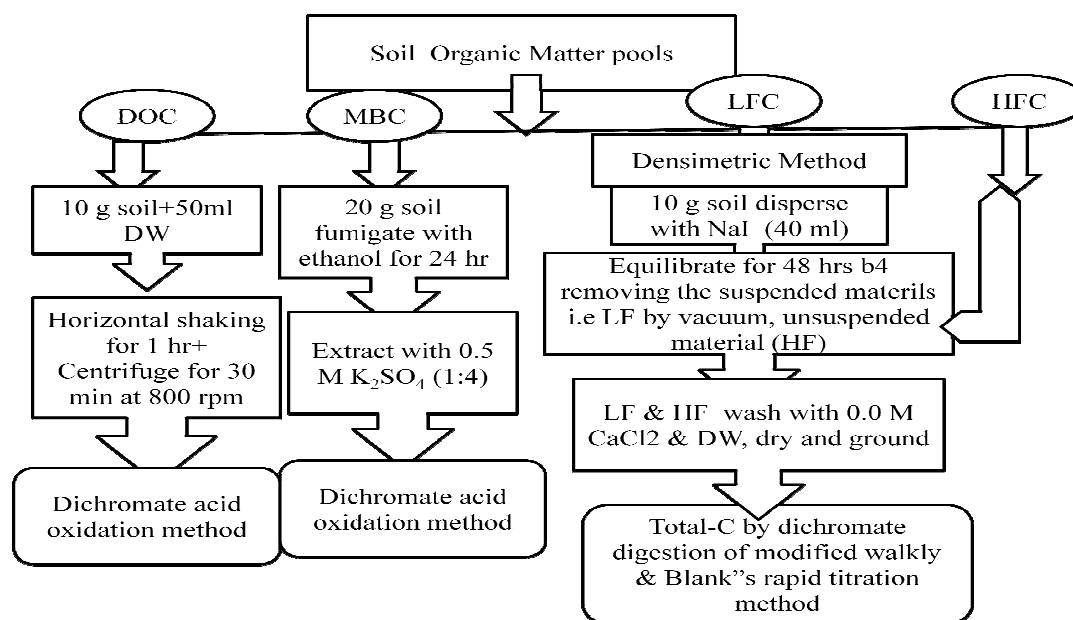


Fig III d: Flow chart of the fractionation of soil organic carbon pools was carried out by an adopted version of the procedure

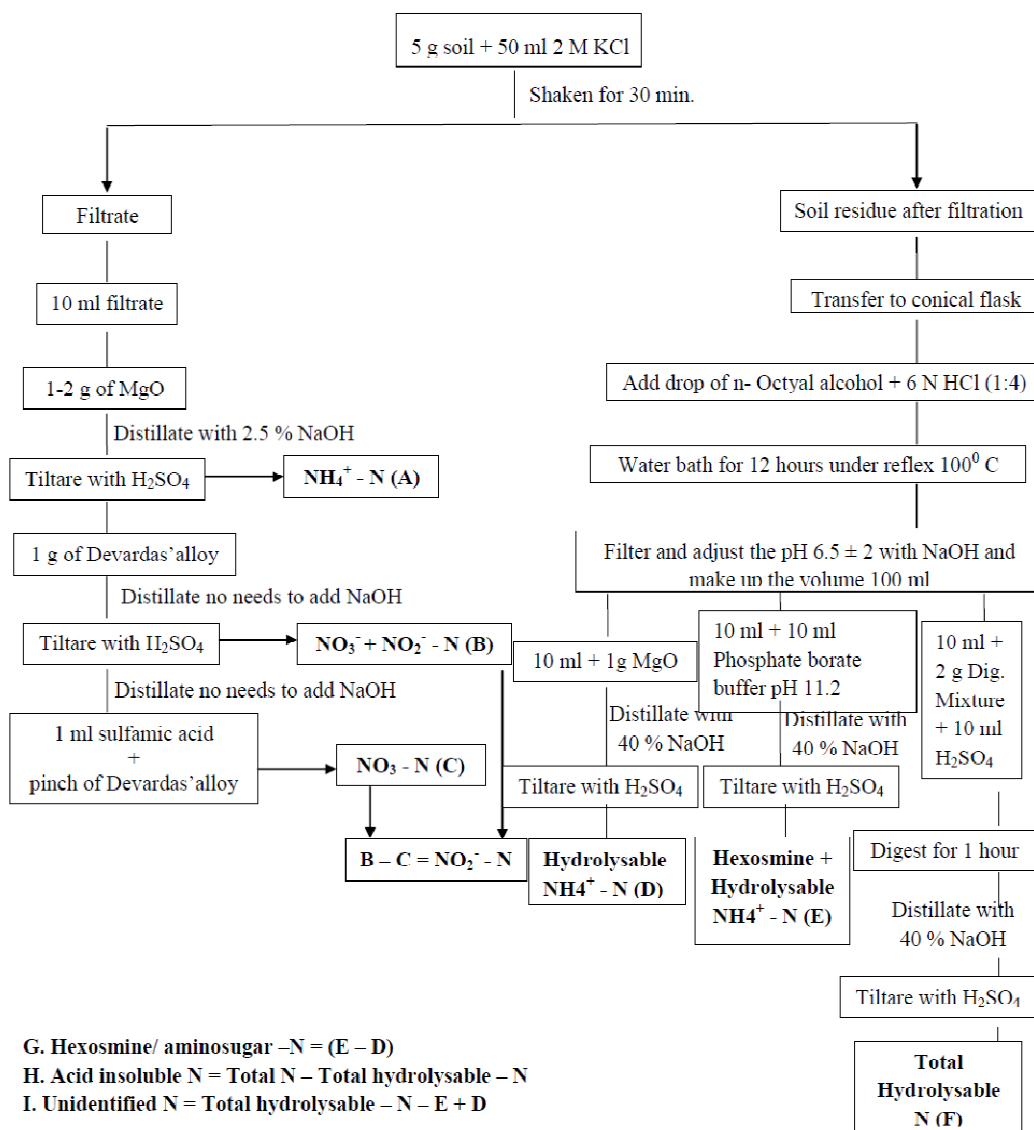


Fig. III e: Flow chart of the fractionation of soil organic N fractions was carried out by an adopted version of the procedure given by Page *et al.* (1982)

CHAPTER-IV

EXPERIMENTAL RESULTS

The results of the experimental study entitled "**long-term effects of organic manures and fertilizers on soil organic carbon pools and nitrogen fractions**" conducted at the research farm Department of Soil science, CCS HAU, Hisar is presented in this chapter.

Experiment: I: To study the impact of modes and levels of FYM and fertilizer N

4.1. Soil organic matter pools

4.1.1 Dissolved Organic Carbon (DOC)

The data pertaining to DOC influenced by modes and levels of FYM and fertilizer N is presented in Table 1. The DOC content increased significantly with increasing levels of FYM from 5 to 15 Mg ha⁻¹ over control. However, increase in DOC with the application of different doses of FYM was highest in 15 Mg ha⁻¹ (362.7 mg kg⁻¹) followed by 10 Mg ha⁻¹ (245.9 mg kg⁻¹) and 5 Mg ha⁻¹ (160.2 mg kg⁻¹). A significant increase in DOC was observed when FYM was applied in both the seasons (kharif and rabi) compared to applied either in kharif or rabi season. However, application of FYM in rabi season was found more beneficial than its application in kharif season. About 3.67 times increase in DOC was recorded when FYM was applied in both the seasons followed by rabi (2.12 times) and kharif (1.84 times) over control.

Fertilizer N has increased the DOC concentration significantly at all the modes and levels of FYM. A significant increase in DOC was observed with application of 120 kg N ha⁻¹ over 0 kg N ha⁻¹. Application of FYM from 0 to 15 Mg ha⁻¹ increase of the DOC content at all the levels of N and modes of FYM application which was significantly superior over 10 and 5 Mg FYM ha⁻¹. Highest DOC of 586.0 mg kg⁻¹ was noticed when 15 Mg FYM ha⁻¹ along with 120 kg N ha⁻¹ was applied in both the seasons.

Interaction between modes of FYM and N levels showed significant difference in DOC content. Application of 120 kg N ha⁻¹ increases the DOC concentration over 0 kg N ha⁻¹ at all the modes of FYM application.

4.1.2 Relationships between DOC and C pools and N fractions

The highly significant relationship was observed between DOC and MBC ($R^2 = 0.91$) followed by LFC ($R^2 = 0.90$), organic C ($R^2 = 0.88$) and HFC ($R^2 = 0.87$). The slightly significant relationship was also established between N fractions and DOC, highest with amino sugar-N ($R^2 = 0.82$) and followed by amino acid-N ($R^2 = 0.79$), acid insoluble-N ($R^2 = 0.72$), and lowest with hydrolysable unknown-N ($R^2 = 0.65$), hydrolysable NH₃-N ($R^2 = 0.62$) and total hydrolysable-N ($R^2 = 0.45$).

4.1.3 Microbial Biomass Carbon (MBC)

The data pertaining to MBC influenced by modes and levels FYM and fertilizer N is presented in Table 1. The MBC content increased significantly with the application of FYM from 0 to 15 Mg ha⁻¹. The increase in MBC content was 3.53, 4.52 and 7.64 times upon application of 5, 10 and 15 Mg ha⁻¹ over the control, respectively. The amount increase in MBC was not consistent with increasing doses of FYM with respect to modes. Highest content of MBC (763.9 mg kg⁻¹) was observed when FYM was applied in both the seasons (kharif and rabi) and higher build up was when FYM was applied to in rabi season (486.5 mg kg⁻¹) than to kharif season (398.0 mg kg⁻¹). Highest MBC was recorded when 15 Mg FYM ha⁻¹ was applied along with 120 kg N ha⁻¹ in both seasons (1175 mg kg⁻¹) followed by rabi (672.5 mg kg⁻¹) and kharif (552.3 mg kg⁻¹).

There was a significant difference in MBC of soil receiving 0 and 120 kg N ha⁻¹. Significant increase in MBC (30.8 %) was observed with application of 120 kg N ha⁻¹ over 0 kg N ha⁻¹. Highest MBC was observed where 15 Mg FYM ha⁻¹ was applied in conjunction with 120 kg N ha⁻¹ followed by 10 and 5 Mg ha⁻¹ FYM.

Interaction between modes of FYM and N levels showed significant difference in MBC content. Application of FYM applied either in both the seasons or rabi or kharif increased MBC content of soil irrespective of levels of applied N.

4.1.4 Relationships between MBC and C pools and N fractions

A highly significant relationship was observed between MBC and LFC ($R^2 = 0.95$) followed by HFC ($R^2 = 0.93$), organic C ($R^2 = 0.90$) and DOC ($R^2 = 0.91$). The highly significant relationship between N fractions and MBC was observed, it was highest with amino sugar-N ($R^2 = 0.95$) and followed by amino acid-N ($R^2 = 0.92$), acid insoluble-N ($R^2 = 0.90$), hydrolysable unknown-N ($R^2 = 0.87$), hydrolysable NH₃-N ($R^2 = 0.85$) and total hydrolysable-N ($R^2 = 0.73$).

4.1.5 Light Fraction Carbon (LFC)

The effect of modes and levels of FYM and fertilizer N on LFC content is presented in Table 1. Increasing levels of FYM from 0 to 15 Mg ha⁻¹ increased the LFC content of soil from 0.22 to 0.46 g kg⁻¹. Increase in LFC was observed when FYM was applied in both the seasons (kharif and rabi) than its application in kharif or rabi seasons. However, highest LFC (0.47 g kg⁻¹) was noticed when of 15 Mg FYM and 120 kg N ha⁻¹ was applied in both season followed by rabi (0.41 g kg⁻¹) and kharif (0.33 g kg⁻¹).

The LFC content increased significant with the application of fertilizer N from 0 to 120 kg ha⁻¹. There was a significant difference in LFC of soil receiving varied levels of N. Highest LFC was recorded with 120 kg N and 15 Mg FYM ha⁻¹ which was significantly superior over 10 and 5 Mg FYM ha⁻¹.

Table 1: Long-term effect of modes and levels of FYM and fertilizer N on organic C pools after 43 cycles of pearl millet-wheat cropping system

Level (Mg ha ⁻¹)	FYM Mode	DOC (mg L ⁻¹)			MBC (mg kg ⁻¹ soil)			LFC (g kg ⁻¹)			HFC (g kg ⁻¹)		
		0 N (kg ha ⁻¹)	120 N (kg ha ⁻¹)	Mean	0 N (kg ha ⁻¹)	120 N (kg ha ⁻¹)	Mean	0 N (kg ha ⁻¹)	120 N (kg ha ⁻¹)	Mean	0 N (kg ha ⁻¹)	120 N (kg ha ⁻¹)	Mean
0		91.3	110.0	100.7	83.4	130.2	106.8	0.21	0.23	0.22	0.40	0.50	0.45
5	Rabi	144.0	158.0	151.0	312.0	451.0	381.5	0.34	0.38	0.36	0.98	1.12	1.05
10		190.0	245.5	217.7	421.4	545.6	483.5	0.41	0.43	0.42	1.00	1.20	1.10
15		255.0	290.4	272.7	516.6	672.5	594.6	0.44	0.47	0.46	1.23	1.43	1.33
	Mean	196.3	231.3	213.8	416.7	556.4	486.5	0.40	0.43	0.41	1.07	1.25	1.16
5	Kharif	128.0	136.0	132.0	254.6	334.8	294.7	0.23	0.28	0.26	0.90	1.00	0.95
10		166.5	195.0	180.7	335.0	441.3	388.2	0.31	0.36	0.34	0.95	1.00	0.98
15		213.6	271.0	242.3	470.0	552.3	511.2	0.39	0.41	0.40	1.05	1.23	1.14
	Mean	169.4	200.7	185.0	353.2	442.8	398.0	0.31	0.35	0.33	0.97	1.08	1.02
5	Kharif and Rabi	179.5	215.4	197.5	488.5	623.7	556.1	0.38	0.41	0.40	1.10	1.18	1.14
10		312.6	366.0	339.3	630.0	800.3	715.2	0.45	0.48	0.47	1.32	1.40	1.36
15		560.0	586.0	573.0	866.0	1175.0	1020.5	0.50	0.55	0.53	1.72	2.05	1.89
	Mean	350.7	389.1	369.9	661.5	866.3	763.9	0.44	0.48	0.47	1.38	1.54	1.46
	Overall Mean	224.1	257.3	240.7	437.8	572.7	505.2	0.37	0.40	0.38	1.07	1.21	1.14
LSD (0.05):		FYM level	:38.0		FYM level	:98.5		FYM level	:0.03		FYM level	:0.04	
		FYM Mode	:30.0		FYM Mode	:95.0		FYM Mode	:0.04		FYM Mode	:0.03	
		N level	:21.0		N level	:135		N level	:0.02		N level	:0.12	
		Mode X N level	:73.4		Mode X N level	:73.4		Mode X N level	:0.03		Mode X N level	:0.03	

A significant interaction was observed between modes of FYM and N levels for LFC content of soil. Application of fertilizer N increased LFC significantly at all the modes of FYM application.

4.1.6 Relationships between LFC and C pools and N fractions

A highly significant polynomial relationship was noticed between LFC with MBC ($R^2 = 0.93$) followed by DOC ($R^2 = 0.90$) and HFC ($R^2 = 0.81$). LFC was correlated with HFC ($R^2 = 0.81$) and very less correlated with HFC/LFC ratio ($R^2 = 0.12$). A significant relationship was observed between N fractions with LFC, highest with hydrolysable unknown-N ($R^2 = 0.89$) followed by acid insoluble-N ($R^2 = 0.88$), ammonia N ($R^2 = 0.85$), and hydrolysable N ($R^2 = 0.82$) and amino acid N ($R^2 = 0.82$).

4.1.7 Heavy Fraction Carbon (HFC)

The HFC content increases significantly with the application of FYM from 0 to 15 Mg ha⁻¹ and fertilizer N from 0 to 120 kg ha⁻¹ (Table 1). Addition of 15 Mg FYM ha⁻¹ increased HFC content of soil by a factor of 3.22 over control. A significant increase in HFC (1.46 g kg⁻¹) was noticed when 15 Mg FYM ha⁻¹ was applied in both season as compared to applied in rabi (1.16 g kg⁻¹) and kharif (1.02 g kg⁻¹) over control.

Highest HFC (2.05 g kg⁻¹) was recorded where 120 kg N and 15 Mg FYM ha⁻¹ was applied in both the seasons followed by 10 (1.40 g kg⁻¹) and 5 Mg FYM ha⁻¹ (1.18 g kg⁻¹).

Interaction between modes of FYM and N levels showed significant difference in HFC content. Application of FYM either in both the seasons or in rabi or in kharif increased the HFC content at both the levels of applied N.

4.1.6 Relationships between HFC and C pools and N fractions

The HFC showed highly significant relationship with MBC ($R^2 = 0.95$) followed by organic C ($R^2 = 0.93$), DOC ($R^2 = 0.87$) and LFC ($R^2 = 0.81$). Also a significant relationship was observed between N fractions and HFC, highest with amino acid-N ($R^2 = 0.96$) followed by acid insoluble-N ($R^2 = 0.95$), hydrolysable unknown-N ($R^2 = 0.94$), ammonia N ($R^2 = 0.92$) and lowest with amino sugar-N ($R^2 = 0.90$) and hydrolysable-N ($R^2 = 0.89$).

4.2. Nitrogen Fractions

4.2.1 Amino acid N

The data pertaining to amino acid N influenced by modes and levels of FYM and fertilizer N is presented in Table 2. Increasing levels of FYM from 0 to 15 Mg ha⁻¹ increased the amino acid-N from 68.3 to 144.1 mg kg⁻¹. There was a significant increase in amino acid-N was noticed when FYM was applied in both the seasons followed by rabi and kharif. The mean increase in amino acid-N was 86.1, 95.6 and 131.5 % over control with the application of 15 Mg FYM ha⁻¹ in kharif, rabi and both the seasons, respectively.

Fertilizer N has increased the amino acid-N content significantly at all the modes and levels of FYM application. A significant increase in amino acid-N was observed with

application of 120 kg N ha⁻¹ over control. Highest amino acid-N content was recorded with application of 15 Mg FYM plus 120 kg N ha⁻¹. There was a significant difference in amino acid-N of soil receiving varied levels of N. However, higher amino acid-N was recorded with application of 120 kg N ha⁻¹ irrespective of modes and levels of FYM.

Interaction between modes of FYM and N levels showed significant difference in amino acid-N content. The application of FYM in rabi season had more effect towards build up of amino acid-N compared to FYM applied in rabi or kharif at both the levels (0 and 120 kg N ha⁻¹) of applied N.

4.2.2 Relationships between amino acid - N and other N fractions

The amino acid-N showed highly significant relationship with amino sugar-N ($R^2 = 0.95$), acid insoluble-N ($R^2 = 0.99$), hydrolysable unknown-N ($R^2 = 0.99$), ammonia N ($R^2 = 0.99$), amino sugar-N ($R^2 = 0.95$) and hydrolysable-N ($R^2 = 0.96$). There was a significant relationship of amino acid-N with available N ($R^2 = 0.97$), amino acid-N and N content of pearl millet ($R^2 = 0.87$) and wheat ($R^2 = 0.87$).

4.2.3 Amino sugar- N

The amino sugar- N content of soil increased significantly from 19.0 to 56.3 mg kg⁻¹ with increased levels of FYM from 0 to 15 Mg ha⁻¹ (Table 2). Highest amino sugar-N (50.9 mg kg⁻¹) was noticed when FYM was applied in both seasons followed by rabi (38.9 mg kg⁻¹) and kharif (34.7 mg kg⁻¹). The mean increase in amino sugar-N was 82.6, 104.7 and 167.9 % over control with the application of 15 Mg FYM ha⁻¹ in kharif, rabi and both the seasons, respectively.

There was increase in amino sugar-N (10.67 %) with application of 120 kg N ha⁻¹ over 0 kg N ha⁻¹. There was a significant difference in amino sugar-N of soil receiving varied levels of N. Highest amino sugar-N of 60.5 mg kg⁻¹ was noticed when 15 Mg FYM ha⁻¹ was applied in both the seasons along with 120 kg N ha⁻¹ which was significantly superior over 10 and 5 Mg FYM ha⁻¹.

A significant interaction was observed between modes of FYM and N levels on amino sugar-N indicating that when was applied FYM in both seasons recorded higher amino sugar-N content of 53.4 mg kg⁻¹ compared to its application in rabi (40.7 mg kg⁻¹) and kharif (36.4 mg kg⁻¹) at 120 kg N ha⁻¹.

4.2.4 Relationships between amino sugar-N and other N fractions

The amino sugar-N showed highly significant relationship with amino acid-N ($R^2 = 0.95$), acid insoluble-N ($R^2 = 0.94$), hydrolysable unknown-N ($R^2 = 0.94$), ammonia N ($R^2 = 0.93$), amino sugar-N ($R^2 = 0.95$) and hydrolysable-N ($R^2 = 0.86$). A significant relationship was also observed between amino acid-N and available N ($R^2 = 0.97$), and amino acid-N with N content of pearl millet ($R^2 = 0.91$) and wheat ($R^2 = 0.90$).

Table 2: Long-term effect of modes and levels of FYM and fertilizer N on N fractions after 43 cycles of pearl millet-wheat cropping system

FYM		Amino acid N (mg kg ⁻¹)			Amino sugar N (mg kg ⁻¹)			Ammonia N (mg kg ⁻¹)		
Level (Mg ha ⁻¹)	Mode	0 N (kg ha ⁻¹)	120 N (kg ha ⁻¹)	Mean	0 N (kg ha ⁻¹)	120 N (kg ha ⁻¹)	Mean	0 N (kg ha ⁻¹)	120 N (kg ha ⁻¹)	Mean
0	Rabi	65.3	71.2	68.3	19.0	23.4	21.2	60.4	65.3	62.9
5		120.0	123.2	121.6	35.6	38.4	37.0	130.4	134.2	132.3
10		123.3	126.2	124.8	36.7	40.0	38.4	134.7	139.8	137.3
15		135.3	138.3	136.8	39.0	43.6	41.3	138.9	145.1	142.0
Mean		126.2	129.2	127.7	37.1	40.7	38.9	134.7	139.7	137.2
5	Kharif	115.0	118.3	116.7	30.3	33.5	31.9	126.0	128.4	127.2
10		120.0	122.4	121.2	32.7	36.5	34.6	127.8	129.0	128.4
15		124.4	128.6	126.5	36.3	39.1	37.7	130.1	135.3	132.7
Mean		119.8	123.1	121.5	33.1	36.4	34.7	128.0	130.9	129.4
5	Kharif and Rabi	132.4	138.5	135.5	43.5	49.4	46.5	141.3	145.4	143.4
10		145.4	152.3	148.9	45.5	50.3	47.9	146.7	151.0	148.9
15		163.2	175.0	169.1	56.3	60.5	58.4	153.4	159.0	156.2
Mean		147.0	155.3	151.2	48.4	53.4	50.9	147.1	151.8	149.5
Overall Mean		124.4	129.4	126.9	37.5	41.5	39.5	129.0	133.3	131.1
LSD (0.05):		FYM level FYM Mode N level Mode X N level	:10.3 :3.30 :4.80 :4.50	FYM level FYM Mode N level Mode X N level	:1.5 :5.5 :3.7 :1.3	FYM level FYM Mode N level Mode X N level	:3.5 :4.2 :3.7 :4.0			

4.2.5 Ammonia- N

The ammonia-N in the present study varied from 60.4 to 159.0 mg kg⁻¹ in the control plot without application of either FYM or fertilizer N and the plot where 15 Mg FYM ha⁻¹ was applied in conjunction with 120 kg N ha⁻¹ in both the seasons (Table 2). A significant increase in ammonia-N was observed when FYM applied at 15 Mg ha⁻¹ (143.6 mg kg⁻¹) followed by 10 (138.2 mg kg⁻¹) and 5 Mg ha⁻¹ (134.3 mg kg⁻¹) over control. Highest ammonia-N (149.5 mg kg⁻¹) was noticed where FYM was applied in both season followed by rabi (137.2 mg kg⁻¹) and lowest with kharif (129.4 mg kg⁻¹).

The ammonia-N content of soil increased significantly with increased levels of N from 0 to 120 kg N ha⁻¹. The increases in ammonia-N due to application of fertilizer-N at 120 kg ha⁻¹ were 3.71, 2.27 and 3.19 % during rabi, kharif and both the seasons, respectively, over control.

Interaction between modes of FYM and N levels showed significant difference in ammonia-N content. At all the modes of FYM application, the application of 120 kg N ha⁻¹ increased the ammonia-N over 0 kg N ha⁻¹.

4.2.6 Relationships between ammonia - N and other N fractions

The ammonia-N showed highly significant relationship with amino acid-N ($R^2 = 0.99$), hydrolysable-N ($R^2 = 0.99$), hydrolysable unknown-N ($R^2 = 0.99$), acid insoluble-N ($R^2 = 0.98$), amino sugar-N ($R^2 = 0.93$). Similarly, a significant relationship of ammonia-N with available N ($R^2 = 0.98$) and N content of pearl millet ($R^2 = 0.85$) and wheat ($R^2 = 0.85$) was also observed.

4.2.7 Hydrolysable-N

Results presented in the Table 3 revealed that hydrolysable-N increased due to the application FYM from 0 to 15 Mg ha⁻¹ and fertilizer N levels from 0 to 120 kg ha⁻¹ and it ranged from 151.0 to 489.5 mg kg⁻¹. Highest hydrolysable-N was recorded when FYM applied at 15 Mg ha⁻¹ (464.3 mg kg⁻¹) followed by 10 (451.2 mg kg⁻¹) and 5 Mg ha⁻¹ (446.7 mg kg⁻¹). A significant increase in hydrolysable-N (469.6 mg kg⁻¹) was noticed when FYM was applied in both seasons followed by rabi (450.0 mg kg⁻¹) and kharif (442.7 mg kg⁻¹) over control.

Highest hydrolysable-N (489.5 mg kg⁻¹) was observed where 15 Mg FYM ha⁻¹ + 120 kg N ha⁻¹ was applied in both the seasons followed by 10 (470.0 mg kg⁻¹) and 5 Mg FYM ha⁻¹ (459.0 mg kg⁻¹). There was a significant difference in hydrolysable-N of soil receiving varied levels of N. However, higher hydrolysable-N was recorded in 120 kg N ha⁻¹ irrespective of modes and levels of FYM. The buildup of ammonia-N with respect to modes, highest was recorded in both seasons (211 %) followed by rabi (198 %) and kharif (193 %) over control without application of either FYM or fertilizer N.

Interaction between modes of FYM and N levels showed significant difference in hydrolysable-N content. Application of 120 kg N ha⁻¹ increased the hydrolysable-N over 0 kg N ha⁻¹ at all the modes of FYM application.

4.2.8 Relationships between hydrolysable-N and other N fractions

The hydrolysable-N showed highly significant relationship with ammonia N ($R^2 = 0.99$), hydrolysable unknown-N ($R^2 = 0.99$), amino acid-N ($R^2 = 0.96$), acid insoluble-N ($R^2 = 0.94$), amino sugar-N ($R^2 = 0.93$), available N ($R^2 = 0.97$), N content of pearl millet ($R^2 = 0.79$) and wheat ($R^2 = 0.79$).

4.2.9 Total hydrolysable Unknown-N

The total hydrolysable unknown-N content of soil ranged from 65.0 to 179.0 mg kg⁻¹ due to the application of modes and levels of FYM and fertilizer N (Table 3). Application of FYM significantly increased the total hydrolysable-N. There was significant increase in total hydrolysable unknown-N (164.7 mg kg⁻¹) was noticed when FYM was applied in both seasons as compared to applied in rabi (150.6 mg kg⁻¹) or kharif (140.1 mg kg⁻¹). Highest hydrolysable unknown-N was recorded with application of 15 Mg FYM ha⁻¹ plus 120 kg N ha⁻¹ (179.0 mg kg⁻¹) followed by 10 (166.0 mg kg⁻¹) and 5 Mg FYM ha⁻¹ (157.9 mg kg⁻¹). The buildup of hydrolysable unknown-N with respect to FYM modes, highest was recorded with FYM applied in both seasons (153.4 %) followed by rabi (131.7 %) and kharif (115.5 %) over control without FYM and N.

A significant increase in total hydrolysable unknown-N was observed with application of 120 kg N ha⁻¹ over 0 kg N ha⁻¹.

Interaction between modes of FYM and N levels showed significant difference in total hydrolysable unknown-N content. Application of 120 kg N ha⁻¹ irrespective of FYM modes increased mean total hydrolysable unknown-N content over 0 kg N ha⁻¹.

4.2.10 Relationships between total hydrolysable unknown-N and other N fractions

The total hydrolysable unknown-N showed highly significant ($R^2 = 0.99$) relationship with ammonia N, hydrolysable-N, amino acid-N, acid insoluble-N. The total hydrolysable unknown-N also showed significant relationship with available N ($R^2 = 0.98$), N content of pearl millet ($R^2 = 0.84$) and wheat ($R^2 = 0.86$).

4.2.11 Acid Insoluble-N

The acid insoluble-N varied widely among the different treatments consisting of different modes and levels of FYM and fertilizer-N (Table 3). It varied between 75.1 (in control plot- without application of FYM and N) to 178.7 mg kg⁻¹ (plot received 15 Mg FYM ha⁻¹ along with 120 kg N ha⁻¹ in both the seasons). The acid insoluble-N significantly increased with application of FYM and fertilizer N over control (Table 3). The acid insoluble-N was increased significantly with the application of FYM from 0 to 15 Mg ka⁻¹ at all the modes of FYM application.

Table 3: Long-term effect of modes and levels of FYM and fertilizer N on N fractions after 43 cycles of pearl millet-wheat cropping system

FYM		Hydrolysable-N (mg kg ⁻¹)			Total hydrolysable unknown-N (mg kg ⁻¹)			Acid insoluble-N (mg kg ⁻¹)		
Level (Mg ha ⁻¹)	Mode	0 N (kg ha ⁻¹)	120 N (kg ha ⁻¹)	Mean	0 N (kg ha ⁻¹)	120 N (kg ha ⁻¹)	Mean	0 N (kg ha ⁻¹)	120 N (kg ha ⁻¹)	Mean
0		151.0	159.4	155.2	65.0	69.5	67.3	75.1	79.0	77.1
5		442.0	445.3	445.2	145.3	148.2	146.8	140.0	143.3	141.7
10	Rabi	448.3	451.3	449.8	148.0	150.6	149.3	145.1	148.7	146.9
15		452.4	457.3	454.9	153.4	157.8	155.6	152.0	157.0	154.5
	Mean	447.6	451.3	450.0	148.9	152.2	150.6	145.7	149.7	147.7
5		436.4	438.6	437.5	133.4	136.5	135.0	133.0	135.5	134.3
10	Kharif	437.3	439.0	438.2	136.3	140.2	138.3	138.9	142.0	140.5
15		451.2	453.3	452.3	144.6	149.5	147.1	144.6	149.4	147.0
	Mean	441.6	443.6	442.7	138.1	142.1	140.1	138.8	142.3	140.6
5		455.6	459.0	457.3	152.3	157.4	154.9	148.0	155.4	151.7
10	Kharif and Rabi	461.3	470.0	465.7	160.5	166.0	163.3	158.9	166.4	162.7
15		482.0	489.5	485.8	172.5	179.0	175.8	172.0	178.7	175.4
	Mean	466.3	472.8	469.6	161.8	167.5	164.7	159.6	166.8	163.3
	Overall Mean	422.1	428.3	425.2	141.1	145.5	143.3	140.8	145.5	143.2
LSD (0.05):		FYM level :2.1			FYM level :2.8			FYM level :5.1		
		FYM Mode :4.0			FYM Mode :8.2			FYM Mode :6.0		
		N level :5.7			N level :3.6			N level :4.5		
		Mode X N level :3.8			Mode X level :2.1			Mode X N level :4.2		

Highest acid insoluble-N was recorded when FYM was at 15 Mg ha⁻¹ along with 120 kg N ha⁻¹ in both the seasons (178.7 mg kg⁻¹) followed by 10 (166.4 mg kg⁻¹) and 5 Mg ha⁻¹ (155.4 mg kg⁻¹). A significant increase in acid insoluble-N was noticed when 15 Mg FYM ha⁻¹ was applied in both seasons as compared to applied either in rabi or kharif. The mean increase in acid insoluble-N was 90.7, 100.4 and 127.5 % over control with the application of 15 Mg FYM ha⁻¹ in kharif, rabi and both the seasons, respectively.

Application of 120 kg N ha⁻¹ increased the mean acid insoluble-N (3.33 %) significantly over 0 kg N ha⁻¹.

A significant interaction was observed between modes of FYM and N levels on acid insoluble-N indicating that FYM applied in both seasons recorded higher amino sugar-N as compared to its application in rabi and kharif at both the levels of applied N.

4.2.12. Relationships between acid insoluble-N and other N fractions

The acid insoluble-N showed highly significant relationship with amino sugar-N ($R^2 = 0.99$), ammonia N ($R^2 = 0.99$), hydrolysable unknown-N ($R^2 = 0.99$), amino acid-N ($R^2 = 0.99$), available N ($R^2 = 0.98$), and N content of pearl millet ($R^2 = 0.86$) and wheat ($R^2 = 0.87$).

4.3. Grain yield of pearl millet and wheat

The grain yield of pearl millet and wheat increased significantly with the application of N and FYM (Table 4). Highest grain yields were recorded when FYM applied at 15 Mg ha⁻¹ followed by 10 and 5 Mg ha⁻¹ and values were 25.57, 27.02 and 28.60 q ha⁻¹ of pearl millet and 43.49, 45.34 and 47.72 q ha⁻¹ of wheat, respectively. The increase in pearl millet grain yield was about 23, 30 and 37 % and that of wheat grain was 28, 34 and 41 % upon application of FYM at 5, 10 and 15 Mg ha⁻¹ over the control, respectively. Application of FYM in both the seasons (kharif and rabi) gave maximum yield followed by rabi and kharif applications. Application of FYM in rabi season was, however, found to be more beneficial than its application in kharif season. The mean increase in pearl millet and wheat grain yield was 31 and 35, 45 and 39, and 46 and 51 % over control with the application of 15 Mg kg⁻¹ in kharif, rabi and both the seasons, respectively. Integrated use of N and FYM resulted in higher grain yield of both the crops and it was highest with the application of 15 Mg FYM ha⁻¹ and 120 kg N ha⁻¹.

Interaction between modes of FYM and N levels showed non-significant difference in grain yield of pearl millet and wheat.

Table 4: Long-term effect of modes and levels of FYM and fertilizer N on grain yield of pearl millet and wheat after 43 cycles of pearl millet-wheat cropping system

FYM		Pearl millet (q ha ⁻¹)			Wheat (q ha ⁻¹)		
Level (Mg ha ⁻¹)	Mode	0 N (kg ha ⁻¹)	120 N (kg ha ⁻¹)	Mean	0 N (kg ha ⁻¹)	120 N (kg ha ⁻¹)	Mean
0		17.13	24.38	20.76	26.83	41.25	34.04
5	Rabi	20.70	27.04	23.87	33.38	47.71	40.55
10		23.51	28.04	25.78	36.22	48.15	42.19
15		24.78	30.08	27.43	38.57	52.22	45.4
Mean		23.00	28.39	25.69	36.06	49.36	42.71
5	Kharif	22.13	28.09	25.11	34.68	48.8	41.74
10		24.00	28.60	26.30	37.91	50.85	44.38
15		25.70	30.38	28.04	40.65	53.62	47.14
Mean		23.94	29.02	26.48	37.75	51.09	44.42
5	Kharif and Rabi	24.86	30.58	27.72	41.78	54.55	48.17
10		26.30	31.66	28.98	42.57	56.35	49.46
15		26.80	33.87	30.34	43.11	58.11	50.61
Mean		25.99	32.04	29.01	42.49	56.34	49.41
Overall Mean		23.59	29.27	26.43	37.57	51.16	44.37

LSD (0.05):	FYM level	:0.5	FYM level	:0.4
	FYM mode	:6.1	FYM mode	:3.8
	N level	:1.3	N level	:4.9
	Mode X N level	:NS	Mode X N level	:NS

4.4. NPK (%) content of Pearl millet grain

The N, P and K content of pearl millet grain varied between 0.68, 0.12 and 1.61 % respectively, in control plots (without FYM and N) to 1.52, 0.60 and 2.44 % with the application of 15 Mg FYM ha⁻¹ along with 120 kg N ha⁻¹ during both the seasons (Table 5). There were significant difference in NPK content of pearl millet grain in different modes and levels of FYM and N. The N, P and K content of pearl millet grain increased significantly with the application of FYM from 0 to 15 Mg ha⁻¹ and fertilizer N from 0 to 120 kg ha⁻¹. There was an increase in NPK content in pearl millet gain with addition of 15 Mg FYM ha⁻¹ followed by 10 and 5 Mg ha⁻¹ and values were 1.15, 1.23 and 1.32 % N; and 0.37, 0.43 and 0.49 % P and 2.08, 2.16 and 2.24 % K in grain of pearl millet, respectively. Highest NPK content was observed when FYM was applied in both seasons followed by rabi and kharif.

The interaction between N levels and modes of FYM was not significant for NPK content of pearl millet grain. However, application of 120 kg N + 15 Mg FYM ha⁻¹ in both seasons recorded higher N, P and K content.

Interaction of N levels with different doses and modes of FYM was showed non-significant with respect to NPK content of pearl millet grain.

Table 5: Long-term effect of modes and levels of FYM and fertilizer N on NPK content of pearl millet grain after 43 cycles of pearl millet-wheat cropping system

FYM		N (%)			P (%)			K (%)		
Level (Mg ha ⁻¹)	Mode	0 N (kg ha ⁻¹)	120 N (kg ha ⁻¹)	Mean	0 N (kg ha ⁻¹)	120 N (kg ha ⁻¹)	Mean	0 N (kg ha ⁻¹)	120 N (kg ha ⁻¹)	Mean
0	Rabi	0.68	0.89	0.79	0.12	0.20	0.16	1.61	1.82	1.72
5		1.00	1.11	1.06	0.34	0.38	0.36	1.93	2.04	1.99
10		1.12	1.21	1.17	0.39	0.42	0.41	2.05	2.14	2.10
15		1.23	1.34	1.29	0.44	0.47	0.46	2.16	2.25	2.21
Mean		1.12	1.22	1.17	0.39	0.42	0.41	2.05	2.14	2.10
5	Kharif	1.00	1.05	1.03	0.29	0.34	0.36	1.93	1.98	1.96
10		1.10	1.15	1.13	0.31	0.38	0.41	2.03	2.08	2.06
15		1.16	1.25	1.21	0.42	0.48	0.46	2.09	2.18	2.14
Mean		1.09	1.15	1.12	0.34	0.40	0.37	2.02	2.08	2.05
5	Kharif and Rabi	1.34	1.38	1.36	0.37	0.42	0.40	2.27	2.31	2.29
10		1.35	1.45	1.40	0.46	0.49	0.48	2.28	2.38	2.33
15		1.36	1.52	1.45	0.50	0.60	0.55	2.29	2.44	2.37
Mean		1.35	1.45	1.40	0.44	0.50	0.48	2.28	2.38	2.33
Overall Mean		1.13	1.24	1.18	0.36	0.42	0.39	2.06	2.16	2.11
LSD (0.05):		FYM level FYM mode N level Mode X N level	:0.04 :0.1 :0.1 :NS	FYM level FYM mode N level Modes X N level	:0.05 :0.06 :0.05 :NS	FYM level FYM mode N level Mode X N level	:0.03 :0.04 :0.09 :NS			

4.5 Wheat grain NPK (%) content

The data presented in Table 6 revealed that increasing levels of FYM from 0 to 15 Mg ha⁻¹ increased the NPK content in wheat grain from 1.42 to 1.94 % N, 0.51 to 0.84 % P and 0.92 to 1.44 % K. There was an increase in NPK content in wheat grain with addition of 15 Mg FYM ha⁻¹ followed by 10 and 5 Mg ha⁻¹ and values were 1.78, 1.86 and 1.94 % N; and 0.71, 0.76 and 0.84 % P and 1.28, 1.36 and 1.44 % K, respectively. Higher content of N, P and K was observed when FYM was applied in both the seasons (kharif and rabi) followed by applied in rabi and kharif season.

NPK content of wheat grain increased with successive levels of N from 0 to 120 kg N ha⁻¹. Highest N (2.14 %), P (0.95 %) and K (1.64 %) content was recorded when FYM was applied in conjunction with 120 kg N ha⁻¹ in both seasons as compared to applied either in rabi or kharif season.

The interaction between FYM modes and N levels was found non-significant for NPK content in wheat grain.

4.6 Organic C (%)

The organic C content of soil increased significantly with the application of FYM at all the levels of fertilizer N and it ranged from 0.48 to 2.20 %. A significant increase in organic C was observed when FYM applied at 15 Mg ha⁻¹ (2.1 %) followed by 10 (1.5 %) and 5 Mg ha⁻¹ (1.2 %). Highest content of organic C was noted when FYM was applied in both the seasons compared to applied rabi or kharif season. Highest build up of organic C (2.09) was noticed when 15 Mg ha⁻¹ FYM was applied in the both seasons in conjunction with 120 kg N ha⁻¹ for 43 years by raising pearl millet-wheat cropping system (Table 7). However, the corresponding build up of organic C was about 1.18 % in kharif season and 1.21 % in rabi season.

Interaction of N levels and modes of FYM showed significant differences for organic C content of soil.

The organic C showed highly significant correlation with HFC ($R^2 = 0.96$), DOC ($R^2 = 0.95$) and DOC and MBC ($R^2 = 0.93$) and less with LFC ($R^2 = 0.80$).

4.7 Available Nitrogen

Available N content of soil increased significantly with an increasing levels of FYM from 0 to 15 Mg ha⁻¹ and fertilizer N from 0 to 120 kg N ha⁻¹ (Table 7). Forty three years of continuous cultivation of pearl millet-wheat system with different amounts of FYM and fertilizer N added either in rabi or kharif seasons could not sustained the initial N content (100 mg kg⁻¹). Higher increase in available N was recorded when FYM applied at 15 Mg ha⁻¹ (108.4 mg kg⁻¹) followed by 10 (98.1 mg kg⁻¹) and 5 Mg ha⁻¹ (94.1 mg kg⁻¹).

There was a significant difference in available N content of soil receiving varied levels of N.

Table 6: Long-term effect of modes and levels of FYM and fertilizer N on NPK content of wheat grain after 43 cycles of pearl millet-wheat cropping system

FYM		N (%)			P (%)			K (%)		
Level (Mg ha ⁻¹)	Mode	0 N (kg ha ⁻¹)	120 N (kg ha ⁻¹)	Mean	0 N (kg ha ⁻¹)	120 N (kg ha ⁻¹)	Mean	0 N (kg ha ⁻¹)	120 N (kg ha ⁻¹)	Mean
0	Rabi	1.31	1.52	1.42	0.47	0.55	0.51	0.81	1.02	0.92
5		1.63	1.74	1.69	0.69	0.73	0.71	1.13	1.24	1.19
10		1.75	1.84	1.80	0.74	0.77	0.76	1.25	1.34	1.30
15		1.86	1.95	1.91	0.79	0.82	0.81	1.36	1.45	1.41
Mean		1.75	1.84	1.80	0.74	0.77	0.76	1.25	1.34	1.30
5	Kharif	1.63	1.68	1.66	0.64	0.69	0.67	1.13	1.18	1.16
10		1.73	1.78	1.76	0.66	0.73	0.70	1.23	1.28	1.26
15		1.79	1.88	1.84	0.77	0.83	0.80	1.29	1.38	1.34
Mean		1.72	1.78	1.75	0.69	0.75	0.72	1.22	1.28	1.25
5	Kharif and Rabi	1.97	2.01	1.99	0.72	0.77	0.75	1.47	1.51	1.49
10		1.98	2.08	2.03	0.81	0.84	0.83	1.48	1.58	1.53
15		1.99	2.14	2.07	0.85	0.95	0.90	1.49	1.64	1.57
Mean		1.98	2.08	2.03	0.79	0.85	0.83	1.48	1.58	1.53
Overall Mean		1.76	1.86	1.81	0.71	0.77	0.74	1.26	1.36	1.31
LSD (0.05):		FYM level	:0.1		FYM level	:0.07		FYM level	:0.06	
		FYM mode	:0.03		FYM mode	:0.05		FYM mode	:0.04	
		N level	:0.08		N level	:0.04		N level	:0.09	
		Mode X N level	:NS		Mode X N level	:NS		Mode X N level	:NS	

However, available N of soil was significantly higher in 120 kg N ha⁻¹ over 0 kg N ha⁻¹. Highest available N (119.3 mg kg⁻¹) was noticed where FYM was applied in both season followed by rabi (98.7mg kg⁻¹) and kharif (86.6 mg kg⁻¹).

Interaction of N levels and modes of FYM showed significant differences for available N content in soil. Application of fertilizer N increased the available N content of soil at all the modes of FYM application.

4.8 Available Phosphorus

Available P content of soil decreased from 13 to 11 mg P kg⁻¹ soil without application of FYM and fertilizer for 43 years by raising pearl millet and wheat crop in sequence. The result showed that there was a significant increase in available P status of soil with increasing levels of FYM from 0 to 15 Mg ha⁻¹ and fertilizer N from 0 to 120 kg N ha⁻¹ (Table 7). The available P had increased 4.5 times from 11 mg kg⁻¹ in control plot with no addition of either FYM or fertilizer N to 50.0 mg kg⁻¹ in plot receiving 15 Mg ha⁻¹ FYM along with 120 kg N ha⁻¹ in both the seasons.

There was a significant difference between available P content of soil receiving varied levels of N. However, available P of soil was significantly higher in 120 kg N ha⁻¹ over 0 kg N ha⁻¹. Highest available P was recorded in 120 kg N plus 15 Mg FYM ha⁻¹ which was significantly superior over 10 and 5 Mg FYM ha⁻¹ irrespective of modes. Highest available P (41.2 mg kg⁻¹) was noticed when FYM was applied in both season followed by rabi (33.4 mg kg⁻¹) and kharif (28.5 mg kg⁻¹).

Interaction between N levels and modes of FYM showed significant differences in available P content of soil.

4.9 Available Potassium

Available K content of soil decreased without applying FYM and fertilizer N in 43 years cropping of pearl millet and wheat crop in sequence (Table 7). Application of FYM increased the available K content of soil over control.

There were significant differences in available K content of soil receiving varied levels of N. However, available K content of soil was significantly higher at 120 kg N ha⁻¹ over 0 kg N ha⁻¹. Application of FYM in both the seasons (324.7 mg kg⁻¹) resulted in higher build up of available K compared to applying in rabi (291.9 mg kg⁻¹) or kharif (264.2 mg kg⁻¹) seasons. However, build up was higher when FYM applied in rabi than kharif season.

Interaction of N levels and modes of FYM showed significant differences for available K content of soil. The available K content of soil remained higher than its original value (249 mg K kg⁻¹) at both the levels of applied fertilizer N.

Table 7: Long-term effect of modes and levels of FYM and fertilizer N on organic C, available N P and K after 43 cycles of pearl millet-wheat cropping system

FYM		Organic C (%)			N (mg kg ⁻¹)			P (mg kg ⁻¹)			K (mg kg ⁻¹)		
Level (Mg ha ⁻¹)	Mode	0 N (kg ha ⁻¹)	120 N (kg ha ⁻¹)	Mean	0 N (kg ha ⁻¹)	120 N (kg ha ⁻¹)	Mean	0 N (kg ha ⁻¹)	120 N (kg ha ⁻¹)	Mean	0 N (kg ha ⁻¹)	120 N (kg ha ⁻¹)	Mean
0		0.58	0.77	0.68	41.3	49.5	45.4	11.0	26.8	18.9	140.4	150.8	145.6
5	Rabi	1.10	1.20	1.15	93.4	97.0	95.2	29.8	31.4	30.6	261.2	277.0	269.2
10		1.15	1.30	1.23	95.3	100.0	97.7	32.7	34.0	33.4	287.0	297.0	292.0
15		1.19	1.45	1.32	97.8	108.6	103.2	35.4	37.0	36.2	309.2	320.0	314.6
	Mean	1.15	1.32	1.23	95.5	101.9	98.7	32.6	34.1	33.4	285.8	298.0	291.9
5	Kharif	0.99	1.14	1.07	79.3	84.0	81.7	25.3	26.9	26.1	240.8	249.4	245.2
10		1.13	1.22	1.18	85.3	88.4	86.9	26.9	29.3	28.1	255.6	268.0	261.8
15		1.18	1.38	1.28	89.0	93.4	91.2	30.5	31.8	31.2	280.0	291.0	285.6
	Mean	1.10	1.25	1.17	84.5	88.6	86.6	27.6	29.3	28.5	258.8	269.5	264.2
5	Kharif and Rabi	1.12	1.27	1.20	100.5	110.5	105.5	34.3	36.3	35.3	291.6	310.0	300.8
10		1.48	1.55	1.52	118.6	125.0	121.8	39.0	41.7	40.4	321.0	331.0	326.0
15		1.98	2.20	2.09	129.0	132.4	130.7	45.7	50.0	47.9	340.6	354.0	347.4
	Mean	1.53	1.67	1.60	116.0	122.6	119.3	39.7	42.7	41.2	317.7	331.7	324.7
	Overall Mean	1.18	1.34	1.26	94.3	100.1	97.2	27.7	30.5	30.5	272.7	284.8	278.8
LSD (0.05):		FYM level	:0.05	:8.5	FYM level	:8.5	:5.2	FYM level	:5.2	FYM level	:18.5	:18.5	
		FYM Mode	:0.08	:8.2	FYM mode	:8.2	:2.1	FYM mode	:2.1	FYM mode	:14.5	:14.5	
		N level	:0.10	:4.3	N level	:4.3	:0.7	N level	:0.7	N levels	:5.0	:5.0	
		Mode X N level	:0.08	:13.3	Mode X N level	:13.3	:3.3	Mode X N level	:3.3	Mode X N level	:27.3	:27.3	

4.10 DTPA extractable micronutrients (Zn, Mn, Fe and Cu)

There was significant effect of modes and levels of FYM and fertilizer N on DTPA extractable micronutrients (Zn, Mn, Fe and Cu) and it ranged from 0.77 to 2.68 mg kg⁻¹ (Zn), 3.50 to 5.71 mg kg⁻¹ (Mn), 5.00 to 8.86 mg kg⁻¹ (Fe) and 0.44 to 1.03 mg kg⁻¹ (Cu) (Table 8).

There was a significant increase in DTPA extractable Zn, Mn, Fe and Cu in soil with increasing FYM application. Successive increase in FYM levels from 0 to 15 Mg ha⁻¹ increased the DTPA extractable Zn, Mn, Fe and Cu from 0.78 to 2.34, 3.69 to 5.10, 5.00 to 8.10 and 0.44 to 0.94 mg kg⁻¹, respectively. The FYM applied in rabi season contributed more towards build up of DTPA extractable Zn (2.31 mg kg⁻¹), Mn (5.18 mg kg⁻¹), Fe (7.77 mg kg⁻¹) and Cu (0.89 mg kg⁻¹) as compared to applied in kharif season (1.78 mg kg⁻¹ (Zn), 4.16 (Mn), 7.49 mg kg⁻¹ (Fe) and 0.82 mg kg⁻¹ (Cu)). However, application of FYM in both the seasons (kharif and rabi) gave highest build up of DTPA extractable Zn, Mn, Fe and Cu as compared to FYM application either in rabi or kharif seasons or no application. The mean increase in DTPA extractable Zn, Mn, Fe and Cu was 1.83, 1.95, 3.00 and 0.52; 1.08, 0.80, 2.66 and 0.46; and 1.91, 2.21, 3.86, 0.59 mg kg⁻¹ over control with the application of 15 Mg FYM plus 120 kg N ha⁻¹ in kharif, rabi and in both the seasons, respectively. Fertilizer N has increased the DTPA extractable Zn, Mn, Fe and at all the levels and modes of FYM application.

Interaction between N levels and FYM modes was not significant for DTPA extractable Zn, Mn, Fe and Cu.

Experiment: II: To study the effect of various combinations of different organic manures and fertilizers;

4.11. Soil organic matter pools

4.11.1. Dissolved Organic Carbon (DOC)

Data presented in Table 9 (0-15 cm), 10 (15-30 cm) and 11 (30-45 cm) revealed that DOC content of soil ranged from 131 to 247 mg kg⁻¹ in 0-15 cm, 86 to 185 mg kg⁻¹ in 15-30 cm and 29.5 to 76.5 mg kg⁻¹ in 30-45 cm depth. The DOC was low when only organic manures (FYM, Poultry Manure, and Pressmud) were applied and similar trends were followed in sub-surface soil (15-30 and 30-45 cm). Highest DOC was observed when 15 Mg FYM or 7.5 Mg pressmud or 5 Mg poultry manure ha⁻¹ were applied in conjunction with recommended dose of N or NP fertilizers over NP fertilizer applied alone.

Table 8: Long-term effect of modes and levels of FYM and fertilizer N on micronutrients after 43 cycles of pearl millet-wheat cropping system

FYM		Zn (mg kg ⁻¹)			Mn (mg kg ⁻¹)			Fe (mg kg ⁻¹)			Cu (mg kg ⁻¹)		
Level (Mg ha ⁻¹)	Mode	0 N (kg ha ⁻¹)	120 N (kg ha ⁻¹)	Mean	0 N (kg ha ⁻¹)	120 N (kg ha ⁻¹)	Mean	0 N (kg ha ⁻¹)	120 N (kg ha ⁻¹)	Mean	0 N (kg ha ⁻¹)	120 N (kg ha ⁻¹)	Mean
0		0.77	0.79	0.78	3.50	3.88	3.69	5.00	5.23	5.12	0.44	0.46	0.45
5		1.91	2.32	2.12	4.87	5.11	4.99	7.54	7.66	7.60	0.80	0.86	0.83
10	Rabi	2.00	2.45	2.23	5.00	5.32	5.16	7.71	7.78	7.75	0.88	0.90	0.89
15		2.55	2.60	2.57	5.30	5.45	5.38	7.89	8.00	7.95	0.93	0.96	0.95
Mean		2.15	2.46	2.31	5.06	5.29	5.18	7.71	7.81	7.77	0.87	0.91	0.89
5	Kharif	1.70	1.75	1.73	4.00	4.15	4.08	7.23	7.43	7.33	0.76	0.78	0.77
10		1.78	1.79	1.79	4.10	4.20	4.15	7.45	7.56	7.51	0.79	0.81	0.8
15		1.80	1.85	1.83	4.22	4.30	4.26	7.60	7.66	7.63	0.86	0.90	0.88
Mean		1.76	1.80	1.78	4.11	4.22	4.16	7.43	7.55	7.49	0.80	0.83	0.82
5	Kharif and Rabi	2.04	2.40	2.22	5.21	5.32	5.27	7.72	7.76	7.74	0.86	0.88	0.87
10		2.36	2.48	2.42	5.45	5.55	5.50	7.89	8.00	7.95	0.89	0.91	0.9
15		2.58	2.68	2.63	5.65	5.71	5.65	8.80	8.86	8.83	0.95	1.03	0.99
Mean		2.33	2.52	2.42	5.44	5.53	5.47	8.14	8.21	8.17	0.90	0.94	0.92
Overall Mean		1.95	2.12	2.04	4.73	4.81	4.81	7.48	7.59	7.54	0.82	0.85	0.83

LSD (0.05):	FYM level	:0.05	FYM level	:0.05	FYM level	:0.07	FYM level	:0.04
	FYM mode	:0.10	FYM mode	:1.10	FYM mode	:0.40	FYM mode	:0.03
	N level	:0.4	N level	:0.10	N level	:0.10	N level	:0.03
	Mode X N level	:NS	Mode X N level	:NS	Mode X N level	:NS	Mode X N level	:NS

Table 9: Long- term effect of organic manures and fertilizers on organic C pools of surface soil (0-15 cm) after 16 cycles of pearl millet-wheat cropping sequence

Type of manure	Dose (Mg ha ⁻¹)	Fertilizer (kg ha ⁻¹)		Organic C pool			
		N	P ₂ O ₅	DOC (mg kg ⁻¹)	MBC (mg kg ⁻¹)	LFC (g kg ⁻¹)	HFC (g kg ⁻¹)
No manures	0	75	30	131	185	0.77	3.7
	0	150	60	186	196	0.81	3.8
FYM	15	0	0	236	368	1.28	4.9
	15	150	0	237	373	1.38	5.3
	15	150	30	247	383	1.43	5.8
Poultry Manure	5	0	0	222	360	1.20	4.4
	5	150	30	238	373	1.25	4.8
Pressmud	7.5	0	0	226	366	1.26	4.1
	7.5	75	30	236	370	1.28	4.5
	7.5	150	30	242	376	1.32	5.0
LSD (0.05)				5.2	5.0	0.1	0.4

Table 10: Long- term effect of organic manures and fertilizers on organic C pools of sub-surface soil (15-30 cm) after 16 cycles of pearl millet-wheat cropping sequence

Type of manure	Dose (Mg ha ⁻¹)	Fertilizer (kg ha ⁻¹)		Organic C pool			
		N	P ₂ O ₅	DOC (mg kg ⁻¹)	MBC (mg kg ⁻¹)	LFC (g kg ⁻¹)	HFC (g kg ⁻¹)
No manures	0	75	30	86	59	0.15	2.2
	0	150	60	91	129	0.32	2.9
FYM	15	0	0	161	229	0.41	3.5
	15	150	0	168	235	0.45	3.3
	15	150	30	185	247	0.52	3.7
Poultry Manure	5	0	0	168	228	0.32	2.8
	5	150	30	180	245	0.34	3.5
Pressmud	7.5	0	0	148	218	0.37	2.5
	7.5	75	30	154	222	0.41	3.2
	7.5	150	30	176	234	0.44	3.4
LSD (0.05)				4.3	6.1	0.08	0.3

Table 11: Long- term effect of organic manures and fertilizers on organic C pools of sub-surface soil (30-45 cm) after 16 cycles of pearl millet-wheat cropping sequence

Type of manure	Dose (Mg ha ⁻¹)	Fertilizer (kg ha ⁻¹)		Organic C pool			
		N	P ₂ O ₅	DOC (mg kg ⁻¹)	MBC (mg kg ⁻¹)	LFC (g kg ⁻¹)	HFC (g kg ⁻¹)
No manures	0	75	30	29.5	21.5	0.15	0.95
	0	150	60	38.5	60.5	0.19	1.00
FYM	15	0	0	65.0	105.0	0.29	1.10
	15	150	0	69.0	110.5	0.30	1.05
	15	150	30	76.5	114.5	0.37	1.45
Poultry Manure	5	0	0	72.5	105.5	0.28	1.10
	5	150	30	73.0	113.0	0.30	1.25
Pressmud	7.5	0	0	58.5	99.0	0.27	0.95
	7.5	75	30	68.0	109.0	0.32	1.00
	7.5	150	30	69.5	112.5	0.33	1.20
LSD (0.05)				4.1	3.4	0.08	0.15

Irrespective of soil depths, FYM₁₅N₁₅₀P₃₀ invariably showed higher content of DOC over all other treatments. The DOC content under FYM₁₅N₁₅₀P₃₀, pressmud_{7.5}N₁₅₀P₃₀ and poultry manures₅N₁₅₀P₃₀ were 32.8, 30.1 and 28.0% respectively, higher than half of recommended dose of NP fertilizers alone in surface (0-15 cm) soil. In sub-surface soil (15–30 and 30–45 cm) also showed similar trends. Highest accumulation of DOC in soil was observed where only FYM (1.27 folds) applied followed by poultry manure (1.19 folds) and pressmud (1.22) over recommended dose of NP fertilizers in surface soil. Similar trend was observed in sub-surface (15-30 and 30-45 cm) soil. The increase in DOC was higher in the surface soil than in the sub-surface soil. The DOC content decreased with increase in soil depths. The effect of different treatments on DOC of sub-surface soil was almost same to that observed for surface soil. The DOC showed highly significant relationship with LFC ($R^2 = 0.94$) following by MBC ($R^2 = 0.89$), organic C ($R^2 = 0.81$) and HFC ($R^2 = 0.73$).

4.11.2 Microbial Biomass Carbon (MBC)

The MBC differences among treatments not only presented in the surface soil, but also presented in sub-surface soil. The results pertaining to the MBC due to the effect of organic manures and fertilizers at 0-15, 15-30 and 30-45 cm soil depths are represented in Table 9, 10 and 11, respectively. Significant increase in MBC was observed in treatments received the organic manures alone or in combination with N or NP fertilizers over half of recommended dose of NP fertilizer. Among the organic manures applied alone, highest MBC

in surface soil was observed with the application of FYM (368.0 mg kg⁻¹) followed by pressmud (366.0 mg kg⁻¹) and poultry manure (360.0 mg kg⁻¹). As compared to half of the recommended dose of NP fertilizer, manures additions showed two folds increase in MBC. MBC contents under FYM₁₅N₁₅₀P₃₀, pressmud_{7.5}N₁₅₀P₃₀ and poultry manures₅N₁₅₀P₃₀ were 95.4, 91.8 and 90.8% was higher than recommended dose of NP fertilizers in surface soil. Sub-surface (15–30 and 30–45 cm) soil also showed similar trends and MBC decreased with increase in soil depth.

The MBC showed highly significant relationship with LFC ($R^2 = 0.99$) followed by DOC ($R^2 = 0.89$), organic C ($R^2 = 0.83$) and HFC ($R^2 = 0.82$).

4.11.3 Light fraction Carbon (LFC)

Data presented in Table 9 (0-15 cm), 10 (15-30 cm) and 11 (30-45 cm) showed variations in LFC influenced by the long-term application of organic manures and fertilizers in soil. The LFC ranged from 0.77 (N₇₅P₃₀) to 1.43 g kg⁻¹ (FYM₁₅N₁₅₀P₃₀) in surface soil (0-15 cm). Application of organic manure along with recommended dose of NP fertilizer significantly increased the LFC content in soil over full or half of recommended dose of NP fertilizer. Among the fertilizer treatments, the recommended dose of NP fertilizers showed higher the LFC over half of recommended dose of NP fertilizers.

Higher LFC was found in surface soil and decreased with increase in soil depth. At 0–15 cm, LFC content under FYM₁₅N₁₅₀P₃₀, pressmud_{7.5}N₁₅₀P₃₀ and poultry manures₅N₁₅₀P₃₀ were 175.5, 163.0 and 154.3 %, respectively, greater than recommended dose of NP fertilizers applied. In sub-surface soil (15–30 and 30–45 cm), similar trends were observed. Retention of LFC in 15-30 cm depth was lower as compared to 0-15 cm and it was higher in FYM followed by pressmud and poultry manure. Long-term applications of manures or fertilizers alone and applied in combination with recommended dose of N or NP fertilizers were capable of increasing the LFC over half of recommended dose of NP fertilizers. The LFC content decreased with increase in soil depth.

The LFC showed highly significant relationship with MBC ($R^2 = 0.96$), DOC ($R^2 = 0.94$), HFC ($R^2 = 0.88$) and organic C ($R^2 = 0.88$) in surface soil.

4.11.4. Heavy fraction Carbon (HFC)

Results pertaining to HFC in soil recorded at 0-15, 15-30 and 30-45 cm are represented in Table 9, 10 and 11, respectively. HFC in surface soil varied from 3.7 g kg⁻¹ (N₇₅P₃₀) to 5.8 (FYM₁₅N₁₅₀P₃₀). Similar types of trends were observed in sub-surface soil (15–30 and 30–45 cm). highest build up of HFC content in soil was observed where organic manures were applied in combination with NP fertilizers over to manures applied alone or NP fertilizers.

The HFC content under FYM₁₅N₁₅₀P₃₀, pressmud_{7.5}N₁₅₀P₃₀ and poultry manures₅N₁₅₀P₃₀ were 56.8, 35.1 and 29.7 %, respectively, higher than recommended dose of NP

fertilizers in surface soil (0-15 cm). In 15–30 and 30–45 cm, similar types of trends were observed. As compared to surface soil (0-15 cm) soil retention of HFC in 15-30 cm depth was lowest with poultry manure (1.64 times) followed by pressmud (1.46 times) and highest with FYM (1.40 times). A significant relationship was observed between HFC with LFC ($R^2 = 0.90$), HFC and MBC ($R^2 = 0.82$), HFC and DOC ($R^2 = 0.73$) and organic C ($R^2 = 0.73$) in surface soil.

4.12. Nitrogen Fractions

4.12.1. Amino acid-N

The amino acid-N in the soil at 0-15, 15-30 and 30-45 cm depths ranged from 83.0 to 146.7, 68.0 to 114.2 and 31.0 to 75.7 mg kg⁻¹ due to the application of various organic manures and fertilizers (Table 12, 13 and 14). A significant increase of amino acid-N was noticed in organic manures (FYM, pressmud and poultry manure) treated plots over fertilizers applied. Application of NP fertilizers in conjunction with organic manures (FYM, pressmud and poultry manure) resulted significant increase in amino acid-N in soil over NP fertilizers applied alone. The increase in amino acid-N was 25.7 % upon application of recommended dose of NP fertilizers over half of recommended dose of NP fertilizer.

About 40.7, 34.4 and 38.1 % increase in amino acid in surface soil (0-15 cm) was observed with the application of FYM₁₅N₁₅₀P₃₀, pressmud_{7.5}N₁₅₀P₃₀ and poultry manures₅N₁₅₀P₃₀ over N₇₅P₃₀ respectively. The amino acid-N of sub-surface soil (15-30 and 30-45 cm) showed the same trend as observed in surface soil, but the increase was less as compared to surface soil. The amino acid-N decreased with increase in soil depths.

The amino acid-N showed highly significant relationship with hydrolysable-N ($R^2 = 0.98$), hydrolysable unknown-N ($R^2 = 0.98$), acid insoluble-N ($R^2 = 0.97$), amino sugar-N ($R^2 = 0.85$), ammonia-N ($R^2 = 0.81$) and N content of wheat ($R^2 = 0.94$).

4.12.2. Amino sugar-N

The effect of continuous applications of various organic manures and fertilizer on amino sugar-N at 0-15, 15-30 and 30-45 cm are represented in Table 12, 13 and 14, respectively. The amino sugar-N varied from 30 mg kg⁻¹ (N₇₅P₃₀) to 46.0 mg kg⁻¹ (poultry manure₅N₁₅₀P₃₀) in surface soil. Application of NP fertilizers in conjunction with organic manures (FYM, pressmud and poultry manure) resulted significant increase in amino sugar-N in soil over the application of manures alone or NP fertilizers. However, increase in amino sugar-N was at par due to the addition of organic manures alone or along with NP fertilizers. The increase in amino sugar-N was 110 % more upon application of 15 Mg FYM ha⁻¹ along with recommended dose of NP fertilizers over recommended dose of NP fertilizers (N₁₅₀P₃₀).

The amino sugar-N content of soil increased to about 1.67, 1.53 and 1.42 times with the application of FYM₁₅N₁₅₀P₃₀, pressmud_{7.5}N₁₅₀P₃₀ and poultry manures₅N₁₅₀P₃₀ over half of recommended dose of NP fertilizers (N₇₅P₃₀), respectively.

Table 12: Long- term effect of organic manures and fertilizers on N fractions of surface soil (0-15 cm) after 16 cycles of pearl millet-wheat cropping sequence

Type of manure	Dose (Mg ha ⁻¹)	Fertilizer (kg ha ⁻¹)		Different N form (mg kg ⁻¹ soil)					
		N	P ₂ O ₅	Amino acid-N	Amino sugar-N	Ammonia-N	Hydrolysable-N	Total hydrolysable unknown-N	Acid insoluble-N
No manures	0	75	30	83.0	30.0	100.0	213.7	105.0	93.3
	0	150	60	104.3	32.8	125.0	351.3	126.0	126.0
FYM	15	0	0	135.0	38.7	123.7	447.7	151.6	143.3
	15	150	0	138.7	44.0	128.7	455.7	156.0	148.4
	15	150	30	146.7	50.0	138.3	464.3	164.7	158.4
Poultry Manure	5	0	0	130.2	35.3	132.4	424.2	145.0	142.7
	5	150	30	140.2	46.0	133.0	434.0	154.4	148.7
Pressmud	7.5	0	0	133.3	35.3	130.7	438.0	144.3	140.0
	7.5	75	30	138.4	37.3	135.7	442.3	151.0	146.5
	7.5	150	30	144.0	42.7	143.0	448.5	159.3	149.0
LSD (0.05)				3.3	4.7	4.1	6.3	4.1	3.1

Table 13: Long- term effect of organic manures and fertilizers on N fractions of sub-surface soil (15-30 cm) after 16 cycles of pearl millet-wheat cropping sequence

Type of manure	Dose (Mg ha ⁻¹)	Fertilizer (kg ha ⁻¹)		Different N form (mg kg ⁻¹ soil)					
		N	P ₂ O ₅	Amino acid-N	Amino sugar-N	Ammonia-N	Hydrolysable-N	Total hydrolysable unknown-N	Acid insoluble-N
No manures	0	75	30	68.0	22.7	59.7	184.3	57.7	44.0
	0	150	60	84.7	24.0	71.7	202.0	59.3	65.0
FYM	15	0	0	105.0	25.0	100.0	294.3	89.0	87.7
	15	150	0	107.6	28.5	105.6	306.3	100.6	93.7
	15	150	30	112.7	30.0	108.7	315.0	119.0	100.0
Poultry Manure	5	0	0	105.3	24.7	104.3	212.0	100.3	88.3
	5	150	30	110.6	30.6	110.4	230.7	110.7	95.7
Pressmud	7.5	0	0	108.0	25.3	95.7	240.5	102.7	80.0
	7.5	75	30	110.3	27.7	103.3	254.7	111.6	88.7
	7.5	150	30	114.2	32.7	112.4	264.0	115.0	96.7
LSD (0.05)				3.4	5.7	3.0	8.7	3.8	6.3

Table 14: Long-term effect of organic manures and fertilizers on N fractions of sub-surface soil (30-45 cm) after 16 cycles of pearl millet-wheat cropping sequence

Type of manure	Dose (Mg ha ⁻¹)	Fertilizer (kg ha ⁻¹)		Different N form (mg kg ⁻¹ soil)					
		N	P ₂ O ₅	Amino acid-N	Amino sugar-N	Ammonia-N	Hydrolysable-N	Total hydrolysable unknown-N	Acid insoluble-N
No manures	0	75	30	31.0	10.7	27.1	122.0	40.7	30.7
	0	150	60	54.7	15.3	32.6	100.3	47.3	35.3
FYM	15	0	0	63.0	20.5	40.5	126.8	55.3	48.0
	15	150	0	70.0	25.0	45.0	135.3	65.0	50.0
	15	150	30	75.7	27.0	49.3	145.7	70.0	55.3
Poultry Manure	5	0	0	70.3	22.6	42.4	105.6	48.7	48.0
	5	150	30	74.0	29.0	46.2	124.0	55.3	48.7
Pressmud	7.5	0	0	54.4	19.2	45.5	120.4	50.5	45.0
	7.5	75	30	68.3	24.7	48.0	126.6	53.5	46.5
	7.5	150	30	73.8	30.6	52.2	137.0	61.8	47.6
LSD (0.05)				3.2	4.2	5.0	5.0	6.1	6.0

The amino sugar-N of sub-surface soil (15-30 and 30-45 cm) showed the same trend in relation to treatment effects as observed in case of surface soil, but the increase was less as compared to surface soil. The amino sugar-N content of soil decreased with increase in soil depths.

The amino sugar-N was highly significant correlated with hydrolysable unknown-N ($R^2 = 0.93$), hydrolysable-N ($R^2 = 0.83$), acid insoluble-N ($R^2 = 0.84$), ammonia-N ($R^2 = 0.68$) and N content of wheat ($R^2 = 0.93$).

4.12.3. Ammonia-N

Application of FYM, poultry manure and pressmud along with NP fertilizers increased the ammonia-N over recommended dose of NP fertilizers at 0-15, 15-30 and 30-45 cm depths (Table 12, 13 and 14). Among the different treatments where organic manure were applied with the recommended dose of NP fertilizers, highest ammonia-N in surface soil was observed with pressmud_{7.5}N₁₅₀P₃₀ (143.0 mg kg⁻¹) followed by FYM₁₅N₁₅₀P₃₀ (138.0 mg kg⁻¹) and poultry manure₅N₁₅₀P₃₀ (135.3 mg kg⁻¹). Similar type of results were observed in sub-surface soil, however, the increase was less as compared to surface soil.

The ammonia-N content in surface soil increased to about 10.6, 6.4 and 14.4 % with the application of FYM₁₅N₁₅₀P₃₀, pressmud_{7.5}N₁₅₀P₃₀ and poultry manures₅N₁₅₀P₃₀ over N₁₅₀P₃₀ fertilizers applied alone, respectively. The ammonia-N of sub-surface layer (15-30 and 30-45 cm) showed the same was trend in relation to treatment effects as observed in case of surface soil, but the increase was less as compared to surface soil. The amount of ammonia-N was lower in sub-surface (15-30 and 30-45 cm) soil than in surface soil (0-15 cm).

The ammonia-N showed slightly significant relationship with amino acid-N ($R^2 = 0.89$), hydrolysable-N ($R^2 = 0.88$), acid insoluble-N ($R^2 = 0.87$), hydrolysable unknown-N ($R^2 = 0.77$) and N content of wheat ($R^2 = 0.86$).

4.12.4 Hydrolysable-N

The results related to hydrolysable-N in soil recorded at 0-15, 15-30 and 30-45 cm depths are represented in Table 12, 13 and 14, respectively. A significantly increase in hydrolysable-N was observed due to the application of organic manures (FYM, poultry manure, pressmud) over NP fertilizers applied alone. Among the different treatments, highest hydrolysable-N (464.3 mg kg⁻¹) of soil was recorded with combined application of FYM along with NP fertilizers followed by pressmud (448.5 mg kg⁻¹) and poultry manure (434.0 mg kg⁻¹). Soil hydrolysable-N was lower in sub-surface soil than in surface soil, regardless of treatments. Similar types of trends were observed in sub-surface as was observed in surface soil.

Application of organic manures along with N or NP fertilizers increased the hydrolysable-N significantly over N₁₅₀P₃₀ fertilizers applied alone. The ammonia-N content under NP fertilizer along with FYM, pressmud and poultry manures were 113.2, 109.8 and

103.1 %, higher respectively, over half of recommended dose of NP fertilizers in surface soil (0-15 cm). The hydrolysable-N of sub-surface layer of soil showed the identical trend as was observed in surface soil, but the increase was less as compared to surface soil. The hydrolysable-N content of soil decreased with increase in soil depth.

The hydrolysable-N showed highly significant relationship with amino acid-N ($R^2 = 0.98$), acid insoluble ($R^2 = 0.96$), hydrolysable unknown-N ($R^2 = 0.94$), ammonia-N ($R^2 = 0.88$), amino sugar-N ($R^2 = 0.83$) and N content of wheat ($R^2 = 0.97$).

4.12.5. Total Hydrolysable Unknown-N

The effect of organic manures and fertilizers on the total hydrolysable-N at 0-15, 15-30 and 30-45 cm soil depths are presented in Table 12, 13 and 14, respectively. Highest total hydrolysable unknown-N was recorded in FYM₁₅N₁₅₀P₃₀ (164.7 mg kg⁻¹) followed by pressmud₅N₁₅₀P₃₀ (159.3 mg kg⁻¹) and poultry manure₅N₁₅₀P₃₀ (154.4 mg kg⁻¹). Soil hydrolysable-N was lower in sub-surface soil then in surface soil, regardless of treatments. A significant increase in total hydrolysable-N was observed where organic manures were applied in conjunction with N or NP fertilizers over NP fertilizers applied alone.

The increase in amounts of total hydrolysable unknown-N due to N₁₅₀P₃₀ fertilizers along with FYM, pressmud and poultry manure treatments, respectively, was about 156.9, 151.7 and 147.0 % higher over N₇₅P₃₀ fertilizers in surface soil (0-15 cm). The total hydrolysable unknown-N in sub-surface soil in relation to treatment effects showed the same trend as observed in surface soil. However, the increase was less pronounced in sub-surface soil as compared to surface soil.

The hydrolysable-N was highly significantly correlated with amino acid-N ($R^2 = 0.98$), amino sugar-N ($R^2 = 0.93$), hydrolysable-N ($R^2 = 0.94$), acid insoluble ($R^2 = 0.96$), ammonia-N ($R^2 = 0.77$) and N content of wheat ($R^2 = 0.97$).

4.12.6. Acid insoluble-N

Data presented the acid insoluble-N at 0-15 cm, 15-30 cm and 30-45 cm depths are represented in Table 12, 13 and 14, respectively, revealed that when organic manures (FYM, poultry manure and pressmud) were applied with NP fertilizers, resulted increased in acid insoluble-N over manures or fertilizers applied alone. Among the different treatments, FYM₁₅N₁₅₀P₃₀ showed highest acid insoluble-N (158.4 mg kg⁻¹) and this was statistically at par with poultry manure₅N₁₅₀P₃₀ (148.9 mg kg⁻¹) and pressmud₅N₁₅₀P₃₀ (149.0 mg kg⁻¹).

Application of manures in conjunction with fertilizers N or NP increased acid insoluble-N 1.1 folds over N₁₅₀P₃₀. The increase in total hydrolysable unknown-N was 8.6, 6.5 and 10.4 %, respectively, upon application of FYM₁₅N₁₅₀P₃₀, pressmud_{7.5}N₁₅₀P₃₀ and poultry manures₅N₁₅₀P₃₀ over manures applied alone, respectively. The acid insoluble-N of sub-surface soil showed the similar trend as was observed in surface soil. The acid insoluble-N content of soil decreased with increase in soil depth.

The ammonia-N showed highly significant correlation with amino acid-N ($R^2 = 0.97$), hydrolysable-N ($R^2 = 0.96$), hydrolysable unknown-N ($R^2 = 0.96$), amino sugar-N ($R^2 = 0.87$), and N content of wheat ($R^2 = 0.95$).

4.13. Periodic changes of organic C, available N, P and K during wheat growth

4.13.1. Organic C

The organic C content of soil increased significantly with the application of organic manures applied alone or in combination with N or NP fertilizers over fertilizers applied alone (Table 15). The organic C content of soil increased up to 48 days in all the treatments except the no-organic manures plots where increase was very small. After 48 days of manures application, the organic C content decreased in all the plots received organic manures (FYM, Pressmud and poultry manure) alone or with fertilizers.

Table 15: Long- term effects of organic manures and fertilizers on periodical changes of organic C (%) at various periods of wheat growth after 16 cycles of pearl millet-wheat cropping system

Type of manure	Dose (Mg ha ⁻¹)	Fertilizer (kg ha ⁻¹)		Days after manure application					
		N	P ₂ O ₅	0	24	48	72	96	120
No manures	0	75	30	0.30	0.31	0.32	0.31	0.30	0.30
	0	150	60	0.37	0.41	0.42	0.41	0.40	0.38
FYM	15	0	0	0.90	1.78	1.80	1.30	1.22	1.10
	15	150	0	0.97	1.80	1.86	1.37	1.27	1.14
	15	150	30	1.06	1.94	1.98	1.51	1.31	1.24
Poultry Manure	5	0	0	0.48	1.36	1.43	0.93	0.73	0.67
	5	150	30	0.52	1.40	1.49	0.97	0.77	0.70
Pressmud	7.5	0	0	0.67	1.52	1.62	1.22	0.92	0.85
	7.5	75	30	0.70	1.58	1.70	1.25	0.95	0.88
	7.5	150	30	0.71	1.62	1.76	1.28	0.96	0.90
LSD (0.05)				0.04	0.03	0.04	0.03	0.02	0.02

Among the different treatments, higher C was recorded in treatment that received FYM, pressmud and poultry manure throughout wheat growing period. Application of NP fertilizers in conjunction with organic manures (FYM, pressmud and poultry manure) resulted in significant increased in organic C in soil over the application of NP fertilizers alone. It is evident that after 120 days of organic manures application alone or in combination with N or NP fertilizers, the organic C content remained higher than the initial values.

4.13.2. Available Nitrogen

The available N content of the soil during wheat growth increased significantly with application of manures (FYM, pressmud and poultry manure) (Table 16). The available N

content of the soil increased significantly up to 24 days and decreased thereafter in all the treatments.

The available N content of the soil with application of half or full dose of NP fertilizers plot was lower as compared to manures applied alone. Among the different manure treatments, highest available N was recorded in plots that received the pressmud followed by FYM and poultry manure throughout wheat growth. Application of NP fertilizers in conjunction with organic manures (FYM, pressmud and poultry manure) resulted significant increase in available N. Unlike organic C, the available N content of soil after 120 days of organic manures applications decreased its 0 day values.

4.13.3. Available Phosphorus

The available P content of the soil during wheat growth increased significantly with application of manures (FYM, pressmud and poultry manure) (Table 17). The available P content of the soil increased significantly with increasing period up to 48 days and decreased thereafter in all manures treatments. Among the different treatments, the treatment received poultry manure recorded higher available P followed by FYM and pressmud throughout wheat growing period. Application of NP fertilizers in conjunction with organic manures (FYM, pressmud and poultry manure) resulted in significant increased in available P in soil over the application of NP fertilizers alone. The available P content of soil remained in sufficient range during wheat growth in manure treatments.

Table 16: Long-term effect of different treatments on periodical mineralization of available N (mg kg^{-1}) at various periods of wheat growth after 16 cycles of pearl millet-wheat cropping system

Type of manure	Dose (Mg ha^{-1})	Fertilizer (kg ha^{-1})		Days after manure application					
		N	P_2O_5	0	24	48	72	96	120
No manures	0	75	30	7.91	10.39	11.29	9.21	8.80	8.49
	0	150	60	10.60	17.09	18.01	15.90	10.51	9.61
FYM	15	0	0	23.99	35.01	34.50	33.80	29.41	28.00
	15	150	0	23.90	36.89	37.81	35.71	31.29	20.09
	15	150	30	25.00	37.99	38.51	36.80	32.39	31.00
Poultry Manure	5	0	0	26.01	39.00	39.89	37.81	33.40	32.01
	5	150	30	27.60	40.61	41.51	39.40	35.01	33.60
Pressmud	7.5	0	0	23.09	36.11	35.50	35.50	30.51	29.10
	7.5	75	30	24.19	37.21	37.99	36.00	31.61	30.20
	7.5	150	30	24.30	37.30	38.19	36.11	31.70	30.31
LSD (0.05)				0.20	0.29	0.49	0.20	0.40	0.29

Table 17: Long-term effect of different treatments on periodical mineralization of available P (mg kg⁻¹) at various periods of wheat growth after 16 cycles of pearl millet-wheat cropping system

Type of manure	Dose (Mg ha ⁻¹)	Fertilizer (kg ha ⁻¹)		Days after manure application					
		N	P ₂ O ₅	0	24	48	72	96	120
No manures	0	75	30	61.6	64.2	63.0	62.7	62.2	62.0
	0	150	60	64.1	92.6	88.0	78.7	74.5	72.5
FYM	15	0	0	79.6	107.5	103.6	93.0	89.8	87.6
	15	150	0	79.4	107.5	103.8	93.2	89.7	87.7
	15	150	30	84.2	110.6	109.8	94.0	93.7	89.6
Poultry Manure	5	0	0	75.3	103.4	99.6	89.1	85.9	83.4
	5	150	30	78.0	106.0	101.9	91.4	87.8	85.9
Pressmud	7.5	0	0	92.2	120.4	116.7	106.9	102.5	100.5
	7.5	75	30	92.8	121.4	116.3	106.1	104.9	100.7
	7.5	150	30	95.5	123.3	119.7	109.5	105.4	103.3
LSD (0.05)				2.0	2.2	2.3	2.0	2.4	2.3

4.13.4. Available Potassium

The available K content of soil increased significantly with application of organic manures over NP fertilizers alone (Table 18).

Table 18: Long-term effect of different treatments on periodical mineralization of available K (mg kg⁻¹) at various periods of wheat growth after 16 cycles of pearl millet-wheat cropping system

Type of manure	Dose (Mg ha ⁻¹)	Fertilizer (kg ha ⁻¹)		Days after manure application					
		N	P ₂ O ₅	0	24	48	72	96	120
No manures	0	75	30	173.4	219.1	220.1	201.6	192.6	181.4
	0	150	60	187.9	233.6	234.9	216.2	207.2	196.0
FYM	15	0	0	268.4	314.0	320.3	296.6	287.6	276.4
	15	150	0	272.6	318.1	327.3	310.6	291.6	280.7
	15	150	30	294.3	339.8	349.1	332.3	313.6	302.4
Poultry Manure	5	0	0	223.3	269.0	278.3	251.6	242.6	231.4
	5	150	30	217.3	262.8	272.0	265.3	236.3	225.3
Pressmud	7.5	0	0	223.1	268.8	278.0	261.3	242.4	231.4
	7.5	75	30	230.9	276.6	285.9	269.2	250.2	239.0
	7.5	150	30	237.4	282.9	292.2	275.4	256.7	245.5
LSD (0.05)				2.1	2.4	2.3	2.0	2.2	2.6

The available K content of soil increased up to 48 days due to the addition of organic manures except no manures plots where increase was very small. After 48 days of manures application, the available K content decreased in all the treatments. Among different manures, highest available K content was noticed in plots received FYM followed by pressmud and poultry manure throughout wheat growing period. Application of NP fertilizers in conjunction with organic manures (FYM, pressmud and poultry manure) resulted significant increase in available K in soil over the application of NP fertilizers alone. The available K content of soil after 120 days of manures application remained higher than its initial value.

4.14. Soil pH, EC, organic C, available, macro (N, P, and K) and micronutrients (Zn, Mn, Fe and Cu)

4.14.1 Soil pH

Addition of organic manures (FYM, poultry manure and pressmud) alone or in combination with N or NP fertilizer for 16 years decreases the soil pH over the initial value (Table 19). The decrease in pH was more with the addition of FYM compared to poultry manure and pressmud. Highest soil pH (7.87) was observed in plots where only NP fertilizers were applied. Soil pH was lower in sub-surface soil than in surface soil, irrespective of the treatments. The effect of different treatments on pH of sub-surface soils was non-significant and lowest pH was recorded in FYM treated plots.

4.14.2. Soil EC

Continuous application of organic manures for 16 years (Table 19) increased the EC of the soil. However, an increase in soil EC with the continuous application of NP fertilizers over the initial value was marginal. A significant increase in EC of the soil was observed with the combined application of organic manures plus NP fertilizers over application of NP fertilizers alone. The proportionate increase in EC was more with the addition of FYM than poultry manure and pressmud. Soil EC was higher in surface soil than in sub-surface soil. The effect of different treatments in soil EC was almost similar to that observed for surface soil.

4.14.3. Soil organic C

An increase in organic C content was observed with the application of organic manure alone or with NP fertilizers for 16 years (Table 19). The highest content of organic C (1.12 %) was observed when 15 Mg FYM + 150 kg N +30 Kg P₂O₅ ha⁻¹ for 16 years were applied. Increase or decrease in soil organic C was marginal from its initial value with the continuous application of NP fertilizers. However, recommended dose of NP fertilizers were tended to have more organic C in soil compared to half of recommended dose of NP fertilizers. Taking into consideration the amount of FYM, poultry manure and pressmud added during the period of 16 years and assuming no loss of C, the organic C content of soil should have been approximately 73152, 14592 and 36480 kg ha⁻¹, respectively, but the overall corresponding increase was only 0.62, 0.15 and 0.34 % C (over the initial level) and only about 17.0, 20.6 and 18.6% of added organic C was retained in the soil.

Table 19: Effect of long-term application of organic manures and fertilizers on pH, EC and organic C status at different depths of soil after 16 cycles of pearl millet-wheat cropping system

Type of manure	Dose (Mg ha ⁻¹)	Fertilizer (kg ha ⁻¹)		pH			EC (dSm ⁻¹)			Organic C (%)		
		N	P ₂ O ₅	0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm
No manures	0	75	30	8.10	7.87	7.52	0.39	0.28	0.15	0.36	0.29	0.26
	0	150	60	8.02	7.87	7.51	0.41	0.29	0.18	0.43	0.36	0.31
FYM	15	0	0	7.65	7.53	7.19	0.51	0.38	0.26	1.01	0.43	0.35
	15	150	0	7.67	7.55	7.20	0.51	0.39	0.28	0.98	0.64	0.43
	15	150	30	7.78	7.65	7.30	0.51	0.38	0.26	1.12	0.65	0.50
Poultry Manure	5	0	0	7.86	7.72	7.37	0.46	0.34	0.22	0.54	0.46	0.53
	5	150	30	7.85	7.72	7.37	0.44	0.32	0.21	0.58	0.65	0.38
Pressmud	7.5	0	0	7.78	7.67	7.31	0.48	0.36	0.24	0.73	0.64	0.51
	7.5	75	30	7.78	7.67	7.31	0.45	0.33	0.21	0.76	0.65	0.53
	7.5	150	30	7.77	7.65	7.30	0.48	0.36	0.24	0.75	0.53	0.57
Initial in 1995				8.1			0.36			0.39		
LSD (0.05)				0.073	0.013	0.015	0.008	0.009	0.008	0.05	0.04	0.013

The organic C content of soil decreased with increase in soil depth. In the sub-surface soil layer, similar type of trend was observed as was observed in surface soil in relation to treatment effects.

4.14.4. Available N

The available (mineralizable) N content decreased from 98 to 64.5 mg kg⁻¹ due to cropping with 75 kg N + 30 Kg P₂O₅ ha⁻¹ for 16 years (Table 20) whereas it was 82.6 mg kg⁻¹ with 15 Mg FYM ha⁻¹. The depletion of available N in soil was less after FYM addition. A significant increase in available N was observed when organic manures were applied in conjunction with N or NP fertilizers over NP fertilizers applied alone. Available N decreased with soil depth in all the treatments. Considering the amount total N added through FYM, poultry manure and pressmud during the period of 16 years of experimentation (approximately 2266, 1632 and 2976 kg N ha⁻¹, respectively), no residual effect was observed. The available N content of soil decreased with increase in soil depth like surface, available N in sub-surface soil layer in relation to treatment effects demonstrated the identical trend.

4.14.5. Available P

Available P content of the soil decreased from 12.6 to 8.9 mg P kg⁻¹ in soil with applying with 75 kg N + 30 Kg P₂O₅ ha⁻¹ for 16 years by growing pearl millet-wheat crops in sequence. A significant build up in available P was observed in all plots which received the organic manures alone or in combination with N or NP fertilizers (Table 20). Higher build-up in available P was observed with the addition of poultry manure compared to FYM and pressmud, which might be due to variation in their P contents and amounts applied. The build-up of available P in sub-surface soil was lower compared to surface soil. The critical evaluation of the data indicated that considering the amount of total P added through FYM, poultry manure and pressmud during the tenure of experiment (1152, 1126 and 864 kg P ha⁻¹, respectively) but the overall corresponding increase in available P was only 16.4, 16.0 and 14.5 mg kg ha⁻¹ (over the initial level) and about 2.8, 3.2 and 3.4 % available P was retained in the soil. The available P content was higher in surface soil than sub-surface soil. The effect of different treatments on available P of sub-surface soil was almost similar to that observed for surface soil

4.14.6. Available K

The available K content of soil decreased from 217 to 173.4 mg kg⁻¹ due to 16 years of cropping where 75 kg N + 30 Kg P₂O₅ ha⁻¹ fertilizers were applied, whereas it increased to 294.4 mg kg⁻¹ with 15 Mg FYM ha⁻¹ yr⁻¹ (Table 20). Addition of organic manures resulted significant build up in available K over NP fertilizers applied alone. Application of organic manures in conjunction with N or NP fertilizers increased significantly available K content of soil over the organic manures applied alone.

Table 20: Effect of long-term application of organic manures and fertilizers on available N, P and K (mg kg⁻¹) status at different depths of soil after 16 cycles of pearl millet-wheat cropping system

Type of manure	Dose (Mg ha ⁻¹)	Fertilizer (kg ha ⁻¹)		N			P			K		
		N	P ₂ O ₅	0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm
No manures	0	75	30	64.5	41.5	18.5	8.9	8.3	4.5	173.4	156.2	120.4
	0	150	60	67.5	44.5	21.5	9.6	8.6	4.8	178.4	163.2	127.4
FYM	15	0	0	82.6	74.1	51.1	29.0	17.3	13.6	324.1	237.2	201.4
	15	150	0	82.7	74.2	51.2	26.9	17.4	13.7	298.4	241.2	205.4
	15	150	30	84.6	76.1	53.1	28.0	17.3	13.6	302.4	238.2	202.4
Poultry Manure	5	0	0	78.4	72.9	49.9	30.6	17.7	14.0	247.2	212.2	176.4
	5	150	30	80.9	75.4	52.4	31.0	18.0	14.2	253.4	224.2	188.4
Pressmud	7.5	0	0	95.7	89.6	66.6	27.1	16.9	13.1	253.4	213.2	177.4
	7.5	75	30	95.7	89.6	66.6	27.2	16.9	13.2	261.4	225.2	189.4
	7.5	150	30	98.3	92.2	69.2	27.3	17.0	13.3	267.4	232.2	196.4
Initial in 1995				98			12.6			217		
LSD (0.05)				2.2	1.9	1.9	0.2	0.12	0.13	2.6	1.3	2.5

Table 21: Effect of long-term application of organic manures and fertilizers on DTPA extractable Zn, Mn, Fe and Cu (mg kg⁻¹) at different depths after 16 cycles of pearl millet-wheat cropping system

Type of manure	Dose (Mg ha ⁻¹)	Fertilizer (kg ha ⁻¹)		Zn			Mn			Fe			Cu		
		N	P ₂ O ₅	0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm
No manures	0	75	30	0.72	0.37	0.24	3.30	2.81	1.71	5.02	3.81	2.71	0.48	0.33	0.24
	0	150	60	0.76	0.40	0.27	3.55	2.85	1.75	5.03	3.84	2.75	0.50	0.39	0.26
FYM	15	0	0	1.84	0.72	0.59	4.29	3.29	2.19	7.29	5.29	4.19	0.78	0.49	0.39
	15	150	0	1.80	0.66	0.53	4.57	3.39	2.29	7.27	5.30	4.20	0.81	0.51	0.40
	15	150	30	1.79	0.69	0.56	4.59	3.42	2.32	7.27	5.35	4.25	0.76	0.51	0.38
Poultry Manure	5	0	0	1.65	0.63	0.50	3.81	3.27	2.17	6.82	4.92	3.82	0.72	0.48	0.36
	5	150	30	1.72	0.64	0.51	3.92	3.25	2.15	6.80	5.90	4.80	0.69	0.50	0.39
Pressmud	7.5	0	0	1.73	0.65	0.52	4.00	3.40	2.30	6.99	5.15	4.15	0.74	0.50	0.39
	7.5	75	30	1.79	0.67	0.54	4.01	3.44	2.34	7.10	5.29	4.19	0.77	0.49	0.36
	7.5	150	30	1.81	0.63	0.50	4.14	3.56	2.46	8.09	5.35	4.25	0.77	0.52	0.40
LSD (0.05)				0.01	0.01	0.017	0.064	0.016	0.07	0.043	0.002	0.004	0.020	0.024	0.020

The proportionate increase in available K was apparently more with FYM addition followed by pressmud and poultry manure. The available K content in sub-surface soil was less as compared to the surface soil. Considering the amount of total K added through FYM, poultry manure and pressmud during the 16 years of experimentation, total K content of soil should have been approximately 3686, 736 and 768 kg N ha⁻¹, respectively, but the overall corresponding increase in available K was only 77.4, 30.4 and 36.4 mg kg⁻¹ (over the initial level). About 5.8, 8.2 and 9.5 % of available K was retained in soil during the period of 16 years added through FYM, poultry manure and pressmud. The available K content of soil decreased with increase in soil depth and similar trends were observed as was observed in surface soil.

4.15. DTPA extractable micronutrients (Zn, Mn, Fe and Cu)

The lowest DTPA extractable Zn, Mn, Fe and Cu contents was observed where only NP fertilizers were applied (Table 21). A significant increase in DTPA extractable Zn, Mn, Fe and Cu was observed with the application of organic manures over no manure was applied. Application of NP fertilizers along with organic manures had no effect on DTPA extractable Zn, Mn, Fe and Cu in soil over only manures were applied. The proportionate increase in DTPA extractable Zn, Mn, Fe and Cu was recorded with the application of FYM followed by pressmud and poultry manure. DTPA extractable Zn, Mn, Fe and Cu was higher in the surface soil than sub-surface soil. In the sub-surface soil, a similar trend of increase was observed but the rate of increase was less than the surface soil.

4.16. Grain yield of pearl millet and wheat

The lowest grain yield of pearl millet and wheat crops was recorded when either 15 Mg FYM or 5 Mg poultry manure or 7.5 pressmud ha⁻¹ was applied alone (Table 22). However, a significant increase in yield was obtained when organic manures were applied in conjunction with recommended dose of N for these crops and that was comparable with recommended dose of applied NP alone or NP applied in combination with organic manures. There was an increased of about 66, 50 and 60 % in pearl millet grain yield and 126, 92 and 109 % in wheat grain yield upon application of 15 Mg FYM, 5 Mg poultry manure and 7.5 Mg pressmud ha⁻¹ along with recommended N and half of NP over manures applied alone, respectively.

Table 22: Grain yield of pearl millet and wheat under various combinations of manures and fertilizers

Type of manure	Dose (Mg ha ⁻¹)	Fertilizer (kg ha ⁻¹)		Yield (q ha ⁻¹)	
		N	P ₂ O ₅	Pearl millet	wheat
No manures	0	75	30	20.80	34.83
	0	150	60	24.00	48.33
FYM	15	0	0	16.20	24.86
	15	150	0	25.20	52.17
	15	150	30	26.90	56.23
Poultry Manure	5	0	0	16.70	26.71
	5	150	30	25.10	51.28
Pressmud	7.5	0	0	16.90	25.93
	7.5	75	30	23.80	43.33
	7.5	150	30	26.97	54.14

4.16.1. Wheat grain and straw NPK contents

Data presented in Table 23 revealed that when organic manures (FYM, poultry manure and pressmud) were applied alone resulted in lower NPK (%) content of wheat grain. However, when organic manures were applied in conjunction with N or NP fertilizers, a significant increase in wheat grain content of NPK over recommended dose of N or NP fertilizers. The N, P and K content in wheat grain ranged from 0.89 to 2.11, 0.25 to 0.48 and 1.5 to 1.60 %, respectively. Among different manures applied alone, N content in wheat grain was highest in pressmud (1.21 %) followed by FYM (1.19 %) and poultry manure (1.12 %). The P content in wheat grain was highest with poultry manure (0.41 %) followed by FYM (0.33 %) and pressmud (0.26 %). The K content in wheat grain was highest with FYM (1.45 %) followed by pressmud (1.36 %) and poultry manure (1.31 %). The increase in N, P and K content in wheat grain was 2.06, 0.42, and 1.60; 1.34, 0.48 and 1.44; and 2.11, 0.31 and 1.53 % with the application of 15 Mg FYM, 5 Mg poultry manure and 7.5 Mg pressmud ha⁻¹ with recommended dose of N and half of P over 15 Mg FYM, 5 Mg poultry manure and 7.5 Mg pressmud ha⁻¹, respectively.

Table 23: Long-term effect of organic manures and fertilizers on wheat grain and straw NPK (%) contents

Type of manure	Dose (Mg ha ⁻¹)	Fertilizer (kg ha ⁻¹)		Grain			Straw		
		N	P ₂ O ₅	N	P	K	N	P	K
No manures	0	75	30	0.89	0.25	1.15	0.45	0.10	1.17
	0	150	60	1.00	0.28	1.39	0.88	0.18	1.34
FYM	15	0	0	1.19	0.33	1.45	1.12	0.29	1.57
	15	150	0	1.76	0.38	1.50	1.21	0.30	1.61
	15	150	30	2.06	0.42	1.60	1.42	0.34	1.88
Poultry Manure	5	0	0	1.12	0.41	1.31	1.00	0.31	1.45
	5	150	30	1.34	0.48	1.44	1.31	0.39	1.60
Pressmud	7.5	0	0	1.21	0.26	1.36	1.20	0.25	1.51
	7.5	75	30	1.52	0.29	1.46	1.30	0.27	1.56
	7.5	150	30	2.11	0.31	1.53	1.45	0.28	1.75
LSD (0.05)				0.3	0.032	0.061	0.07	0.043	0.010

The results showed that various combinations organic manures (FYM, poultry manure and pressmud) along with fertilizer N or NP and fertilizer N produced appreciable variation in the straw NPK content. When organic manures applied in conjunction with N or NP fertilizers, a significant increase in straw content of NPK over N or NP fertilizers applied alone. The content of N, P and K by wheat straw ranged from 0.45 to 1.45, 0.10 to 0.39 and 1.17 to 1.60 respectively. Like NPK content in wheat grain, the NPK content in wheat straw in relation to different treatment effects showed the identical trend. The N, P and K content in wheat straw was 1.42, 0.34, and 1.88; 1.31, 0.39 and 1.60; and 1.45, 0.28 and 1.75 % was higher in 15 Mg FYM, 5 Mg poultry manure and 7.5 Mg pressmud ha⁻¹ with recommended dose of N and half of P treatments over 15 Mg FYM, 5 Mg poultry manure and 7.5 Mg pressmud ha⁻¹ treatment, respectively.

4.16.2. Pearl millet grain and straw NPK (%) contents

The results presented in Table 24 revealed that when organic manures (FYM, poultry manure and pressmud) were applied alone resulted in less NPK (%) content of pearl millet grain and straw. But when organic manures applied in conjunction with N or NP fertilizers, a significant increase in grain content of NPK over N or NP fertilizers applied alone. The content of N, P and K by pearl millet grain ranged from 0.79 to 1.36, 0.15 to 0.43, 1.23 to 1.54 (%), respectively.

Among different manures applied alone treatments, N content was highest in pressmud (1.25%) followed by FYM (1.20 %) and poultry manure (1.00 %). K content in pearl millet grain was highest with FYM (1.34 %) followed by pressmud (1.28 %) and poultry

manure (1.23 %). But in case of P, highest P content was observed with poultry manure (0.35 %) followed by FYM (0.28 %) pressmud (0.25 %). The increase in N, P and K content in pearl millet grain was 1.29, 0.38, and 1.62; 1.10, 0.43 and 1.25; and 1.36, 0.33 and 1.40 per cent with the application of 15 Mg FYM, 5 Mg poultry manure and 7.5 Mg pressmud ha⁻¹ with recommended dose of N and half of P over 15 Mg FYM, 5 Mg poultry manure and 7.5 Mg pressmud ha⁻¹, respectively.

The results showed that different combinations of organic manures (FYM, poultry manure and pressmud) along with fertilizer N or NP produced appreciable variation in the straw NPK content. A significant increase in NPK content straw over N or NP fertilizers applied. The content of N, P and K by pearl millet straw ranged from 0.33 to 0.91, 0.16 to 0.34 and 2.10 to 3.81 (%), respectively. The effects of different manure treatments on NPK content in pearl millet straw was almost similar to that of observed for NPK content in wheat grain. The percentage increase in N, P and K content in pearl millet straw was 0.85, 0.28, and 3.81; 0.54, 0.34 and 3.25; and 0.91, 0.27 and 3.54 due to the application of 15 Mg FYM, 5 Mg poultry manure and 7.5 Mg pressmud ha⁻¹ with recommended dose of N and half of P over 15 Mg FYM, 5 Mg poultry manure and 7.5 Mg pressmud ha⁻¹.

Table 24: Long-term effect of organic manures and fertilizers on wheat grain and straw NPK (%) contents

Type of manure	Dose (Mg ha ⁻¹)	Fertilizer (kg ha ⁻¹)		Grain			Straw		
		N	P ₂ O ₅	N	P	K	N	P	K
No manures	0	75	30	0.79	0.15	1.23	0.33	0.16	2.10
	0	150	60	0.88	0.19	1.31	0.36	0.19	2.37
FYM	15	0	0	1.20	0.28	1.34	0.55	0.26	3.57
	15	150	0	1.23	0.32	1.54	0.68	0.27	3.68
	15	150	30	1.29	0.38	1.62	0.85	0.28	3.81
Poultry Manure	5	0	0	1.00	0.35	1.23	0.44	0.29	3.07
	5	150	30	1.10	0.43	1.25	0.54	0.34	3.25
Pressmud	7.5	0	0	1.25	0.25	1.28	0.69	0.20	3.27
	7.5	75	30	1.29	0.30	1.32	0.76	0.25	3.46
	7.5	150	30	1.36	0.33	1.40	0.91	0.27	3.54
LSD (0.05)				0.07	0.04	0.05	0.07	0.02	0.09

The results of the investigation on "**long-term effects of organic manures and fertilizers on soil organic carbon pools and nitrogen fractions**" are discussed in this chapter under the following headings.

Experiment: I: To study the impact of modes and levels of FYM and fertilizer N

5.1. Soil organic matter pools

5.1.1. Dissolved Organic Carbon (DOC)

DOC is mobile within the soil solution and has been proposed as important in the transport and supply of C and N to microbial populations. DOC is central in many nutrient cycles within soil and plays an important role in many pedogenic processes. Plants provide a primary input of DOC into soil via root turnover and exudation. The data pertaining to DOC after 43 years cycles of pearl millet-wheat cropping system as influenced by modes and levels of FYM and fertilizer N is presented in Table 1. A significant increase in organic C was observed with increasing levels of FYM. The increase in DOC content with the addition of FYM may be ascribed to the direct addition of water-soluble C through FYM application. On the other hand, organic manure application contributed linearly and contributed in more water soluble C accumulation in the system (Zoltnay, 1996). The changes in DOC are more dynamic than that of organic C and it is more contributed from FYM due to variable amount of organic C. Among different modes of FYM application, highest increase in DOC was observed when FYM was applied in both seasons as compared to applied either applied in rabi or kharif seasons. However, application of FYM in rabi season was found more beneficial than its application in kharif season. It may be due to the residual effect of 6 months (rabi) old applied FYM had significantly higher DOC than that of 12 months (kharif) old. Thus, FYM applied in rabi was utilized by only one crop and FYM applied in kharif was used by two crops as the soil sampling was done after harvest of wheat crop. The humus, light fraction, which constitutes mainly the plant residues in the form of stubbles and roots, can also be important source of dissolved organic matter. The amount of increase in DOC was not consistent with increasing levels of FYM with respect to modes, highest (3.67 folds) was recorded when FYM was applied in both season followed by rabi (2.12 folds) and kharif (1.84 times) seasons.

Fertilizer N has increased the DOC concentration significantly at all the modes and levels of FYM. Although various aspects of the elevated N deposition and N fertilization have been studied, little is known about the effects of N deposition of dissolved organic matter (Kalbitz *et al.*, 2001). A significant increase in DOC was observed with application of 120 kg

N ha⁻¹ over 0 kg N ha⁻¹. Addition of organic manures and chemical fertilizers has been found to increase the content of soil DOC by a factor of 2.7 to 3.2 (Rochette *et al.*, 2000). Application of FYM from 0 to 15 Mg ha⁻¹ increased the DOC content at all the levels of N and modes of FYM application. There was a significant difference in DOC content of soil receiving varied levels of N. This might be due to application of fertilizer N improve crop biomass and more return of crop residues into soil.

The DOC showed highly significant relationship with MBC ($R^2 = 0.91$) followed by LFC ($R^2 = 0.90$). The DOC and MBC are integral part of soil organic matter, which constitutes mainly the plant residues in the form of stubbles and roots, can also be important source of DOC. The content of DOC strongly increases upon incorporation of crop residues, but diminish sharply within a few days. Our results also suggest that the DOC fraction is heterogeneous in composition; the most bioavailable part is consumed by soil microorganisms within a few days whereas the remaining part is fairly constant. A significant and positive correlation between water soluble C and soil MBC was observed (Manna *et al.*, 2012). The slightly significant relationship was observed between N fractions with DOC, highest with amino sugar-N ($R^2=0.82$) followed by amino acid-N ($R^2=0.79$) and acid insoluble-N ($R^2=0.72$). The bioavailable fraction of N in FYM and crop residues in soil showed similar trend as bioavailable fraction DOC. Rapid consumption of DOC and low molecular weight N fractions leads to the small pool size of dissolved organic matter (Jones and Kielland, 2002; Roberts *et al.*, 2007). Normally, DOC and low molecular weight N fractions are less than 3% of soil organic C and N (Kalbitz *et al.*, 2003; Rees and Parker, 2005). This relation agreed with above results that DOC and low molecular weight N fractions were less than 1 % of soil organic C. Preliminary studies showed that initial DOC concentration and light fraction were correlated with N mineralization (Bregliani *et al.*, 2005). Significant relationships were observed between the organic C and N fractions (Bishworjit *et al.*, 2013). Similarly, the organic C was the principal reserve of N in the soil (Havlin *et al.*, 2005) and organic matter additions to soil can result in N immobilization within soil organic C pools (Whalen *et al.*, 2000).

5.1.2. Microbial Biomass Carbon (MBC)

The changes in the index defined by microbial C: organic C ratio reflects to the soils and the efficiency of the conversion to microbial C. Monitoring of microbial C may be a useful indicator of soil organic matter (Sparling *et al.*, 1994). It seems too simple to expect that the measurement of soil microbial biomass alone (or any other soil property) can provide a universally accepted index of soil sustainability. This study focuses on the influence of variability of soil amended with FYM during the kharif, rabi and both seasons on MBC. The effect of modes and levels of FYM and fertilizer N on MBC in soil is presented in Table 1. The MBC content of soil increased with increasing levels of FYM from 0 to 15 Mg ha⁻¹. This

might be attributed to increased application of FYM which increases the soil microbial population especially, bacteria in arid and semi-arid region where there is higher soil pH. Fungi thrives less in arid or semi arid and higher pH, less of C than do bacteria. Similarly, well-developed fungal communities under biological surface soils have been reported in arid and semi-arid ecosystems (Bates *et al.*, 2010). Fungi-dominated communities have a higher microbial N-use efficiency than bacterial-dominated communities, producing biomass with a higher C:N ratio and immobilizing less N per unit of assimilated C (Austin *et al.*, 2004). This is because fungi often use up to 60 % of C in construction of their own cell wall and protoplasm. Bacteria species vary widely in this respect but it seems that most of those active in soil retain only 10-25 % of C in their bodies. The dead cells are then subjected to attack by other organisms, and then release the maximum amount of MBC. The increase in MBC due to addition of FYM can be attributed to increased C supply for soil microorganism. Our results are in agreement with the findings of Singh *et al.*, (2012), who reported that manure amendments enhanced MBC by a factor of 1.3 to 18 compared with mineral fertilizer treatment alone.

A significant increase in MBC was observed when FYM was applied in both the seasons (kharif and rabi) compared to applied in kharif or rabi season. However, FYM applied in rabi season showed higher amount of MBC than applied in kharif season. The residual effect of 6 months (rabi) old applied FYM had significantly higher MBC than that of 12 months (kharif) old applied FYM. Temporal variations of temperature and moisture induced response is one of possible mechanism for shift in the composition of microbial community where more soil organic matter available. For instance, dominant populations at higher temperatures might have the ability to metabolize substrates that are not utilized by members of the microbial community at lower temperatures. This is hypothesized that application of FYM during kharif is longer and higher soil temperature so that decomposition of FYM is more but in case of rabi it is reverse in nature. This might be due to the availability of higher quantity of FYM to microorganism and after turning of lower temperature to higher temperature, activity of soil microorganisms are more it leads to more accumulation of C in soil microbial biomass. Similar findings were also reported by Davidson and Janssen, 2006 and Miken *et al.*, 2002.

The increase in MBC was not consistent with increasing doses of FYM with respect to modes, highest was recorded in both season (6.2 time) followed by rabi (3.6 time) and kharif (2.7 time) over control. It controls the build-up and break-down of organic matter through the decomposition of FYM by soil microorganisms. Microorganisms increase when large amounts of energy are released during FYM decomposition increasing enzyme activity due to continuous growth of micro-organisms (Steenwerth and Belina, 2008). Similar findings were also reported by Lalande *et al.* (2000).

There was a significant difference in MBC of soil receiving 0 and 120 kg N ha⁻¹. The application of 120 kg N ha⁻¹ significantly increased the MBC content of soil over 0 kg N ha⁻¹. The increase in MBC with the addition of N could be related to better plant growth in fertilized treatment resulting in formation of more mucigel and sloughed of cells. Application of fertilizer N also stimulated the microbial biomass in FYM applied treatments and ultimately, MBC had increased at an average of 25-30 % with the application of 120 kg N ha⁻¹. Higher soil C content in FYM treated plots indicated that improvement in microbial population with application of FYM might have increased the metabolic activity by utilizing substrates in form of root exudates. The large amount of microbial community associated with the decomposing particulate organic matter produces binding agent such as exocellular mucilaginous polysaccharides and it acts as a major food and energy for soil fauna. Thus, particulate organic matter is associated with a multitude of soil process and functions and is therefore, key attribute of soil quality (Manna *et al.*, 2012).

The MBC was highly significantly correlated with LFC ($R^2 = 0.95$) followed by HFC ($R^2 = 0.93$), organic C ($R^2 = 0.90$) and DOC ($R^2 = 0.91$). Light-fraction C is probably the better predictor of microbial abundance, as it is correlated more strongly with culturable microbial counts (Whalen, 2000; Swanston, 2002 and Wei *et al.*, 2009). Our results are in agreement with the findings of Manna *et al.*, 2012, who reported a significant correlation between water soluble C and soil MBC. A highly significant relationship was also observed between N fractions with MBC, highest with amino sugar-N ($R^2 = 0.95$) followed by amino acid-N ($R^2 = 0.92$), acid insoluble-N ($R^2 = 0.90$), hydrolysable unknown-N ($R^2 = 0.87$), hydrolysable-N ($R^2 = 0.85$). Our results corroborate the findings of Manna *et al.* (2006) and Mishra *et al.* (2008). Significant relationships were observed between the organic C and mineralized N fractions (Bishworjit *et al.*, 2013).

5.1.3. Light Fraction Carbon (LFC)

Plant residues are the largest source of C entering the soil. These residues enter the soil as dead and decaying aboveground biomass, senescent root tissue, sloughed root cells and root exudates. The carbon in these residues is present in a wide range of substrates, from readily decomposable cytoplasmic materials to more resistant cell wall compounds. Free or uncomplexed organic matter in soil is that which has not undergone significant transformations and can be represented by density fractionation. Light fraction provides a ready source of C to the microorganisms, as they are only the intermediate product between the fresh crop residues and completely soil organic matter. LFC plays an important role in determining the structure and function of the soil ecosystem by acting as an energy source for heterotrophic organisms and as a reservoir of relatively labile C and plant nutrients. The LFC content significantly increased with the application of FYM and fertilizer N over control (Table 1). A significant increase in LFC was observed with the application of different levels

of FYM, highest in 15 Mg ha⁻¹ followed by 10 and 5 Mg ha⁻¹. The higher amount of LFC in the FYM applied treatments confirmed that the light fractions, which is mainly composed of partially decomposed plant residues is highly labile and it can change rapidly in responses to management (Janzen *et al.*, 1992). Increase in LFC was observed when FYM was applied either in both the seasons (kharif and rabi) compared to applied in kharif or rabi season. This might be attributed to higher quantity of FYM applied in both seasons than applied in rabi or kharif season. The FYM applied during rabi might have produced more light fraction than that applied six months earlier during kharif as soil sampling was done after harvest of wheat crop. The gap of six months might have led to more decomposition of soil organic matter, which has reduced the light fraction content. Light fractions of organic matter C are the precursor for formation of soil MBC, soluble fraction of C, humic and non-humic fraction of C in soil.

Significant increase in LFC was observed with the application of 120 kg N ha⁻¹ over control (0 kg N ha⁻¹). There was a significant difference in LFC content of soil receiving varied levels of N. Highest LFC was recorded in 120 kg N plus 15 Mg FYM ha⁻¹ which was significantly superior over 10 and 5 Mg FYM ha⁻¹ irrespective of FYM modes. The effect of increasing levels of fertilizer N had more bearing in increasing the content of LFC. This is clearly understood from the fact that the growth of the crop has a direct influence on the LFC of soil organic matter in a particular cropping system. The growth as well as the yield of a crop is directly related to the availability of nutrients during the cropping period. Supplementary application of fertilizer N improves the crop biomass which leads to more return of crop residues into the soil. In arid and semi-arid or intensive cropping system (pearl millet-wheat) where growth may continue throughout year leads to high return of root biomass and crop biomass as well and also decomposition rate of these residues are very high and enhancement of higher LFC in the soil. This is hypothesized that, FYM a highly resistant soil organic matter has more temperature sensitivity due to these complex molecules having slower decomposition rate and higher activation energies so that it longer retention and enhances soil LFC. Similar finding that understanding the temperature sensitivity of SOC decomposition is challenging because soil organic matter is composed of many different compounds with different inherent kinetic properties (Davidson and Janssen, 2006) and higher activation energy is basically related to greater temperature sensitivity (Miken *et al.*, 2002).

The LFC showed highly significant relationship with MBC ($R^2 = 0.93$) followed by DOC ($R^2 = 0.90$) and HFC ($R^2=0.81$). This shows that the active role of microorganism plays important rules in enhancement of LFC. LFC is associated with non aggregated soil and it is not ready losing from the any tillage practices, and it is easily accumulated in microbial biomass compared to other C fractions. LFC are more rapidly decomposed than the heavy

fractions because light fractions mainly consist of plant residues and microbial biomass which have a rapid turnover rate. Highly significant correlation between LFC and MBC indicates that the microbial activity is closely associated with the transitory pool between fresh residues and humified organic matter. Our findings are in agreement with the findings of David *et al.* (2006). The significant relationship was observed between LFC and N fractions and it was highest with hydrolysable unknown-N ($R^2=0.89$) followed by acid insoluble-N ($R^2=0.88$), ammonia-N ($R^2=0.85$), and hydrolysable N and amino acid N ($R^2=0.82$). Soil organic C pools and N fractions are highly interdependent on physical and chemical quality and composition of plant litter. A significant relationship was observed between the organic C and mineralized N fractions (Bishworjit *et al.*, 2013). The LFC is generally considered a transitory soil organic matter pool dominated by decomposing plant and animal residues and has a specific density considerably less than that of minerals (Christens, 2001)

5.1.3. Heavy Fraction Carbon (HFC)

If we define HFC, which floated in 1.8 g cm^{-3} sodium Iodide and the occluded particulate organic matter with soil matrix is considered as heavy fractions. In HFC organic substances are held to surface of clays by both columbic attractions between negatively charged surface and positively charged organic compound, and positively charged organic compound, and positively charged surface, ion or oligo-ion at surface soils particles and organic anion. A significant increase in HFC was recorded with application of FYM and fertilizer N over control (Table 1). A significant increase in HFC was observed with the application of different levels of FYM and highest with 15 Mg ha^{-1} followed by 10 and 5 Mg ha^{-1} irrespective of FYM application modes. A significant increase in HFC was noticed when 15 Mg ha^{-1} FYM was applied in both season as compared to applied in rabi and kharif seasons. The amount of increase in mean HFC with respect to FYM modes; highest (2.2 times) was recorded in FYM applied both the seasons followed by rabi (1.6 times) and kharif (1.3 times) over control. The FYM applied during rabi produced more HFC compared to the kharif season. FYM applied in kharif season was utilized by two crops and FYM applied rabi season was used by only one crop as the soil sampling was done after harvest of wheat (rabi). The gap of six months might have led to more decomposition of soil organic matter, which has reduced the light fraction content. The increase in HFC in FYM treatments could be related to biochemical resistance of organic-C compounds contained either in organic matter or plant materials. Studies had shown that application of FYM resulted in an increase in lignin and lignin-like products, which are major components of the HFC. Therefore, the significant increases in HFC and its proportion in SOC from FYM added soils suggest that addition of FYM is of great importance for improving the soil organic matter stabilization in the long term and it improve the soil HFC. Besides the higher organics inputs like $15 \text{ Mg FYM ha}^{-1}$, the greater increase in amounts of HFC than that of 10 and 5 Mg FYM ha^{-1} . LFC could

partially be attributed to preferential degradation of labile compounds and accumulation of recalcitrant materials over time. Similar results were also observed by McLauchlan *et al.*, 2006; Yan *et al.*, 2007 and Lopez-Capel *et al.*, 2008. In arid and semi-arid regions soils are more in calcium, which is known to help hold C through the formation of calcium humates that also considered as HFC. Lower amounts of C mineralized after disruption of macroaggregates containing HFC with high C:N ratio was probably due to immobilization of the more labile protected C i. e. HFC. Labile forms of HFC were greater in macroaggregates than in microaggregates, lower proportion of total SOC, suggesting that macroaggregates have a greater proportion of C physically protected from microbial attack. Our finding is in accordance with David *et al.* (2006). More accumulation of FYM in soil mainly determines by formation of organic-inorganic complexes; sorption of the organic matter on the clay particles and fixation crystal lattices of clays and formation of metal-organic compounds. The clays having the 2:1 type structure with high absorptive capacities and with expanding crystal lattices where organic molecules to be trapped are very effective on retention of HFC. FYM application increased HFC and humin fractions at a higher rate than chemical fertilizers (Yang *et al.*, 2004). FYM as C input increases, the mineral fraction of a soil saturates and consequently additional C input will only accumulate in HFC pools that have a relatively faster turnover. These findings were corroborating with Gulde *et al.*, 2008. Manure compost like FYM that have undergone the complete composting process have much higher proportions of stable products than immature products (Bernel *et al.*, 1998).

The application of fertilizer N significantly increase the HFC content in soil compared with control. HFC is the material remains after the breakdown of products and residual materials have reacted with each other chemically and undergone considerable interaction with soil particles. It is very resistant to further biological attack and its specific density is high. In mineral soils, the majority of soil organic matter is associated with the mineral matrix, forming organic-mineral complexes which influence the biological, chemical and physical behaviors of soils (Baldock, 2000). Our findings are accordance with Greenland, 1965 and Barrios, 1996.

The HFC showed highly significant relationship with organic C pools, highest with MBC ($R^2 = 0.95$) followed by organic C (%) ($R^2 = 0.93$), DOC ($R^2 = 0.87$) and LFC ($R^2 = 0.81$). Organic-inorganic interactions relate to the formation of inter particles bonds which affect aggregate formation of HFC by binding of organic matter to clay particles. Significant relationships were observed between the organic C and mineralized N fractions (Bishworjit *et al.*, 2013). Heavy-fraction C dominated total SOC storage in all treatments. The total SOC increase under fertilization treatments is attributed to an increase in C content of both the light and the heavy fraction. However, the SOC increase for the manure treatments was mainly due

to an increase in the C content of the heavy fraction, whereas that for mineral fertilizer treatments was mainly due to an increase in the C content of the light fraction. The non-hydrolyzable fraction (HFC), defined as recalcitrant C pool, is typically comprised of lignin and related compounds as well as fats, waxes, and resins, which could provide clues regarding the potential of SOC sequestration over the long term (Lima *et al.*, 2009). A number of authors have studied the nature and decomposition rate of LFC and HFC (Whalen, 2000; Swanston, 2002 and Wei *et al.*, 2009). Significant relationship was observed between N fractions and HFC, highest with amino acid-N ($R^2 = 0.96$) followed by acid insoluble-N ($R^2 = 0.95$), hydrolysable unknown-N ($R^2 = 0.94$), ammonia N ($R^2 = 0.92$). Relationship between N fractions and HFC are relatively higher. This may be due to that HFC contributes more towards N fractions because it retains more organic N for longer and it is one of the potential sources of organic N. Our findings are agreement with Mulvaney *et al.*, (2001)

5.2. Nitrogen Fractions

Soil organic matter consists of humic and non-humic substances, these non-humic substances sometime designated as active organic matter, are constantly undergoing decomposition at various rates that release N fractions. Organic N fractions in soil organic matter are composed mainly unstable forms that are readily mineralizable and stable forms such as acid insoluble-N, hydrolysable NH_3 -N, amino acid-N, amino sugar-N, hydrolysable unknown-N and total hydrolysable-N that are more resistant to mineralization. These N fractions are discussed from the outcome of the results in the following headlines:

5.2.1. Amino acid N

Soil organic matter typically contains approximately 20–30% of its N in the form of amino acids with the majority present in a polymeric state (e.g. proteins, protein–humic complexes and peptides). There was significant increase in amino acid-N due to the application of FYM from 0 to 15 Mg ha^{-1} and fertilizer N from 0 to 120 kg N ha^{-1} (Table 2). A significant increase in amino acid-N (151.2 mg kg^{-1}) was noticed when FYM was applied in both season followed by rabi season and kharif season. Bremner, (1965) stated that various workers have shown that 20 to 40 % of total N in surface soils is in form of bound amino acids; 5-10 % is in the form of combined hexosamines; and about 1% or less is present as purine and pyrimidine derivatives.

Fertilizer N has increased the amino acid-N concentration significantly at all the levels and modes of FYM application. A significant increase in amino acid-N was observed with application of 120 kg N ha^{-1} over control. Highest amino acid-N concentration was recorded with application of 15 $\text{Mg FYM plus } 120 \text{ kg N ha}^{-1}$. The buildup of amino acid-N with respect to FYM modes, highest was recorded in both seasons (121.4 %) followed by rabi (87.0 %) and kharif (77.9 %) over control. Temporal variation in amino acids is probably due to seasonal shifts in the changes of crop residues and soil microbes. This is because the pool

of free amino acids in the soil is affected by processes that vary over the course of a year such as plant and microbial uptake (Weintraub and Schimel, 2005), root exudation (Jones *et al.*, 2005), turnover of roots and mycorrhizae (Ruess *et al.*, 2006), and litter inputs (Schimel *et al.*, 2004; Schmidt and Lipson, 2004). Direct contribution of amino acid-N was littler in FYM than the fertilizer N. This may be due to lesser N use efficiency in wheat grain yield from the N fertilizer and it around 34.4 to 48.4 kg grain per kg N, remaining applied fertilizer N in the soil may be prone to losses from different N loss processes. So that return of organic form of N was very less compared to FYM amendments in the soil. Similar results are accounted by Ge *et al.* (2010) that turnover rates of the additional amino acids and peptides were soil-dependent and generally followed the order of organic soil > transitional soil > conventional soil. Application of higher doses of FYM in both seasons leads to higher accumulation of SOC and it favours more microbial biomass and also amino acid-N ($R^2 = 0.95$) was highly correlated with MBC which helps in higher amino acid-N content in soil. Similarly, Guggenberger *et al.* (1999) indicated that microbial growth is favored by higher content SOC, which leads to an increase in the occurrence of glucosamine, muramic acid, and other amino sugars. Long-term application of FYM after 43 cycles of pearl millet-wheat cropping system can store more organic matter in soil and it can be decomposed by many climatic factors in such as temperature arid and semi-arid regions. Temperature-driven increases in the rate of decomposition of old soil organic matter will lead to increased availability of free and peptide-bound amino acids (Trumbore, 2000; Jan *et al.*, 2009).

The amino acid-N was highly significantly correlated with amino sugar-N ($R^2 = 0.95$), acid insoluble-N ($R^2 = 0.99$), hydrolysable unknown-N ($R^2 = 0.99$), ammonia-N ($R^2 = 0.99$), amino sugar-N ($R^2 = 0.95$), hydrolysable-N ($R^2 = 0.96$), available N ($R^2 = 0.97$), N content of pearl millet ($R^2 = 0.87$) and wheat ($R^2 = 0.87$). This results suggests that amino acids and amino sugars may differ in the extent to which they occur as stable humic forms, and hence in their tendency to undergo mineralization. Amino acids represent one of the largest inputs of hydrolysable organic N to soil and consequently they constitute a major component of the organic N cycle. Hydrolysable-N compounds that can enter into soil are free and polymeric amino acids (proteins and peptides) (Jones *et al.*, 2005). Presumably much of the amino N in soil in the form of amino acids or peptides complexed with quinines or phenolic compounds and these compounds intimate associations with all other N fractions as in organically bounded compounds. If a particular form of soil organic N is highly labile, then the concentration of this form should be inversely related to crop responsiveness to N fertilization, and a distinct in available N in soil. Based on the correlations of these different N fractions can be employed to estimate soil N availability in soil. Bremner, (1965) suggests that some of the bound amino acid N may be in form of mucopeptides and teichoic acids,

since these polymers are important constituents of bacterial cell walls. Similar findings were agreements with Mulvaney *et al.*, 2001.

5.2.2. Amino sugar- N

Amino sugar N is considered to be largely in the form of high molecular weight compounds. The active organic matter is component of non-humic substances which consists of plant residues that have been formed in during previous years that important for N fraction in soils. Amino sugar-N may play the role in soil serving as a source of N for plant growth and promoting good soil structure. The amino sugar- N significantly increased with application of FYM and fertilizer N over control (Table 2). A significant increase in amino sugar-N was observed when FYM was applied at 15 Mg ha⁻¹ followed by 10 and 5 Mg ha⁻¹. Highest amino sugar- N was noticed when FYM was applied in both seasons as compared to applied either in rabi or kharif season. However, a higher fraction of amino sugar-N was noticed when FYM doses were applied in rabi than in kharif season. The FYM applied during rabi might have produced more amino sugar-N than that applied six months earlier during kharif. The gap of six months might have led to more decomposition of soil organic matter, which has reduced the light fraction content. Amino sugars occur in soils as high-molecular weight substance and are believed to be largely of microbial origin. Hence, amino sugar-N in our results also highly correlated with MBC ($R^2 = 0.95$) in soil. Application of higher doses of FYM in both season leads to higher accumulation of SOC and it favours more microbial biomass and also amino sugar-N was highly correlated with MBC which helps in higher amino sugar-N content in soil. Since Glucosamine represents the dominant amino sugar in soil and is a good combined source of both C and N for microorganisms, it might be considered that biological uptake would be a widely observed phenomenon in soil systems (Rousk *et al.*, 2011). Similar results by Guggenberger *et al.* (1999) indicates that microbial growth is favored by higher content SOC, which leads to an increase in the occurrence of glucosamine, muramic acid, and other amino sugars.

There was increase in amino sugar-N (110.7 %) with application of 120 kg N ha⁻¹ over 0 kg N ha⁻¹. There was a significant difference in amino sugar-N of soil receiving varied levels of N. However, higher amino sugar-N was recorded in 120 kg N plus 15 Mg FYM ha⁻¹ which was significantly superior over 10 and 5 Mg FYM ha⁻¹ irrespective of modes. The buildup of amino sugar-N with respect to FYM modes, highest was recorded when FYM applied in both seasons (167.9 %) followed by rabi (104.7 %) and kharif (82.6 %) over control. Accumulation of amino sugar N in soils may be probably related to N carryover from the previous crop. It means application of inorganic N fertilizers helps to more accumulation of amino sugar-N from previous returned of crops biomass. Such accumulation can almost certainly be attributed to microbial decomposition of the residue, because amino sugars occur extensively in cell wall material produced by bacteria, actinomycetes, or fungi (Parsons,

1981). Most glucosamine is probably present in soil as insoluble cell wall polymers; however, the action of extracellular enzymes (e.g. chitinase) leads to the release of monomers into solution enabling microbial uptake via specific transport systems (Revilla-Nuin *et al.*, 2002). Similar results are accounted by Ge *et al.* (2010) that turnover rates of the additional amino acids and peptides (amino sugar-N and also included all other N fractions) were soil dependent and generally followed the order of organic soil and chemical fertilizers applied soil.

The amino sugar-N was highly significantly correlated with amino acid-N ($R^2 = 0.95$), acid insoluble-N ($R^2 = 0.94$), hydrolysable unknown-N ($R^2 = 0.94$), ammonia N ($R^2 = 0.93$), amino sugar-N ($R^2 = 0.95$) and hydrolysable-N ($R^2 = 0.86$). Above correlations were much of the amino N in soil in the form of amino sugar or amino acids or peptides complexed with quinines or phenolic compounds and these compounds intimate associations with all other N fractions as in organically bounded compounds. So that these N fractions intimately associated with amino acid-N, acid insoluble-N, hydrolysable unknown-N, ammonia N, amino sugar-N and except slightly with hydrolysable-N because this hydrolysable organic N is always associated in soil solution is found in mobile water flowing through pores, cracks and channels, and in immobile water within pores in soil peds. There was significant relationship between amino sugar-N and available N ($R^2 = 0.97$) and similar relationship with N content of pearl millet ($R^2 = 0.91$) and wheat ($R^2 = 0.90$). This indicated that amino sugar-N is more contributed to available N in soils as well as uptake of N in both pearl millet and wheat. Amino sugar-N has been estimated that amino sugars contribute between 5 and 12% of total soil organic N making it a significant reservoir of both C and N in soil (Knicker, 2011). Similar findings were agreement with Bremner (1965); Mulvaney *et al.* (2001) and Ge *et al.* (2010).

5.2.3. Ammonia-N

An appreciable amount of soil N is released as ammonium during acid hydrolysis. Some workers refer to this as the amide N. Half of the N in organic matter is in the form of ammonia-N and about half is in the form of organic material. Microbes that consume the organic compounds excrete ammonium-N. Things will happen to the ammonium regardless of whether it comes directly from the manure or from microbes consuming the organic compounds. The ammonium-N may be used by plants immediately, converted to ammonia-N and lost to the air or converted to nitrate which will be used by plants or microbes. The "immobilized" nutrients become available to plants when the microbes are consumed by other organisms that release ammonium as a waste product. With this background our results also validated with a significant effect on ammonia- N with application of FYM and fertilizer N (Table 2). A significant increase in ammonia-N when FYM was applied at 15 Mg ha⁻¹ followed by 10 and 5 Mg ha⁻¹. Highest ammonia-N was noticed in 15 Mg FYM ha⁻¹ in both

season followed by rabi and lowest with kharif. Ammonia-N in soil mainly depends on soil organic matter and microbial biomass and they are interdependent. Our results also showed that correlation between ammonia-N and MBC ($R^2 = 0.85$). It shows that soil microorganisms are mainly depends on organic form of ammonia-N as sources their food. This indicated that soil microorganisms mainly involved in the degradation and decomposition of soil organic matter as well as crop residues by production of organic acids and ultimately accumulation of ammonia-N from soil organic matter. The increases in ammonia-N due to application of fertilizer-N with 120 kg ha^{-1} were ranged from 202.5 to 222.2 % during rabi applied, 196.6 to 207.2 % during kharif and 222.7 to 243.5 % applied during both the seasons with increase in FYM dose from 5 to 15 Mg ha^{-1} . The buildup of ammonia-N was highest when FYM was applied in both the seasons (137.7 %) followed by rabi (118.1 %) and kharif (105.7 %) over control. Similar findings were agreements with Mulvaney *et al.*, 2001.

The ammonia-N was highly significant correlated with amino acid-N ($R^2 = 0.99$), hydrolysable-N ($R^2 = 0.99$), hydrolysable unknown-N ($R^2 = 0.99$), acid insoluble-N ($R^2 = 0.98$), amino sugar-N ($R^2 = 0.93$). Correlations was much of the amino N in soil in the form of ammonia-N or peptides complexed with organic compounds and these compounds intimate associations with all other N fractions as in organically bounded compounds. There was significant relationship between ammonia-N and available N ($R^2 = 0.98$) and similar relationship with N content of pearl millet ($R^2 = 0.85$) and wheat ($R^2 = 0.85$). Comparison between ammonia-N and N content of pearl mullet and wheat almost similar but in case of available N was highly significantly correlation. This indicated that ammonia-N is more contributed to available N in soils than uptake of N in both pearl millet and wheat. This may be attributed to accumulation of ammonia-N in soil microbes from soil organic matter is initial stage of ammonia-N from soil organic compounds and then microbes released in later stage as ammonium-N form after death and decay of soil microorganisms. Similar findings were agreement with Bremner, (1965); Mulvaney *et al.* (2001) and Ge *et al.* (2010).

5.2.4. Hydrolysable-N

N availability increases relative to soil C availability, greater quantities of hydrolysable-N are released, increasing the proportion of N-rich micro sites in soil aggregates. The hydrolysable-N pool is generally mobile within the soil solution and can easily be transported out of the soil and into groundwater by hydrological events (e.g., soil moisture and fertilization). Results presented in the Table 3 revealed that hydrolysable-N increased due to the application of FYM and fertilizer N levels. Addition of FYM into soil implies that availability of SOC in soil and SOC mainly helpful for improvement of soil structure. Soil organic matter and soil microorganisms are interdependent for formation of soil structure. Soil structure consists of both macro aggregates and micro aggregates, formation of macro aggregates mainly organic compounds after decomposition of soil organic

matter by soil microorganisms whereas micro aggregates directly involved by soil microorganisms. So that accumulation of hydrolysable-N more where soil amended with FYM based on their quantity and modes of application. Highest hydrolysable-N was noticed when FYM was applied in both seasons followed by applied in rabi and kharif season. However, higher fraction of hydrolysable-N was recorded when FYM doses were applied in rabi than in kharif season. The FYM applied during rabi might have produced more hydrolysable-N than that applied six months earlier during kharif. Schimel and Bennett (2004) proposed that moving up the conceptual N-availability gradient, the release of hydrolysable-N and the importance of N mineralization and nitrification increased. It is generally assumed that where microbial growth is C-limited, microbes will use C from dissolved organic matter to support their energy needs and release hydrolysable-N (Schimel and Bennett, 2004 and Bardgett, 2005).

Significant increase in hydrolysable-N was observed with application of 120 kg N ha⁻¹ over 0 kg N ha⁻¹. There were a significant differences in hydrolysable-N of soil receiving varied levels of N. Application of fertilizer N attributed more accumulation of hydrolysable-N due to excess or unutilized fertilizer N by crop as well as soil microorganism and it accumulates in the soil solution as well as micro aggregates of soil. Applied fertilizer N directly or indirectly involved in the formation of soil structure by means of stimulates for actively participating of soil microorganisms in soil structure formation and more returns of crop residues into the soil. The observed trend toward a positive increase in the pentoses: hexoses ratio in both microsites, and the increase of hydrolysable-N, suggests a higher plant-derived decomposition of organic matter in this microsites (Chantigny *et al.*, 2006 and Schimel and Bennett, 2004). Similar results are supported by Schimel and Bennett, 2004 and Bardgett, 2005.

Hydrolysable-N showed highly significant relationship with ammonia N ($R^2 = 0.99$), hydrolysable unknown-N ($R^2 = 0.99$), amino acid-N ($R^2 = 0.96$), acid insoluble-N ($R^2 = 0.94$), amino sugar-N ($R^2 = 0.93$). All these N fractions are integral part of organic compounds in soil organic matter except hydrolysable-N. Hydrolysable-N mainly accumulated in soil solution where soil micro aggregates are more in soil. Account of hydrolysable-N is more proportion in soil solution and also highly correlated with all other N fractions. This may be attributed to all these above N fractions were formed from the soil organic compounds by indirect effect of hydrolysable-N from soil microorganisms. Hydrolysable-N consists of many compounds, including low molecular weight compounds, such as amino acids, peptides, amino sugars, and urea, and high-molecular-weight compounds, such as proteins, chlorophyll, DNA, and RNA (Antia *et al.*, 1991). There was significant relationship between hydrolysable-N and available N ($R^2 = 0.97$), and similar relationship with N content of pearl millet ($R^2 = 0.79$) and wheat ($R^2 = 0.79$). Generally, availability of N in soil mainly depends on good soil

structure so that hydrolysable-N mainly helps to various dependent factors for formation of soil structure. But in case of correlations values of available N and N content of pearl millet and wheat were wider differences. This might be hydrolysable-N more involves in soil constructive mechanism than plant uptake N during crop growing period so that it may not be longer available during crop growing period and it might be transformed to available form of N after post harvest of crops that's why hydrolysable-N highly correlated with available N in soil. All N forms from hydrolysable-N enter into the soil from a range of sources, including dry and wet deposition, litterfall, root and microbial exudation, turnover of roots and organisms, and organic fertilizer additions (Kalbitz *et al.*, 2000 and Christou *et al.*, 2006).

5.2.5. Hydrolysable Unknown-N

The reactions of amino acids with phenolic compounds, mainly from lignin biodegradation, have been postulated as mechanisms of incorporation into the hydrolysable unknown-N fraction, and in fact these reactions are still assumed to be essential for the generation of humic substances (Stevenson, 1982; Kelley and Stevenson, 1996). About 15 to 30 per cent of total N included in this unidentified portion is non-hydrolysable and is sometimes referred to as insoluble humin N. Hydrolysable unknown-N mainly depends on heterogeneity and wider decomposition rate of soil organic matter. Hydrolysable unknown-N was higher than other N fractions except hydrolysable-N in soil. Highest hydrolysable-N was recorded when levels of FYM applied at 15 Mg ha⁻¹ followed by 10 and 5 Mg ha⁻¹ (Table 3). This might be due to carry-over effect of continuous use of organic sources and accumulation of organic residue which in turn contributed higher build up in the soil. The buildup of hydrolysable unknown- N with respect to different modes, highest was recorded in both seasons (1.44 times) followed by rabi (1.23 times) and kharif (1.10 times) over control. The FYM applied during rabi have produced more hydrolysable unknown-N as FYM applied in rabi was used by only one crop and FYM applied in kharif was utilized by two crops. FYM is bulky in nature and less rapid decomposition rate so that it contributes more in total hydrolysable unknown-N in the soil (Sihag *et al.*, 2005).

There was significant increase in total hydrolysable unknown-N with application of 120 kg N ha⁻¹ over 0 kg N ha⁻¹. However, higher total hydrolysable unknown-N was recorded with application of 120 kg N ha⁻¹ along with 15 Mg FYM ha⁻¹ which was significantly superior over 10 and 5 Mg FYM ha⁻¹ irrespective of modes. This may be attributed to continuous application of FYM and fertilizer N from the four decade and accumulation of organic residue from return of crop residues which in turn contributed higher accumulation of hydrolysable unknown-N of in the soil. More accumulation of hydrolysable unknown-N is to tendency of recalcitrant soil N to increase with long-term application of FYM. This result agrees with Olson and Lowe, (1989) for instance, observed a strong increase in the proportion of unhydrolyzable N at the end of 40 years of cultivation.

The hydrolysable unknown-N showed highly significant ($R^2 = 0.99$) relationship with all N fractions such as ammonia N, hydrolysable unknown-N, amino acid-N, acid insoluble-N and amino sugar-N ($R^2 = 0.94$). The hydrolysable unknown-N was mainly depends on long-term application FYM along with fertilizer N. Hydrolysable unknown-N constant accumulation in soil and it more contribution to all other N fractions but slightly less with amino sugar-N. This may be attributed to proportion of amino sugar-N was less in soil compared to all other N fractions. This might be due the less contribution of amino sugar-N from hydrolysable unknown-N in soil. There was significant relationship between hydrolysable unknown-N and available N ($R^2 = 0.98$), and similar relationship with N content of pearl millet ($R^2 = 0.84$) and wheat ($R^2 = 0.86$). More contribution of available N during crop growing period more from hydrolysable unknown-N and hence increases uptake of N from soil. Similar results were supported by Schimel and Bennett, 2004 and Bardgett, 2005.

5.2.6. Acid Insoluble-N

A large amount of soil N, usually about 25-35%, is recovered as acid insoluble-N and has been termed unknown N. The acid insoluble-N increased significantly with the application of FYM at all the modes of FYM application. However, there was significant increase an acid insoluble-N was noticed when 15 Mg FYM ha⁻¹ was applied in both seasons as compared to applied either in rabi or kharif season (Table 3). The application of 120 kg N ha⁻¹ significantly increased acid insoluble-N over 0 kg N ha⁻¹. Highest acid insoluble-N was recorded when 120 kg N ha⁻¹ was applied along with 15 Mg FYM ha⁻¹ followed by 10 and 5 Mg FYM ha⁻¹ irrespective of modes. The buildup of acid insoluble-N with respect to different modes, highest was recorded in both seasons (111.8 %) followed by rabi (91.6 %) and kharif (82.4 %) over control. Handayanto *et al.* (1997) demonstrated that by including crop residues with high active polyphenol content in the mixture N fractions and N utilization of the higher quality residue can be reduced due to the protein binding capacity of the polyphenol. Results indicated that addition of FYM along with fertilizer N improves the crop biomass N content and it increases protein binding capacity in crop residues ultimately increases the N fractions (acid insoluble-N) in soil.

The acid insoluble-N showed highly significant ($R^2 = 0.99$) relationship with other N fractions such as amino sugar-N, ammonia N, hydrolysable unknown-N, amino acid-N and acid insoluble-N and hydrolysable-N ($R^2 = 0.90$). The acid insoluble-N was mainly depends on long-term application of FYM along with fertilizer N. Acid insoluble-N constant accumulation in soil and it more contribution to all other N fractions but slightly less with hydrolysable-N. This may be attributed to proportion of hydrolysable-N was less in soil compared to all other N fractions. There was significant relationship between acid insoluble-N and available N ($R^2 = 0.98$), and similar relationship with N content of pearl millet ($R^2 =$

0.86) and wheat ($R^2=87$). More contribution of available N during crop growing period more from acid insoluble-N and hence increases uptake of N from soil.

5.3. Grain yield of pearl millet and wheat

The grain yield of both pearl millet and wheat crops increased significantly with the application of N and FYM (Table 4). Yield decline in long-term experiments could occur because of adversity of many factors such as decline of soil organic matter and associated nutrients and imbalanced fertilizers use. Application of FYM in both the seasons (kharif and rabi) gave maximum yield followed by rabi and kharif applications. Tahir *et al.* (2011) recommended that organic matter alone with synthetic fertilizers could be helpful for enhancing stagnant wheat yield. Soil productivity is associated with SOC the decline in its content could adversely affect crop yields. The results revealed that addition of FYM favourably improved soil physical, chemical and biological properties of soil and improved the crop yield. Integrated use of N and FYM resulted in higher grain yield of both the crops and it was highest with the application of 15 Mg FYM along with 120 kg N ha⁻¹. Results from long-term experiment could be helpful in establishing cause and effective relationship to monitor long-term change in soil C pools and nutrients supply on yield of these crops. The increase in SOC pools and N fractions with application of FYM could be attributed to an increase in yield compared to control plots. In control plots, there is a wide spread concern over possible changes, which might be affecting yield trends due to decrease in photosynthesis, increased respiration, shortened vegetative and leads to less return of crop biomass into the soil. Continual addition of FYM increases MBC, which could lead to a positive effect on both soil aggregation and macro porosity and it improves the growth and development of crops. DOC and LFC are active C is a fraction of organic matter, it acts as a buffering agent in replenishment mechanisms like soil colloids, dissolution from litter, and exudation from plant roots leads to increases the soil fertility and higher bioavailability of nutrients to crops leads to increases the yields of pearl millet and wheat crops. Grain yields were more than doubled under FYM treatments over control, both wheat and pearl millet grain yields were significantly correlated with soil organic C, available N and P. These results were validated by Zhang *et al.*, 2009. Integration of organic and inorganic sources resulted in higher biological yield in sunflower that is attributed to more availability of nutrients and their uptake, which increased flowering, leaf area index, biomass (Munir *et al.*, 2007). Increase of nutrients, structural development and changes in soil health might have collectively contributed to improve in crop yields. Under high intensive cropping system recommended dose of inorganic NPK and NPK+FYM maintained soil quality parameters, which in turn supports better crop productivity and C sequestration in soil (Manna *et al.*, 2012). The balanced use of NPK+FYM is an important management to arrest the decline of crop yield (Manna *et al.*, 2013).

5.4. NPK (%) content of pearl millet grain

The N, P and K content of pearl millet grain significantly increased with increasing levels of FYM and N (Table 5). Addition of FYM can favor the growth of both the root and the aerial parts of the plant and encourage nutrient absorption. Organic materials are required for recycling of plant nutrients in soils through soil organic matter and crop residues. Increase in crop nutrients contents by improvements of SOC pools and N fractions are also attributed to numerous factors. This was in accordance with correlation of N content of pearl millet and organic N fractions with acid insoluble-N ($R^2=0.86$), hydrolysable $\text{NH}_3\text{-N}$ ($R^2=0.85$), amino acid-N ($R^2=0.87$), amino sugar-N ($R^2=0.91$), hydrolysable unknown-N ($R^2=0.84$) and total hydrolysable-N ($R^2=0.79$) in soil. Importance of these fractions are increase in soil biology, increase in activity of soil fauna, and improvement in soil fertility. Similar constructive statement by Jones *et al.*, (2005) that plants are hypothesized to take up only the fast cycling low molecular weight of N fractions in form of amino acids.

Highest P content of 0.60 % was recorded with application of N at 120 kg N ha^{-1} and $15 \text{ Mg FYM ha}^{-1}$ applied in both seasons followed by applied either in rabi and kharif seasons. The FYM applied in rabi season contributed more towards P content as compared to applied in kharif. Increase in nutrients contents may be due to improvement in soil organic matter. The soil organic matter is easily measured by the different properties of soil such as organic C and N pools that correlations between organic C pools and available P with DOC ($R^2=0.93$), MBC ($R^2=0.95$), and LFC ($R^2=0.89$) and HFC ($R^2=0.93$) and N fractions also are attributed to numerous factors for indirectly in improvement of available P in soil. DOC and LFC are active C is a small fraction of organic matter, it acts as a buffering agent in replenishment mechanisms like soil colloids, dissolution from litter, and exudation from plant roots leads to increases the soil fertility and higher bioavailability of nutrients to crops. Under high intensive cropping system recommended dose of inorganic NPK and NPK+FYM maintained soil quality parameters, which in turn supports better crop productivity and nutrient absorption in soil (Manna *et al.*, 2012).

There was an increase in K content of pearl millet grain with addition of FYM and fertilizer N. Highest K content was recorded with application of N of 120 kg N ha^{-1} and $15 \text{ Mg FYM ha}^{-1}$ applied in both seasons and followed by rabi and kharif. Increase in K content may be due to improvements in organic C pools. K content showed highly significant correlation with DOC ($R^2=0.88$), MBC ($R^2=0.94$), and LFC ($R^2=0.94$) and HFC ($R^2=0.92$) and they were correlated with available K content in soil and N fractions are also attributed to numerous factors in available K in soil (Fig. 2). Increase of nutrients, structural development and changes in soil health might have collectively contributed to improve in crop yields and increases nutrients content. Similar results balanced use of NPK+FYM is an important

management to arrest the decline of crop yield and nutrient absorption given by Manna *et al.* (2013). Proportion of NPK content in pearl millet was highest with K followed by N and P content. This may be attributed to the pearl millet is a drought resistant crop in arid or semi-arid regions and also K one of the drought resistant major nutrient element in plant system and it activates numerous enzymes in soils as well as in plant system. It involves in switch on and switch off mechanism in the guard cells of stomata so that it avoids the excess loss of water from the crops.

5.5. Wheat grain NPK (%) content

The data presented in Table 6 revealed that increasing levels of FYM from 0 to 15 Mg ha⁻¹ increased the NPK content in wheat grain. The N content with each successive levels of FYM, the response of N content was highest when FYM was applied in both season (kharif and rabi) followed by applied in rabi and kharif season. This might be due to higher quantity of FYM applied in both season and it contributes more N content than applied in rabi or kharif season. The FYM applied during rabi might have more available N content of soil than that applied six months earlier during kharif. Highest mean N content was recorded in 120 kg N ha⁻¹ irrespective of modes and doses of FYM. This was accordance with correlation of N content of pearl millet with N fractions viz. acid insoluble-N ($R^2 = 0.87$), hydrolysable NH₃-N ($R^2 = 0.85$), amino acid-N ($R^2 = 0.87$), amino sugar-N ($R^2 = 0.97$), hydrolysable unknown-N ($R^2 = 0.86$) and total hydrolysable-N ($R^2 = 0.79$) in soil.

The concentration of nutrients in the soil solution is an indicator of mobility of nutrients especially P toward the root surface and in the vertical direction, in arid climates, it difficult to move nutrients from soil to crops due to unfavorable soil physical-chemical properties due fixation in soil clay minerals. Therefore, an addition of FYM favours the all physical-chemical properties and enhances the soil nutrient P concentration and it can easily movement to plant system from soil solution. P content of wheat grain increased with successive dose of FYM up to 15 Mg ha⁻¹ and fertilizer dose up to 120 kg N ha⁻¹. Increase in available P content of soil depends upon the soil organic matter content. In our study, improvements in organic C pools were observed by addition of FYM. The correlation between P content of wheat grain and soil C pools were DOC ($R^2 = 0.87$), MBC ($R^2 = 0.95$), and LFC ($R^2 = 0.91$) and HFC ($R^2 = 0.93$) (Fig.1). Among these C pools the DOC and LFC are active C is a small fraction of organic matter, it acts as a buffering agent in replenishment mechanisms leads to higher bioavailability of nutrients to crops. Highest P content of 0.95 % was recorded FYM was applied in both seasons as compared to applied either in rabi or kharif. However, higher P content was observed when FYM was applied in rabi than in kharif season. Soils with high organic matter contain considerable amounts of organic P, which are mineralized to provide available P for plant growth (Havlin *et al.*, 2005). There was significant correlations between soil organic C and available P ($R^2 = 0.90$), P content in wheat

grain ($R^2 = 0.92$) and MBC ($R^2 = 0.93$). Wheat grain P content, available P and MBC correlation with soil organic C has also been reported by various researchers are Cleveland and Liptzin, 2007; Havlin *et al.*, 2005 and Ahmed *et al.*, 2010.

K is mainly supplied via diffusion, i.e. concentration gradient, by addition of FYM that improves the more concentration of K in soil solution due to higher content of K in FYM. Characteristics of K in soil, shape and width of the depletion zone in different soils strongly depends on their soil organic matter content, which is an important parameter of the buffer capacity for K, and that improves the CEC, the higher in equilibrium concentration of K in soil solution, ultimately higher in uptake of K. Our experimental results were validated with these statements where FYM amended as a organic sources, highest K content of 1.68 per cent was recorded with application of 120 kg N along with 15 Mg FYM ha⁻¹ in both seasons followed by rabi and kharif. This might be attributed to higher quantity of FYM applied in both seasons than individual applied FYM in rabi or kharif season. The residual effect of 6 months (rabi) old FYM had significantly higher K content than that of 12 months (kharif) old FYM applied. Increase of nutrients, structural development and changes in soil health might have collectively contributed to improve in crop yields and increases nutrients content. Similar type of results were also given by Gupta *et al.* (1992); Narwal and Antil (2005); Manna *et al.*, (2013). Proportion of NPK content in wheat gain was highest with N followed by K and P content. This may be attributed to wheat grain contains high protein content (7-8 %) and also N is an integral part of protein which contains higher proportion of N compared to P and K. This was hypothesized that plants grown with organic manures accumulate more NPK than without organic amendments (Mujeeb *et al.*, 2008).

5.6 Organic C and available NPK

Soil nutrients recovery trajectory are affected by the degree of change from the historical amendment of FYM in different modes and doses of the intervention and N levels discussed below:

5.6.1. Organic C

Net mineralization in FYM amended soil was twice that of non-amended FYM in soil after four decades when different levels N fertilizer were added. C rich soils store nutrients and have the potential to remain fertile over time. Soil organic matter constitutes N reservoir that is never completely empty and yet seldom full enough to provide enough of element to permit maximum growth of most common crops. Long-term FYM amendments influencing organic C, available NP and K at different N levels are presented in the Table 7. A significant increase in organic C was observed when FYM applied at 15 Mg ha⁻¹ followed by 10 and 5 Mg ha⁻¹. Highest content of organic C was noted when FYM was applied in both the seasons compared to rabi or kharif seasons. Taylor, (2005) reported that the most important quality index for organic manure is N concentration, often expressed as C:N ratio.

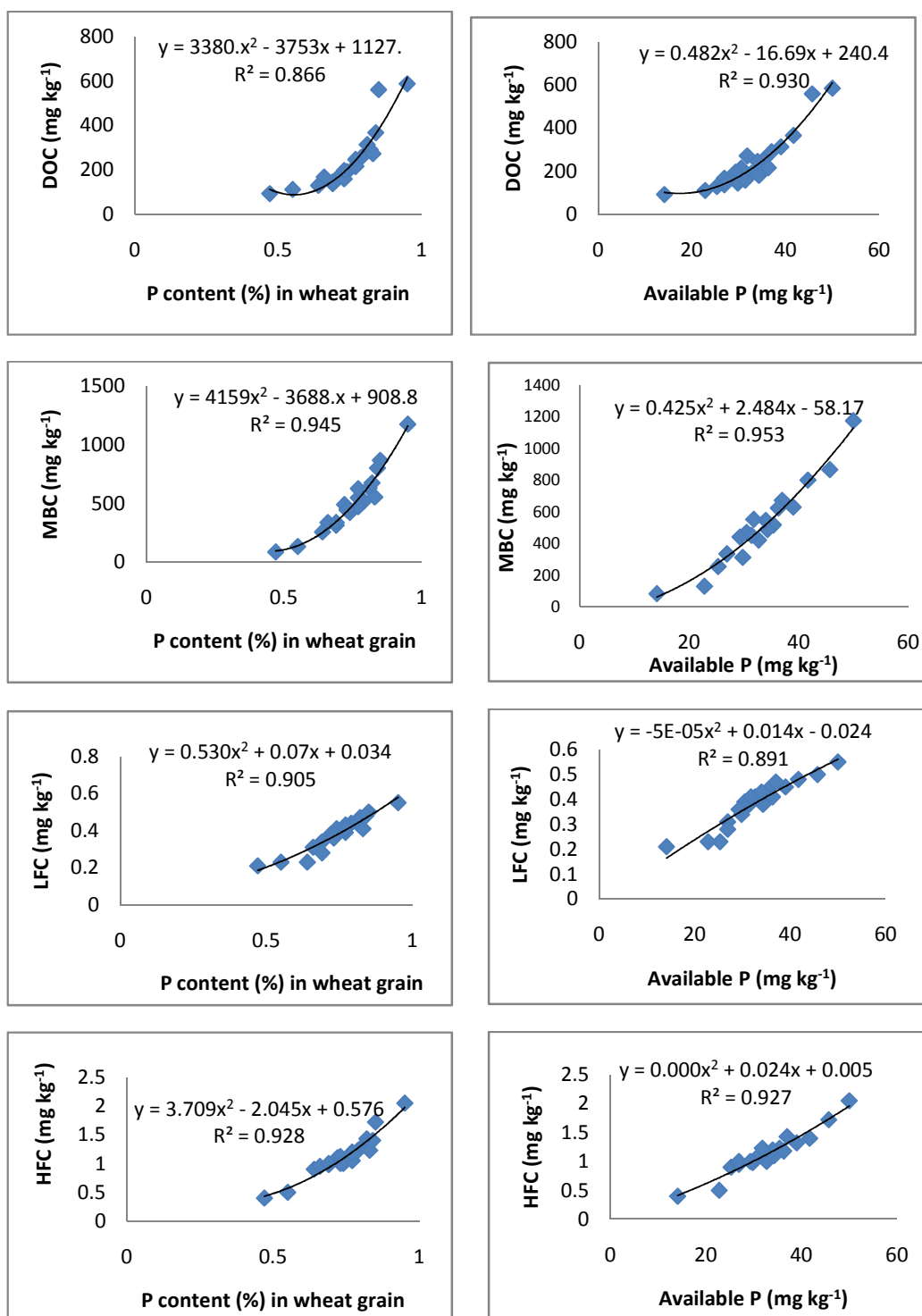


Fig. 1: Long-term effect of various modes and doses of FYM and N levels on relationships between SOC pools and P content in wheat grain and available P under pearl millet –wheat cropping sequence

Highest build up of organic C (2.09 %) was noticed when 15 Mg ha⁻¹ FYM was applied in the both seasons in conjunction with 120 kg N ha⁻¹ for 43 years by raising pearl millet and wheat

cropping in sequence. The soil organic C concentration significantly increased with the lapse of 43 year in the C input treatments (N+FYM). Application of FYM as soil amendment and integrated with fertilizer N, can achieve the positive and balanced soil nutrient budget in soil. A significantly higher SOC content was observed in the FYM treatment than fertilizers addition (Yang *et al.*, 2004). Soil organic matter produced different effects on soil N status depending upon their composition, stage of decomposition and environmental factors (Cooperband *et al.*, 2002; Hadas and Portnoy, 1997). Most of researcher indicated that the application of organic manure in combination with inorganic fertilizer linearly increased SOC levels (Rudrappa *et al.*, 2006 and Li *et al.*, 2010). It is well known that changes in MBC, LFC, DOC and HFC in soil correspond to changes in the availability of decomposable substrate like FYM. Thus, the FYM addition provided more available N, P and K and organic C. Long-term application of NPK+FYM maintained or improved SOC content over initial level (Manna *et al.*, 2012). This is consistent with the finding of Bohme *et al.* (2005) who reported that available nutrients were greater in soil after the application of FYM.

SOC was highly correlated with labile pools of C (DOC, MBC, LFC and HFC). The correlation coefficient was highest between HFC and SOC ($R^2 = 0.96$), followed by DOC and SOC ($R^2 = 0.95$) and DOC and MBC ($R^2 = 0.93$). Our result confirms that C fractions are sensitive indicators for detecting changes in soil organic matter in the short term, before they are readily measurable in total C. Such high correlations have also been reported by Rudrappa *et al.* (2006) and Liang *et al.* (2011) and it is not surprising that the measures of labile organic matter were closely correlated since they are closely interrelated properties.

5.6.2 Available N

Improved ability to predict the availability of N from organic source, including FYM and return of plant residues into the soil would serve two complimentary purposes. Result showed that there was a significant difference in available N status of post harvest soil samples at different modes and levels of FYM and N (Table 7). Forty three years of continuous cultivation of pearl millet-wheat system with different amounts of FYM and fertilizer N added in rabi or kharif season could not sustained the initial N content (100 mg kg^{-1}). However, increase in available N was observed when FYM applied at 15 Mg ha^{-1} followed by 10 and 5 Mg ha^{-1} . Highest available N was recorded when FYM was applied in both the seasons and it was doubles than the value recorded in kharif season. This may be attributed highest quantum of FYM and also steadily availability of soil organic C throughout seasons and minimizes losses of inorganic N or mineralized N these are enhances the availability of N in soil. Higher available N was observed when FYM was applied in rabi compared to kharif. This might be residual effect of 6 months (rabi) old FYM had significantly higher available N than that of 12 months (kharif) old as soil sampling was done after harvest of wheat (rabi) crop. Our results also collaborative supports of available N as well as N content both pearl millet-wheat with different N fractions in soil. The

immobilization of inorganic N is generally increased with increasing availability C through addition of FYM. However, microbes may be N limited if C is in excess supply, leading to variations in the abundance and proportions of fungi and bacteria and thus differences in soil N cycling (Boyle *et al.*, 2008). FYM containing N that are released into soils during litter degradation will remain in soil solution only transitionally before becoming bound and precipitated by high molecular weight polyphenolic compounds which were generated from applied FYM so that longer availability N in soil. Similar results were reported by Majuakim and Kitayama, (2013). Application of N fertilizers with FYM resulted in significant increased in available N in soil over FYM alone irrespective of FYM modes. A wide range of N compounds can be used by soil microorganisms, but availability of C to the soil microbial biomass is an important determinant of the dynamics of soil N transformations (Burger and Jackson, 2003).

5.6.3 Available P

The total P content in organic matter is very variable and nearly 70% of total P in manure is labile. The available P in FYM treated plots was relatively higher as compared to control (Table 7). Significant difference in available P status of post harvest soil samples was observed at different modes and levels of applied FYM and N. Highest available P was recorded in plots that received 120 kg N along with 15 Mg FYM ha⁻¹ which was significantly superior over 10 and 5 Mg FYM ha⁻¹ irrespective of modes. Highest available P of 41.2 mg kg⁻¹ was noticed in plots received FYM in both seasons followed by applied in rabi and kharif seasons. Organic matter contains large amounts of organic P, such as phospholipids and nucleic acids (Turner and Leytem, 2004), which can be released to increase soil inorganic P concentrations by mineralization. P adsorption to soil particles can be greatly reduced through applying FYM. The humic acids contain large numbers of negative charges, carboxyl and hydroxyl groups, which strongly compete for the adsorption sites with inorganic P. Application of FYM, can also change soil pH and thus it can be achieved and alters the soil P availability in soil. Application of higher quantity of FYM may increases the soil moisture conservation which leads to more P availability in soil. P is relatively immobile nutrient in soil and diffusion is the major process controlling its movement. Hence indirectly soil moisture regulates soil P mobility (Marschner, 1995). Addition of organic manure increased soil moisture contents (Boateng *et al.*, 2006), which may be the reason of improved P availability in soil. In arid and semi-arid availability of P is different due to P fixation by calcium and other cations. The probable reason for addition of FYM increase might be the binding of P-fixing agents (Ca) especially in arid and semi-arid regions that ultimately decreased P precipitation and increased P availability in soil. Furthermore, it seemed to be more advantageous to apply FYM amendments in calcareous soils to improve the availability of P to plants due to the high retention of P in to the soil (Braschi *et al.*, 2003).

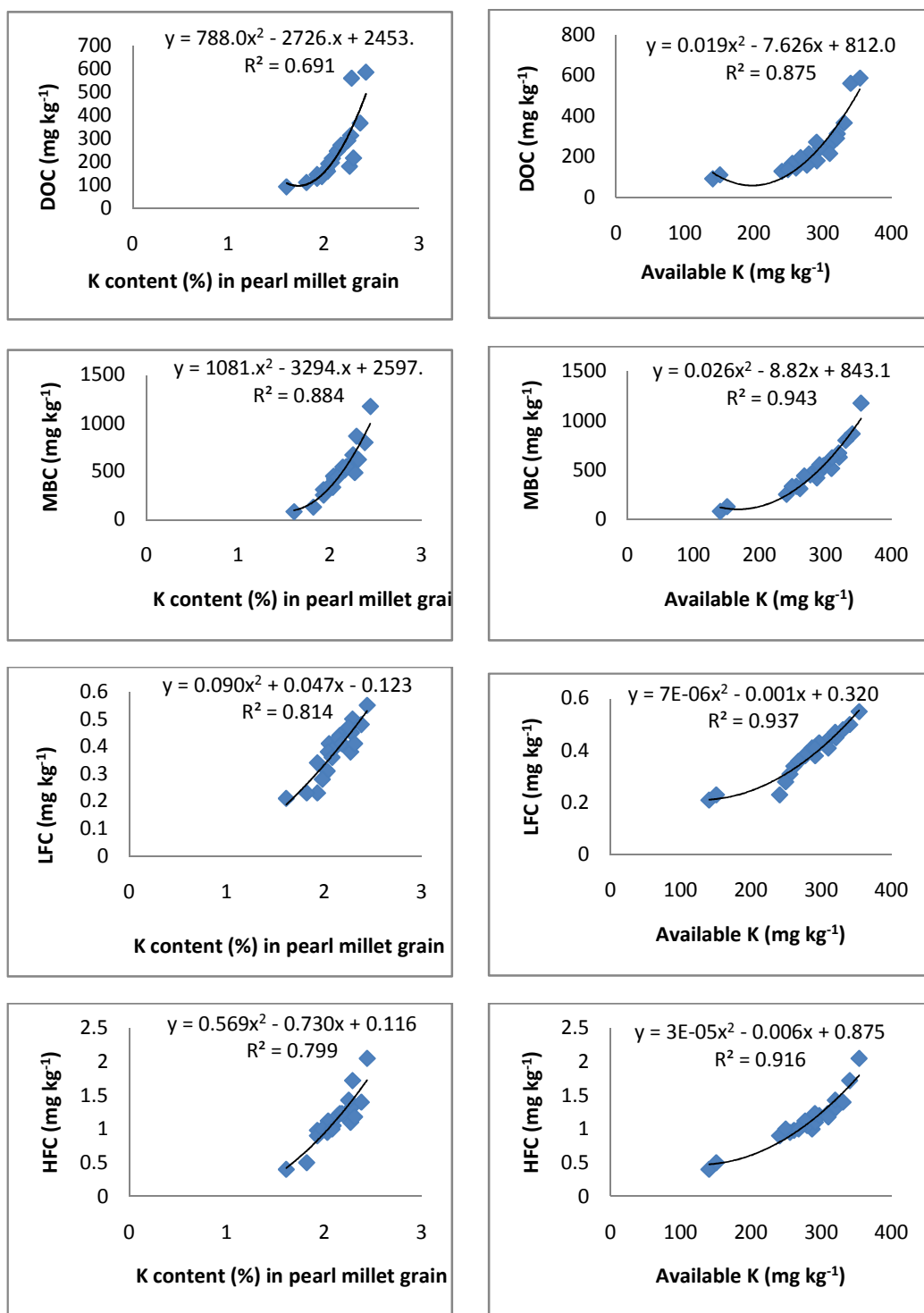


Fig. 2: Long-term effect of various modes and Levels of FYM and N levels on relationships between SOC pools and K content in pearl millet and available K under pearl millet –wheat cropping sequence

Similar results collaborate that small molecular organic acids from mineralization of humic substances in manure can dissolve Ca phosphate, and especially for citrate, it can efficiently

weaken the nano particle stability of humic acid phosphate, by controlling the free Ca availability and thereby the nucleation rate (Martins *et al.*, 2008). Soils with high organic matter contain considerable amounts of organic P, which are mineralized to provide available P for plant growth (Havlin *et al.*, 2005). High C: P ratios are considered to facilitate soil organic matter buildup because metabolic needs of microbes immobilized P in microbial biomass, as C:P ratios increases within microbial biomass. There is a significant correlations between soil organic C and available P ($R^2 = 0.90$) available P and MBC ($R^2 = 0.93$). Cavigelli and Thien, (2004) also found increased bioavailability of P in soils by addition of organic matter. Similar relations had been found in soils at our study and around the world (Cleveland and Liptzin, 2007; Havlin *et al.*, 2005 and Ahmed *et al.*, 2010). The P concentration in soil solution and P mobility are enhanced by complexation with organic ligands binding sites, particularly effective in P mobilization are organic acid anions which are released by roots and microorganisms or produced during FYM decomposition. There was a significant difference between available P statuses of soil receiving varied levels of N. application of N had increased available P content significantly at all the doses and modes of FYM application. Application of inorganic N enhanced the decomposition rate of FYM and greater availability of nutrients in crop growing period. The maximum accumulation of C was observed in treatment receiving continuous application of FYM either alone or in combination with N fertilizer. Similar findings were validated that increase in soil organic matter, the N and P availability also increases (Ewulo *et al.*, 2008).

5.6.4. Available K

The available K content in the organically fertilized plots was higher compared to control. Available K content of soil decreased without applying FYM and fertilizer N in 43 years cropping of pearl millet and wheat crop in sequence (Table 7). There was a significant difference in available K statuses of soil receiving varied levels of N. However, available K of soil was significantly higher in 120 kg N ha⁻¹ over control. Application of FYM in both the seasons resulted in higher build up of available K compared to applied either in rabi or kharif seasons. However, build up was higher when FYM applied in rabi than kharif. K occurs in soil, in aqueous solution, adsorbed on organic or inorganic colloids, in the form of insoluble inorganic compounds and as a constituent of organic and living microorganisms. Organic substances are known to hold certain metallic cation very strongly, it is usually stated that organic substances holds di and trivalent metabolic cations much more firmly than monovalent so that it made available K in soil solution. The tenacity with which organic substance hold K, thereby exchange complex (available form of K) it does decrease loss by leaching and prevents inorganic fixation. Furthermore, plant residues that are high in K also serve as excellent; readily available due to addition of extra inorganic N induces the more biomass crop return to the soil. Temporal changes in available K content in soil were due the

changes in SOC. Despite annual K additions at recommended rates through fertilizers and at more than the recommended rates through organic manures, available K content decreased due to continuous cropping at five locations reported by Yadav *et al.* (2000). These findings are in agreement with the observation of Varalakshmi *et al.*, (2005). Similar results were reported by Bulluck *et al.* (2002) and Edmeades, (2003) who reported that increased K availability with organic amendments could be due to the release of K from organic material and lower fixation and leaching losses

5.7. DTPA extractable micronutrients (Zn, Mn, Fe and Cu)

The concentration of DTPA extractable micronutrients (Mn, Fe, Zn and Cu) in soil solution mainly depends on soil pH, redox potential and these all depend upon the soil organic matter. Organic matter is very important role in availability micronutrients in soils. Higher available micronutrients in soil were noticed with the application of N and FYM (Table 8). There were different proportions of micronutrients with modes and levels of FYM and fertilizer N levels, among them highest was Fe followed by Mn, Zn and Cu. An increase in pH can decrease the concentration of micronutrients but addition of FYM which can decrease the soil pH due to release of their organic acids and thereby improves the availability of micronutrients. There was significant increase in micronutrients with addition of FYM and fertilizer N. Successive increase in FYM levels from 0 to 15 Mg ha⁻¹ increased the DTPA extractable Zn, Mn, Fe and Cu from 0.77 to 3.34, 3.50 to 5.10, 5.00 to 8.10 and 0.44 to 0.94 mg kg⁻¹, respectively. The FYM applied in rabi season (2.31, 5.18, 7.77 and 0.89 mg kg⁻¹) contributed more towards build up of DTPA extractable Zn, Mn, Fe and Cu as compared to applied in kharif season (1.78, 4.16, 7.49 and 0.82 mg kg⁻¹). However, application of FYM to both the seasons (kharif and rabi) gave highest build up of DTPA extractable Zn, Mn, Fe and Cu as compared to FYM applied either in rabi or kharif seasons or no application. This might be attributed to higher quantity of FYM available in both seasons and this contributes more micronutrients than individual season applied either in rabi or kharif. The higher SOC content might have enhanced the microbial activity in the soil, and consequent release of complex organic substances (chelating agents) which form stable chelates with these elements thus decreases the susceptibility to precipitation, fixation, oxidation and leaching of micronutrients. These results are in conformity with findings of Deepak Kher, 1993; Lindsay, 1979; Stevenson, 1994; Rajeev Kumar *et al.*, 1993 and Tisdale *et al.*, 1995. Dependent on soil organic matter content, proportion of complexed cations increases in the order: Fe>Mn>Zn>Cu. Primarily, organic matter extract chelates with Fe and microorganism made available if ferric iron is reduced to ferrous. Organic matter plays an important role not only in Fe oxidation and reduction but also forms complexes with any soluble Fe and carbonic acid evolved from decomposing plant residues plays a role in Fe availability. In saline-calcareous (arid and semi-arid) CO₂ formed act as keep the Fe in insoluble forms but addition of organic

matter, produces the maximum only carbonic acid instead of CO₂ then more availability of Fe. If Cu is present in organic soils it usually reacts to form complexes. It may either enter the exchange complex or be chelated by organic matter. Zn more strongly bound on organic acids than it salts, it less strongly held than Cu or Fe ion. The micronutrients concentration in the soil solution varies widely, depending on such factors as soil water content, soil depth, pH, CEC, redox potential, and microbial activity etc these are only favorable through addition of FYM to the soil.

Experiment: II: To study the effect of various combinations of different organic manures and fertilizers;

5.8. Soil organic matter pools

5.8.1. Dissolved Organic Carbon (DOC)

DOC is considered to be the most active component of soil organic matter. It is the main energy source for soil microorganisms and is a primary source of mineralizable N, P and S and it influences the availability of metal ions in soils by forming soluble complexes (Stevenson, 1994). Understanding the role of DOC in nutrient cycling is an important factor for sustainable ecosystem management (Silveira, 2005). The content of DOC was low in surface soil (0-15 cm) when only organic manures (FYM, Poultry Manure, and Pressmud) or fertilizers were applied (Table 9, 10 and 11 and Fig.3). However, a significant increase in DOC in surface soil (0-15 cm) was observed when organic manure applied in conjunction with fertilizers N or NP. This may be ascribed to the addition of manures along with fertilizers improved the soil quality and produced more plant biomass as well as roots thereby enhanced DOC in soil. This effect may also be due to the direct addition of water soluble through organic manures. Zolsnay, (1996) reported that organic manures addition contributed linearly and contributed in more soluble C accumulation in the system. The amounts of DOC in sub-surface soil (15-30 and 30-45 cm) were lower than in surface soil (0-15 cm). This may be due to less leaching of DOC to sub-surface soil and presumably higher organic inputs in the plow layer. The effect of different treatments on DOC of sub-surface soil was almost identical to that observed in surface soil. These data suggest that shoot/root allocations combined with vertical root distributions, affect the distribution of SOC with depth and also imbalanced application of fertilizers exerted adverse effect on DOC in soil. DOC constituting mainly plant residues in the form of stubbles, roots and to a lesser extent leaves in the cultivated soil could be an important source of DOC. Addition of fertilizers led to relatively little inorganic materials in a soil hence resulted into little DOC accumulation in soil. Crop rotations and FYM application had significant effects on organic C fractions (Yang *et al.*, 2004).

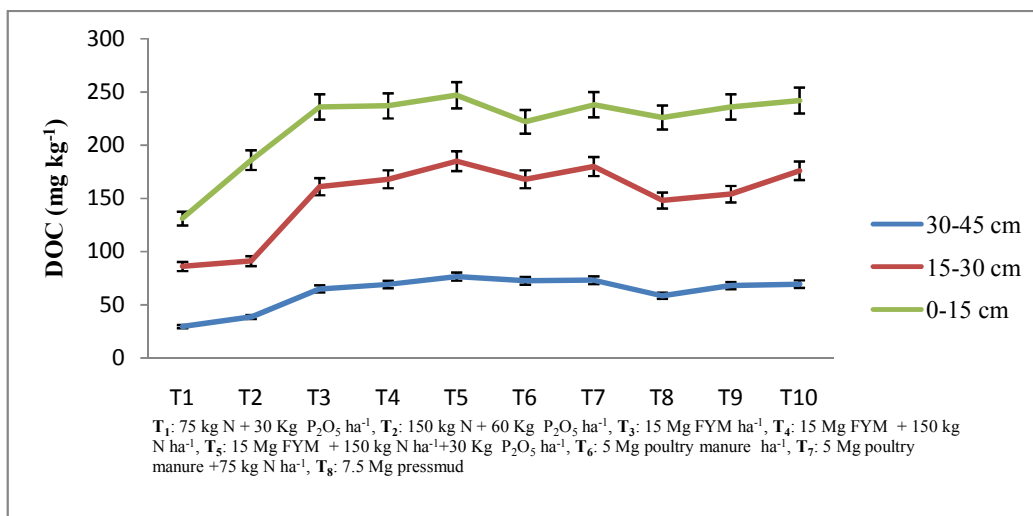


Fig. 3: Long- term effect of various combinations of organic manures and fertilizers on DOC at different soil depths

Irrespective of soil depths, FYM₁₅N₁₅₀P₃₀ invariably showed higher content of DOC over all other treatments. In surface soil (0–15 cm), the DOC content 32.8, 30.1 and 28.0 % higher in FYM₁₅N₁₅₀P₃₀, pressmud_{7.5}N₁₅₀P₃₀ and poultry manures₅N₁₅₀P₃₀, respectively, treatment compared to half of recommended dose of NP fertilizers alone. Accumulation of DOC in soil was lowest with application of pressmud (1.53 folds) and poultry manure (1.50 folds) and highest with FYM (1.47 folds) in 15-30 cm as compared to 0-15 cm depth and similar trend was observed in 30-45 cm soil depth. In this study, reduction in the active pools of C and N was recorded from surface to sub-surface soil. Production of DOC was more in surface soil as compared to sub-surfaces soil due to less availability of applied manures as well as crop belowground biomass. It also attributed to less contribution of microorganism for degradation of organic residues in sub-surfaces. Rapid decline in pool size of water extractable C with soil depth is due to decomposition of manures and particularly, sorption to mineral components (Hassouna *et al.*, 2010). The DOC showed highly significant relationship with LFC ($R^2 = 0.94$) following by MBC ($R^2 = 0.89$), organic C ($R^2 = 0.81$) and HFC ($R^2 = 0.73$). The DOC relationship with LFC and MBC may be due to more immediate and potential availability of C to soil microorganism. Lower relation with HFC may be due to its intimate association with soil particles so that less potential available to soil microorganisms. Positive relationship between water soluble C and soil MBC were also observed by Manna *et al.*, 2012.

5.8.2. Microbial Biomass Carbon (MBC)

Microbial population composition and density is an important attribute of soil organic manures quality and quantity, as it provides an indication of a soil's ability to store and recycle nutrients and energy. It also serves as a sensitive indicator of change and future trends

in organic matter level. Significant increase in MBC in surface soil (0-15 cm) was observed in plots received the organic manures alone or in combination with N or NP fertilizers over half or full recommended dose of NP fertilizers (Table 9, 10 and 11 and Fig. 4). Among the organic manures applied alone, highest MBC was observed with the application of FYM as compared to pressmud and poultry manure in surface soil. The highest MBC was observed in the organic manures treatment and the lowest in treatments that received only fertilizers. Similar types of observations were also reported by Verma and Mathur, (2009). As compared to half of the recommended dose of NP fertilizer applied, manures additions showed two folds increase in MBC. MBC contents under $\text{FYM}_{15}\text{N}_{150}\text{P}_{30}$, $\text{pressmud}_{7.5}\text{N}_{150}\text{P}_{30}$ and poultry manures $_{5}\text{N}_{150}\text{P}_{30}$ were 95.4, 91.8 and 90.8 % were higher than recommended dose of NP fertilizers in surface soil. Addition of organic manures improved the microbial biomass in soils and enhances the MBC. The organic matter contents in soil differed significantly among rhizosphere (surface) and sub-soil being significantly higher in rhizosphere soil than the sub-surface soil. Increased microbial activity in rhizosphere and released organic substances by plants might be responsible for higher organic matter contents in rhizosphere soil than in sub-surface soil. Mishra *et al.*, (2008) reported that soil microbial biomass, acts as an agent of transformation of all substances and reflect on a labile pool of C, N, P, S and micronutrients. The variations in soil MBC may be attributed to variation in soil organic matter content consequently the microbial activity. Further the variation in SOM may be attributed to variation in residue return to soil and addition of organic manures. Similar results have been reported by Geo Jose, (2006) in the FYM applied plots of long term manurial trial in Alfisol under rice-pulse cropping systems.

The supply of additional mineralizable and readily hydrolysable C due to organic manure application resulted in higher microbial activity and their biomass C. It indicates that addition of manures resulted in higher soil MBC then in inorganic fertilizers. The MBC was highest with application of FYM which may greater input of C than other organic manures (poultry manure and pressmud). The application of organic materials along with chemical fertilizers increased biomass C content substantially. Sridevi *et al.* (2003) reported that organic residues resulted in significant increase in MBC over its initial value. If the MBC content of soils is used as an early indicator of changing soil organic matter contents, then the larger proportion of total soil C as microbial biomass in manured soils indicated that C levels in soils receiving manures will increase. Examined that the associations of vertical distribution of MBC for depths at 15 cm intervals due to climate, soil texture, and vegetation biomass. Decreasing MBC turnover with depth, resulting in lower SOC accumulations per unit of C input in deep soil layers. Decreasing root turn over with depth, causing lower C inputs per unit of standing roots biomass in deep soil layers and lesser vertical mixing by soil

organisms in sub-soils ultimately decreasing the soil MBC. Similar findings are accordance with Trumbore, 2000 and Allen *et al.*, 2000.

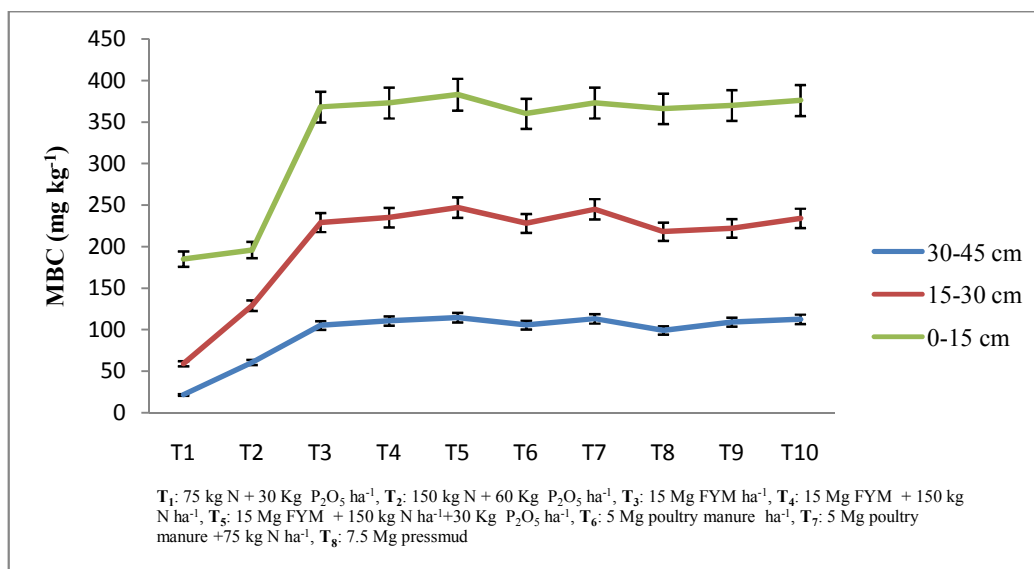


Fig. 4: Long- term effect of various combinations of organic manures and fertilizers on MBC at different soil depths

The highly significant relationship of MBC was observed with LFC ($R^2 = 0.99$) followed by DOC ($R^2 = 0.89$), organic C ($R^2 = 0.83$) and HFC ($R^2 = 0.82$). LFC is intimate association with MBC and it might be food for soil microorganisms and they built up C in their bodies. Alvarez and Alvarez (2000) reported the MBC is highly correlated to total C content of soil. Addition of organic manure increases microbial activity in the soil (Marschner, 1995), which was correlated with the organic matter contents in soils compared to control. Similar finding that soil MBC and DOC are considered to be the most active and highly labile fractions of SOC and they enhance nutrients supply in response to nutrient management practice (Janzen *et al.*, 1992).

5.8.3. Light fraction Carbon (LFC)

The LFC, low specific gravity, wider C:N ratio fraction, and it represents a transitory pool between fresh residues and humified stable organic matter; it consists mainly of decomposing plant and animal residues, contains appreciable amounts of microbial debris and it has rapid turnover in soil. Application of organic manure alone or along with recommended dose of NP fertilizer significantly increased the LFC content in soil over full or half of recommended dose of NP fertilizer (Table 9, 10 and 11 and Fig. 5). Among the fertilizer treatments, the recommended dose of NP fertilizers showed higher the LFC over half of recommended dose of NP fertilizers. Therefore, long-term applications of manures or fertilizers alone and applied in combination were capable of increasing the LFC over half of recommended dose of NP fertilizers. The variable increase in LFC content among different

manure treatments may be attributed to the variations of amounts and composition of organic manures (FYM, pressmud and poultry manure) added to soil (Campbell *et al.*, 1992). Diels *et al.* (2004) reported that the addition of NPK fertilizers had little effect on the quantities of aboveground plant residues returned to the soil. The above results indicated that organic manures application was the most important practice that can be expected to enhance soil each organic C fraction especially light organic C. The observed increase in LFC in higher organic input systems could be attributable to differences in inputs of external organic matter. In addition, chemical fertilization combined with organic manures did not change soil organic C levels, but produced significant higher levels of LFC as compared with organic manures alone. This findings are validates with Rovira and Vallejo, 2002.

The differences in LFC content are attributable to the variation in total C input applied through different manures and quality and composition of manures subjected to decomposition rates. Lower concentrations of LFC in imbalanced inorganic fertilizer plots may be due to lesser return of crop residue to soils. But in balanced application of mineral fertilizer may have stimulated microbial activity and enhanced decomposition, but more soil organic matter was decomposed and more available nutrients could then be provided for better crop growth, resulting in increased crop residues (root debris and secretion) being returned to the soil and retains more LFC. Higher LFC was found in surface soil and decreased with increases in soil depth. The effect of different treatments an LFC of sub-surface soil was almost same to that observed for surface soil. The LFC content in surface soil FYM₁₅N₁₅₀P₃₀, pressmud_{7.5}N₁₅₀P₃₀ and poultry manures₅N₁₅₀P₃₀ treatments was 175.5, 163.0 and 154.3 %, respectively, higher than recommended dose of NP fertilizers applied. The lower LFC in sub-surface soil suggest that no fresh materials were added to sub-surface layer. These differences in LFC are mainly attributed to the less return of crop residue inputs. The reason for relatively low LFC content of soil might be attributed to high moisture condition for longer time and consequent lower microbial activity in the soil. The lower content in LFC in lower depth of soil might be attributed to the lower vertical mixing of soils are less disturbed by tillage operation.

In a long-term field trial, Li *et al.* (2012) reported that the soil organic C and light fraction of particulate organic C concentrations were considerably greater in soils receiving manures along with NPK fertilizers. About 3.5 % of total organic carbon (Curtin and Fraser, 2003) in top 15 cm layer of soil was in light fraction. Addition of large inputs of organic manures from the crops is an important factor contributing to increases in labile organic matter (Williams *et al.*, 2000). Similarly, reported by Aziz *et al.* (2010) that organic manures substantially improved the plant height, leaf area and shoot and root fresh and dry weights and enhance the organic C pools. The hypothesized that crop shoot/roots patterns of allocation, would be the major determinant of the relative vertical distribution of LFC. Significant

changes in soil organic C profiles, which can be differences in root distributions and above and belowground distribution patterns. Root distributions affect the vertical placement of C in the soil, and above and belowground allocation affects the relative amount of LFC in soil. Similar findings are accordance with Trumbore, 2000 and Allen *et al.*, 2000.

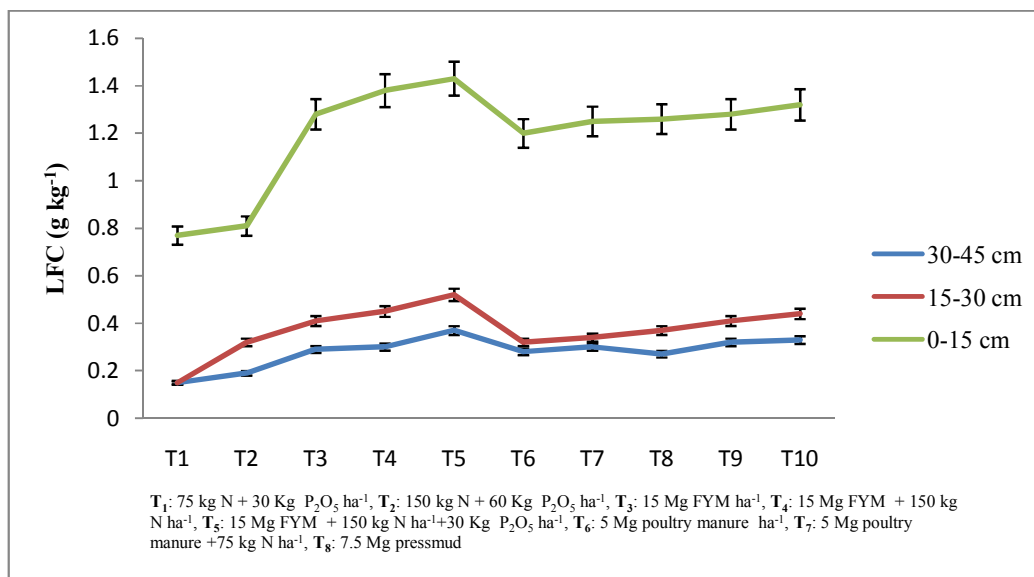


Fig. 5: Long- term effect of various combinations of organic manures and fertilizers on LFC at different soil depths

The LFC showed highly significant relationship with MBC ($R^2 = 0.96$) followed by DOC ($R^2 = 0.94$), HFC ($R^2 = 0.88$) and organic C ($R^2 = 0.88$) in surface soil. LFC is intimate association with DOC and it might be easily dissolves to soil solution and it help in accumulation of C in microorganisms. Continuous addition of organic manures helped in the maintenance of the balanced proportion of LFC and MBC. Greater soil organic C concentration in macroaggregates suggested that the presence of decomposing roots and fungal hyphae within macroaggregates not only increased C concentration but also contribution to their stabilization. Further, the bioproducts released by decomposition of manures and by root exudation processes enhance aggregation of clay and silt particles and temporary binding agents' increases with labile pools of soil organic C like LFC, MBC and DOC. The results confirm the findings of Ravankar *et al.* (2003). Long-term application of NPK+FYM maintained or improved soil organic C content over initial level and activate further fractions of soil organic C viz., particulate organic C, water-soluble C and soil MBC (Manna *et al.*, 2012). The LFC is a transient pool of soil organic C that is intermediate in decay continuum soil organic matter and exert greater on soil aggregates stability (Nccizah and Wakindiki, 2012).

5.8.4. Heavy fraction Carbon (HFC)

The HFC, defined as recalcitrant C pool, is typically comprised of lignin and related compounds as well as fats, waxes, and resins, and it intimate association with soil particles which could provide clues regarding the potential of SOC sequestration over the long term.

Application of organic manures alone or in combination with FYM, pressmud and poultry manure resulted in a significant increase in HFC content of surface soil over full or half of recommended dose of NP fertilizers (Table 9, 10 and 11 and Fig.2). Similar type of trend was also observed in sub-surface (15-30 and 30-45 cm) soil. These results clearly support the hypothesis that organic manures have greatly positive impact on soil C storage and its sequestration. The amount of HFC was 3.5 to 4.0 times higher than the LFC, regardless of manural and fertilizers treatments. The HFC content in FYM₁₅N₁₅₀P₃₀, pressmud_{7.5}N₁₅₀P₃₀ and poultry manure₅N₁₅₀P₃₀ treatments were 56.8, 35.1 and 29.7 %, respectively, higher than recommended dose of NP fertilizers in surface soil. In sub-surface (15–30 and 30–45 cm) soil similar trends were observed as in case of surface soil. For soils amended with manures, the increase in soil organic C was more due to the increase in HFC, while for soils that only received mineral fertilizer; the increase in soil organic C was more due to the increase in LFC. The HFC due to its organo-mineral association is protected from its environment and is less prone to further transformation and mineralization, which is useful for sustaining the soil fertility. FYM application increased HFC and humin fractions at a higher rate than chemical fertilizers (Yang *et al.*, 2004). The above results indicated that organic manure fertilization was the most important practice that can be expected to enhance soil each organic C fraction especially HFC. Similar results documented by Diels *et al.* (2004) that the addition of NPK fertilizers had little effect on the quantities of aboveground plant residues returned to the soil compared to the control. Retention of HFC was higher in treatments received FYM as compared to pressmud and poultry manure applied treatments. The FYM is less homogenous manure and accumulation of more resistant end products of a variety of reactions than other like slightly homogenous poultry manure and pressmud.

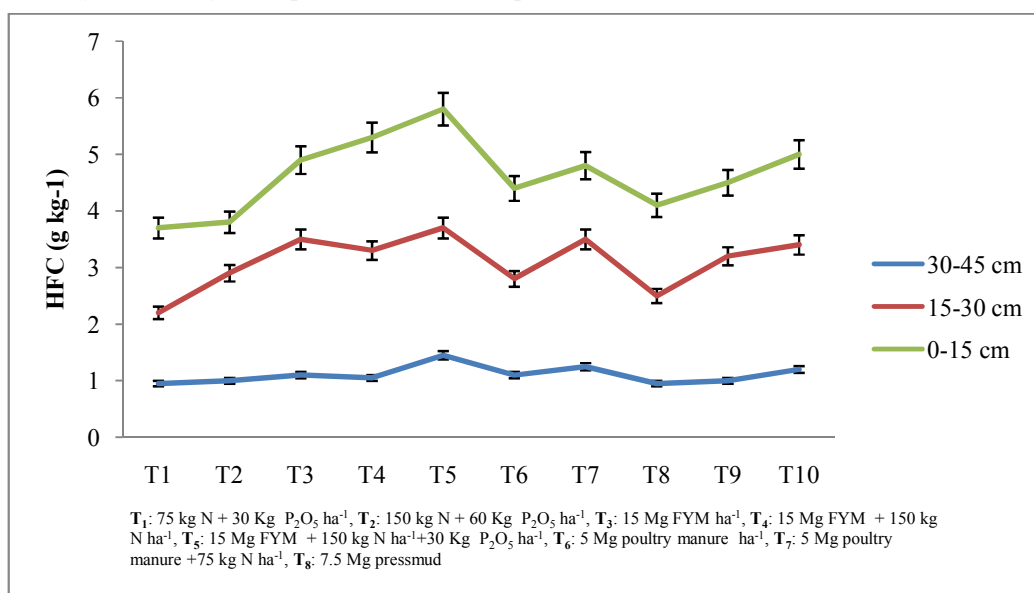


Fig. 6: Long- term effect of various combinations of organic manures and fertilizers on HFC at different soil depths

There was significant relationship between HFC and LFC ($R^2 = 0.90$) followed by with MBC ($R^2 = 0.82$), DOC ($R^2 = 0.73$) and organic C ($R^2 = 0.73$) in surface soil. LFC was positively correlated with LFC/HFC ratio. The basic idea is that soil minerals can randomly adsorb LFC and further form HFC until HFC has reached its saturation state. This interaction between soil minerals and LFC may be regarded as an adsorption and desorption processes. In this study, the relationship between LFC and HFC is not the same with inorganic and organic fertilizer treatments but it has been significantly correlated each other, implying that the relationship between LFC and HFC may change due to use of different organic manures (FYM, Pressmud and Poultry manure) even for the same soil. These results corroborate with the finding of Mahapatra *et al.* (2007) and Lu and Yin, (2006).

5.9. Nitrogen Fractions

Organic N fractions in organic manures (FYM, Poultry manure and Pressmud) are composed mainly unstable forms that are readily mineralizable and stable forms (acid insoluble-N, hydrolysable $\text{NH}_3\text{-N}$, amino acid-N, amino sugar-N, hydrolysable unknown-N and total hydrolysable-N) understanding effect of organic manures on the interplay between different form of organic N is a prerequisite for managing N inputs in a given soil.

5.9.1. Amino acid-N

Sowden *et al.* (1977) reported that amino acid composition in soil microbial biomass and it indicates that in soils microbes play a major role in the synthesis of proteins, peptides, and amino acids from plant and animal residues. Application of organic manures (FYM, pressmud and poultry manure) alone or along with N or NP fertilizers significantly increased amino acid-N over the NP fertilizers treatment (Table 12, 13 and 14 and Fig. 7). The contents of amino acid-N was higher by 162.7, 160.6 and 156.9 % in the FYM, pressmud and poultry manure amended treatments, respectively, than half of recommended doses of NP fertilizers. The variable increase in amino acid-N among different manures can be attributed to the variations in amount and composition of organic manures added to soil. Application of FYM resulted into highest amount of amino acid N followed by pressmud and poultry manure. Fertilizer N applied had a stronger effect upon the amino acid-N content of soil than the increased application of manures. Increased amounts of NP fertilizer and possibly higher N contents in crop residues did not cause a significant rise in the amino acid-N contents in top soil. Because amino acids are essential components of both organic manures and their humic substances, the hypothesis has been formulated that the protein and amino acid turnover in the soil has a decisive influence on the level of soil organic matter (Scheller, 1996). The effect of different treatments on amino acid-N of sub-surface soil was almost similar to that trend as observed in surface soil, but the increase was less as compared to surface soil. The amino acid-N decreased with increase in soil depths. Application of chemical fertilizers alone or their combined use with organic manures significantly increased all the forms of N except

unidentified hydrolysable-N over control or initial status and among the various N fractions, amino acid-N, was dominant N fraction (Sihag *et al.*, 2005).

The amino acid-N showed highly significant relationship with hydrolysable-N ($R^2 = 0.98$), hydrolysable unknown-N ($R^2 = 0.98$), acid insoluble-N ($R^2 = 0.97$), amino sugar-N ($R^2 = 0.85$) and ammonia-N ($R^2 = 0.81$). There was significant relationship between amino acid-N and N content of wheat ($R^2 = 0.94$). Among the most important fractions, amino acid-N, amino sugar-N, and ammonia-N were found to be most important fractions contributing to N uptake of rice and wheat crops (Sekhon *et al.*, 2011). A similar correlation reported by Ju *et al.* (2004) that amino acid-N content is significantly correlated with ammonia-N, available N, total N content and hydrolysable-N content.

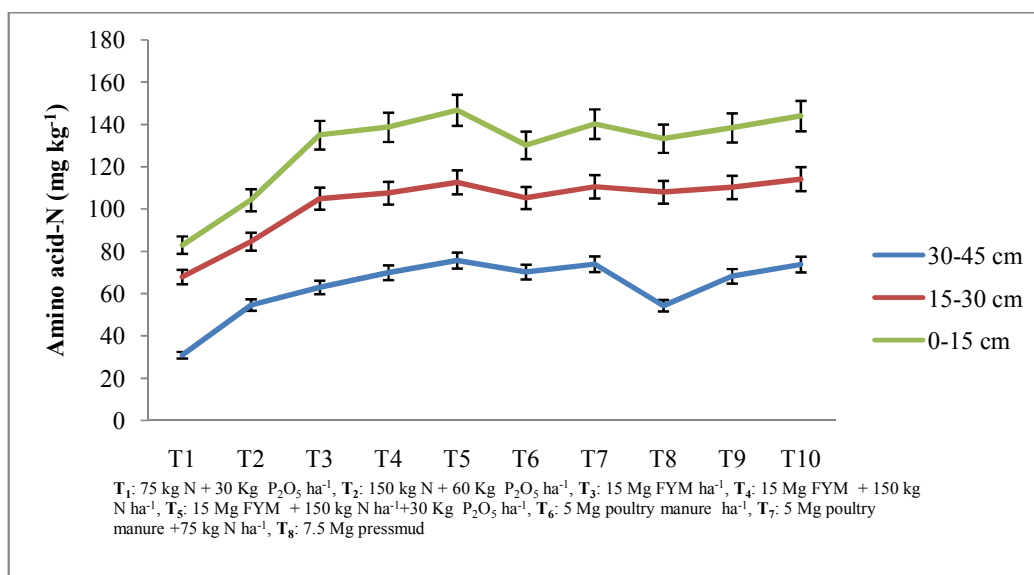


Fig. 7: Long- term effect of various combinations of organic manures and fertilizers on amino acid-N at different soil depths

5.9.2. Amino sugar-N

The most prominent amino sugars detected in soils are D-glucosamine and D-galactosamine, with the former occurring in greater amounts (Stevenson 1994). Amino sugars represent a major constituent of microbial cell walls (e.g. chitin, peptidoglycan) and they are present in large quantities in soil organic matter. Application of NP fertilizers in conjunction with organic manures (FYM, pressmud and poultry manure) resulted in significant increased in amino sugar-N in soil over the application of NP fertilizers alone (Table 12, 13, 14 and Fig. 8). Among the different organic manures treatments, highest increase in amino sugar-N was noticed with poultry manure followed by FYM and pressmud. Amino sugars, as cell wall components of microorganisms, are rapidly formed as by-products of microbial growth and decomposition, making up a significant portion of more resistant nutrient reserves (Liang *et al.*, 2007). Wang *et al.* (1993) reported that residual N in inorganic fertilizer would mainly

transform into hydrolysable unknown N and amino acid N, whereas residual N in organic fertilizer would chiefly transform into amino sugar N. The above results indicated that contribution of more amino sugar-N from organic manures than the NP fertilizers. The amino sugar-N content in surface soil in recommended doses of NP fertilizer along with FYM, pressmud and poultry manures was 152.4, 130.2 and 140.2 %, respectively, higher than half doses of NP fertilizers. Amino sugars are one of important indicators to microbial, turnover of biomass and organic manures and their heterogeneity so that large amounts of amino sugars are stabilized in soil. This results support by Lydia *et al.* (2012) that amino sugars are important microbial C and N sources and drivers of C and N cycling in soils. The results corroborate the finding of Glaser *et al.*, 2004; Liang *et al.*, 2007; Wang *et al.*, 2010.

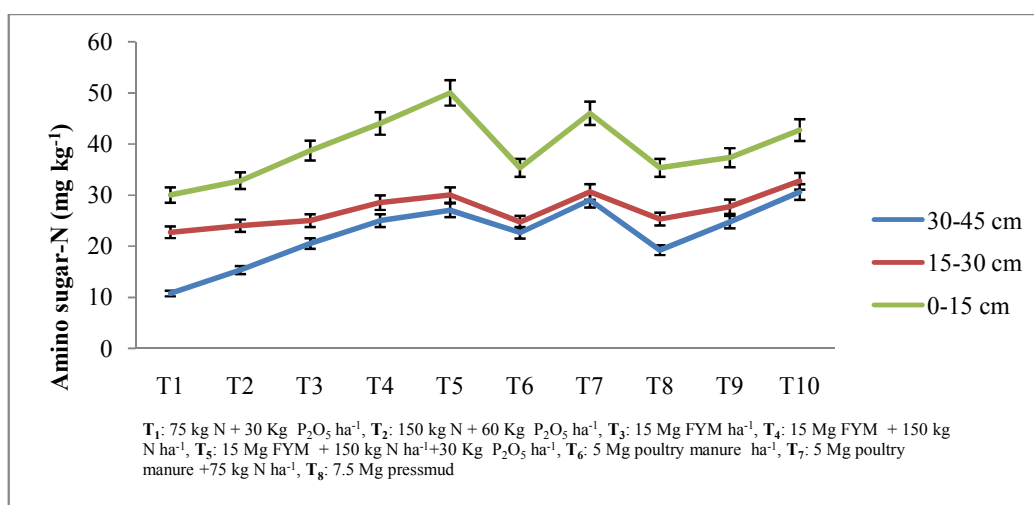


Fig. 8: Long- term effect of various combinations of organic manures and fertilizers on amino sugar-N at different soil depths

The amino sugar-N was highly significantly correlated with hydrolysable unknown-N ($R^2 = 0.93$), followed by hydrolysable-N ($R^2 = 0.83$), acid insoluble-N ($R^2 = 0.84$) and ammonia-N ($R^2 = 0.68$). A significant relationship was also observed between amino sugar-N and N content of wheat ($R^2 = 0.93$). Based on the amount of amino sugar polymers in soil (e.g. chitin, peptidoglycan), large amounts of free amino sugars (monomer units) must pass through the other N fractions each year during microbial turnover of organic manures. Hence, it could be concluded that the use of organic manures represented a sound approach to significantly increased the ammonia-N, non-hydrolysable N, amino sugar N, and hydrolysable unknown N. This was in accordance with the result of the study of Ju *et al.* (2004).

5.9.3. Ammonia-N

Microbes that consume the organic compounds excrete ammonium-N. The ammonium regardless of whether it comes directly from the manure or from microbes consuming the organic compounds. The ammonium-N may be used by plants immediately, converted to ammonia-N and lost to the air or converted to nitrate which will be used by

plants or microbes. Among the different treatments where organic manures were applied with the recommended dose of NP fertilizers, application of pressmud_{7.5}N₁₅₀P₃₀ (143.0 mg kg⁻¹) showed highest ammonia-N followed by FYM₁₅N₁₅₀P₃₀ (138.0 mg kg⁻¹) and poultry manure₅N₁₅₀P₃₀ (133.0 mg kg⁻¹) in surface soil. Similar type of trend was also observed in sub-surface soil (15-30 and 30-45 cm), but the increase was less pronounced as compared to surface soil (Table 12, 13, 14 and Fig. 9). Application of pressmud along with N or NP fertilizers recorded 1.0 fold more over N₁₅₀P₆₀. This shows that pressmud contributing more ammonia-N to soil due to more content N and also narrow C: N ratio. The effect of pressmud treatment was more pronounced in increasing ammonia-N compared with FYM or green manure treatment (Sekhon *et al.*, 2011). The ammonia-N content in surface soil increased to about 10.6, 6.4 and 14.4 % with the application of FYM₁₅N₁₅₀P₃₀, pressmud_{7.5}N₁₅₀P₃₀ and poultry manure₅N₁₅₀P₃₀ over N₁₅₀P₃₀ fertilizers applied alone, respectively. The ammonia-N of sub-surface soil showed the same trend as was observed in surface soil, but the increase was less pronounced compared to surface soil. Appel and Mengel, (1992) found that the soil organic N pool does not indicate that the fraction is not turning over and external supplying N to plants. Our results also indicated that organic manures amendment applied alone or applied in conjunction applied in with NP fertilizers increases ammonia-N content in soil. The (lignin + polyphenols) and N ratio had the highest influence on release of N fractions. Addition of organic manures increases the lignin and polyphenols into soil and it helps to substrates for soil microbes. The transition from N immobilization in the form to organic N fractions is regulated through the soil microbial biomass by the ratio of available C to N substrates (Handayanto *et al.*, 1995).

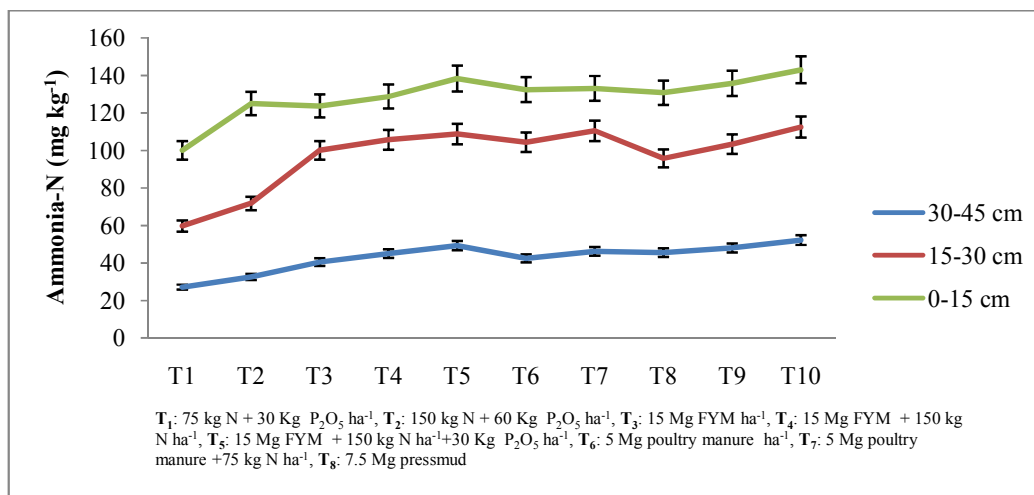


Fig. 9: Long- term effect of various combinations of organic manures and fertilizers on ammonia-N at different soil depths

The ammonia-N was significantly correlated with amino acid-N ($R^2=0.89$), hydrolysable-N ($R^2=0.88$), acid insoluble-N ($R^2=0.87$) and hydrolysable unknown-N ($R^2=0.77$). There was significant relationship between ammonia-N and N content of wheat (R^2

= 0.86). Similar results were also reported by Sądej and Przekwas, (2008) that an increase in the levels of organic N fractions, i.e. N contained in amino sugars and amino acids as well as ammonia N from decomposition of amides, amino sugars and amino acids, was conditioned primarily on the application of organic fertilizers, particularly manures.

5.9.4. Hydrolysable-N

Hydrolysable organic N in soil solution is found in mobile water flowing through pores, cracks and channels, and in immobile water within pores in soil peds. The role of hydrolysable organic N in N cycling and there is a blockage of N losses processes from soil and subsequent ammonification and nitrification of organic N in soil N supply to the crops. A significant increase in hydrolysable-N was observed due to the application of organic manures (FYM, poultry manure, pressmud) over NP fertilizers alone (Table 12, 13, 14 and Fig. 10). Among the different treatments, highest hydrolysable-N in surface soil was recorded with combined application of FYM along with NP fertilizers followed by pressmud and poultry manure. The amounts of hydrolysable-N were lower in sub-surface soil (15-30 and 30-45 cm) than in surface soil, regardless of treatments. The ammonia-N content in NP fertilizer along with FYM, pressmud and poultry manures were 113.2, 109.8 and 103.1 %, respectively, higher half of recommended dose of NP fertilizers in surface soil. Hydrolysable organic N from organic manures latches dominantly composed of decay-resistant organic acids formed by partial decomposition of plant, microbial and animal tissues (Currie *et al.*, 1996). Similar information was accounted by Singh *et al.* (2001) found a decline in total hydrolysable N with the application of inorganic fertilizers as compared to organic amendments in a rice-wheat system and suggested that such a practice may not sustain soil productivity over a longer period.

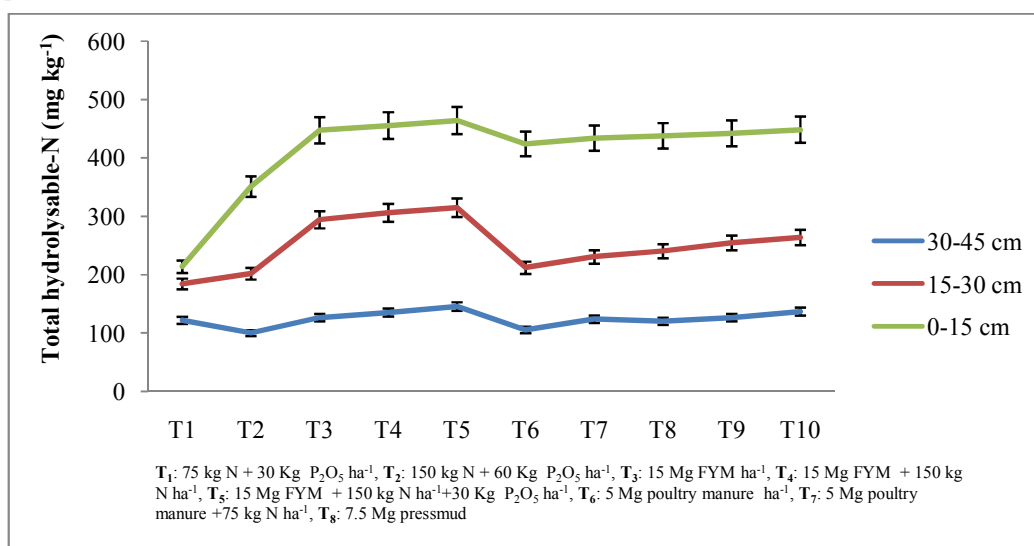


Fig. 10: Long- term effect of various combinations of organic manures and fertilizers on total hydrolysable-N at different soil depths

The hydrolysable-N was highly significantly correlated with amino acid-N ($R^2 = 0.98$), acid insoluble ($R^2 = 0.96$), hydrolysable unknown-N ($R^2 = 0.94$), ammonia ($R^2 = 0.88$) and amino sugar-N ($R^2 = 0.83$). The results also indicated that amino acid N and unidentified N were the main compositions of hydrolyzable acid N, the second was ammonical N and the last was amino sugar N (Zhang *et al.*, 2010). Similar correlations between hydrolysable-N and other N fraction were also observed by Yu *et al.* (2002) and Jones *et al.* (2004) indicated two functional hydrolysable-N, a fast cycling, labile pool of low molecular weight (such as amino acids and peptides) and a more slowly cycling, stable pool of high molecular weight (such as polyphenol bound N, proteins, and polyamines) and other N fractions. There was a significant relationship between amino acid-N and N content of wheat ($R^2 = 0.97$). Hydrolysable-N has low molecular weight of hydrolysable-N may be a direct regulator of the rate of nitrification and ammonification in soil because it provides the initial substrate for N transformation pathways and it leads to more plants available N in soil. Similar findings are accordance with Jones and Kielland, 2002 and Jones *et al.*, 2004.

5.9.5. Total Hydrolysable Unknown-N

Schnitzer *et al.* (1983) developed a chromatographic separation procedure that could separate unidentified N from the known. Several fractions were prepared from the humic and fulvic acids which contained between 97.5% and 98.6% unidentified N. Application of organic manures in conjunction with fertilizers significantly increased the concentration of total hydrolysable unknown-N over fertilizers applied alone both in surface and sub-surface soils (Table 12, 13, 14 and Fig. 11). The highest total hydrolysable unknown-N was recorded in FYM₁₅N₁₅₀P₃₀ (164.7 mg kg⁻¹) followed by pressmud₅N₁₅₀P₃₀ (159.3 mg kg⁻¹) and poultry manure₅N₁₅₀P₃₀ (154.4 mg kg⁻¹). The increase in amounts of total hydrolysable unknown-N due to N₁₅₀P₃₀ fertilizers along with FYM, pressmud and poultry manure treatments, respectively, was about 156.9, 151.7 and 147.0 % higher than the N₇₅P₃₀ fertilizers in surface soil. The effects of different treatments on hydrolysable unknown-N of sub-surface were almost similar to that observed in surface soil, but the increase was less as compared to surface soil. The hydrolysable-N decreased with increase in soil depth. This indicates that the movement of bulky organic manures less into the sub-surface leads to less accumulations of total hydrolysable unknown-N. This might be due to carry-over effect of continuous use of organic sources and accumulation of organic residue which in turn contributed higher build up in the soil and FYM is bulky in nature and less rapid decomposition rate so that it contributes more in total hydrolysable unknown-N in the soil (Sihag *et al.*, 2005).

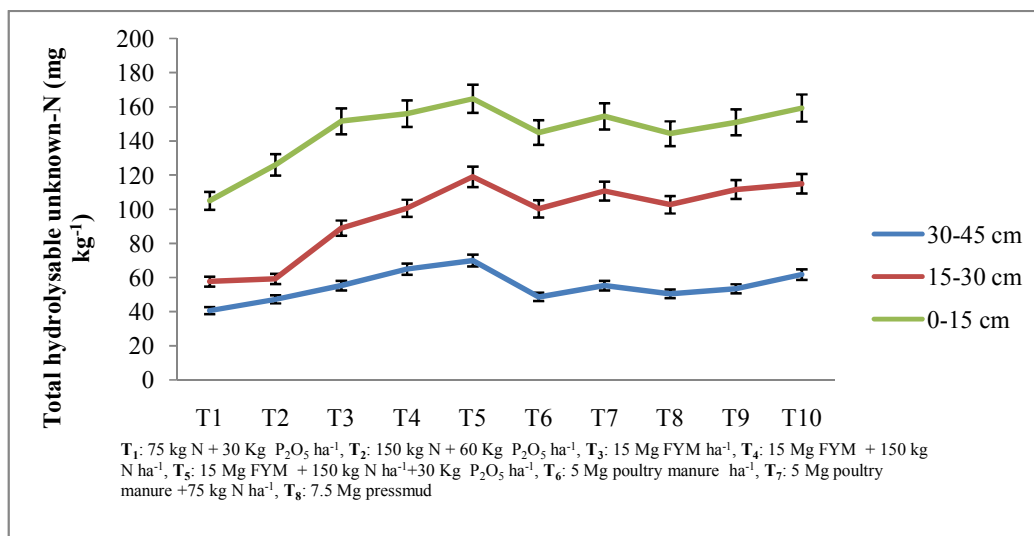


Fig. 11: Long- term effect of various combinations of organic manures and fertilizers on total hydrolysable unknown-N at different soil depths

The total hydrolysable unknown-N was highly significant correlated with amino acid-N ($R^2 = 0.98$), amino sugar-N ($R^2 = 0.93$), hydrolysable-N ($R^2 = 0.94$), acid insoluble-N ($R^2 = 0.96$). There was a significant relationship between amino acid-N and N content of wheat ($R^2 = 0.97$). Similar to combined application of manures with fertilizers, N application also significantly increased total N, acid hydrolysable N and hydrolysable N over control. N fertilizer significantly increased ammonium N, amino sugar N, amino acid N and hydrolysable unknown-N (Ju *et al.*, 2008). Similar findings are accordance with Jones and Kielland, 2002; Jones *et al.*, 2004 and Zhang *et al.*, 2010.

5.9.6. Acid insoluble-N

Manure significantly increased the percent of acid insoluble-N but not humin-N present as amino acid and amino sugar-N, but increased amino acids and the amino sugars in the humin hydrolysate (Campbell *et al.*, 1999). Highest total hydrolysable unknown-N was recorded in FYM₁₅N₁₅₀P₃₀ (164.7 mg kg⁻¹) followed by pressmud₅N₁₅₀P₃₀ (159.3 mg kg⁻¹) and poultry manure₅N₁₅₀P₃₀ (154.4 mg kg⁻¹). Soil hydrolysable-N was lower in sub-surface soil than in surface soil, regardless of treatments. This means that the effect of different type's manures was stronger than the effect of the amount of manures application (Table 12, 13, 14 and Fig. 12). The increase in amounts of total hydrolysable unknown-N due to N₁₅₀P₃₀ fertilizers along with FYM, pressmud and poultry manure treatments, respectively, was about 156.9, 151.7 and 147.0 % higher than the N₇₅P₃₀ fertilizers in surface soil. This indicates that the difference was caused not only by manures supply, but also by an intensified decay of organic matter in the mineral fertilizer NP treatment as a consequence of inorganic NP affecting microbial biomass metabolism. The priming effect of mineral fertilizer NP supports this interpretation. The higher acid insoluble-N content in the manure treatment with NP

fertilizers compared with manure alone can be understood as a modification of organic N metabolism towards anabolism by microorganisms in soil. Similar findings were also reported by Campbell *et al.* (1999).

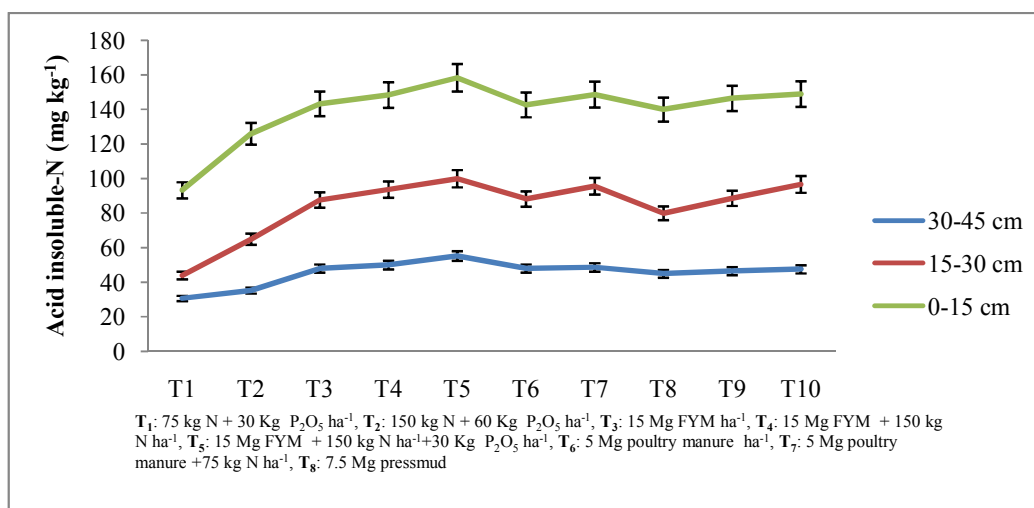


Fig. 12: Long- term effect of various combinations of organic manures and fertilizers on acid insoluble-N at different soil depths

The acid insoluble-N was significant correlated with amino acid-N ($R^2 = 0.97$), hydrolysable-N ($R^2 = 0.96$), hydrolysable unknown-N ($R^2 = 0.96$) and amino sugar-N ($R^2 = 0.87$) and. There was a significant relationship between acid insoluble-N and N content of wheat ($R^2 = 0.95$). There was positive correlated relationship between different N fractions with application of NPK and manures and it increased soil fertility and enhance the N supplying capability of paddy soils (Peng *et al.*, 2008). Similar results also reported by Liang *et al.* (2011) that application of manure with chemical fertilizer significantly increased the contents of all forms of N, especially the content of amino acid N.

5.10. Periodic changes of organic C, available N, P and K during wheat growth

5.10.1. Organic C

The organic C content of soil increased significantly with application of organic manures alone or over application of NP fertilizers alone (Table 15 and Fig. 13). The organic C content of soil increased up to 48 days in all the treatments (organic manures alone or along with fertilizers) except the no-manure plots where increase was very small. After 48 days of manures application, the organic C content decreased in all different manures (FYM, Pressmud and poultry manure) applied alone or with fertilizers. The rates of C mineralization of the microbial biomass were closely related to total soil organic C contents but have been positively influenced by the NPK fertilization (Hopkins *et al.*, 2011). Among the different manures, the treatment received FYM recorded higher organic C compared to pressmud and poultry manure throughout wheat growing period. Golakiya *et al.* (2006) reported that during the year 1980 and 2000, the FYM at 25 Mg ha⁻¹ treatment improved SOC content (0.45 and

0.66 %) as compared to that of NP (0.36 and 0.60 %), $\frac{1}{2}$ NP+K (0.36 and 0.54 %), $\frac{1}{2}$ NP (0.30 and 0.40 %) and control (0.30 and 0.36 %). The periodical changes of soil organic C mainly depending on the quantity and quality of applied organic manures and soil microbial biomass. Soil microbial population density is well recognized as a sensitive indicator in both SOC and biological properties of soil quality and soil health. Soil microorganisms have the ability to degrade organic compounds and modify inorganic products, contributing in particular to the mineralization of nutrients (Ley and Schmidt, 2002). A larger proportion of the higher C content or C sequestration in FYM treated plots might have resulted from slower decomposition rate than other organic manures. The higher C sequestration in FYM₁₅N₁₅₀P₃₀ treated plots have greater implications in semi-arid subtropical environment like north-western India by offsetting the adverse effects of green house gas emissions from pearl millet-wheat cropping sequences. In the present study it was observed that all the long-term imbalanced fertilizer treatments were not encouraged for C sequestration rate and efficiency in soils. The carbon sequestration rate showed a negative trends with negative magnitude (-18.8 kg ha⁻¹yr⁻¹) in 75 kg N + 30 Kg P₂O₅ ha⁻¹ for 16 years whereas it was 387.5 kg ha⁻¹yr⁻¹ was with 15 Mg FYM ha⁻¹. Taking into consideration the combined application fertilizer with FYM, poultry manure and pressmud added during the period of 16 years of C sequestration rate of soil was 456.3, 118.8 and 225.0 kg ha⁻¹yr⁻¹, respectively. The increase C sequestration rate of soil with the addition of organic manure plus NP fertilizers might be due to better crop growth with concomitant higher roots biomass generation and higher return of left over surface plant residues. For a particular agro ecosystem when vegetation, mineralogical compositions, the depth of solum, soil drainage, the availability of water and air, and the temperature of the environment are similar and only to improve the management practices which will allow crop yields to be maintained and soil carbon reserves to be increased (Carter and Hall, 1995; Lal and Kimble, 1997; Lal, 1997). It is evident that after 120 days of organic manures application alone or in combination with N or NP fertilizers, the organic C content remained higher than the initial values. Similar types of finding were also stated by Lal, 2005.

5.10.2. Available N

The dynamics of the availability of N in the soils amended with different organic manures were determined. Estimating the amount of mineral N available from manures during the growing season of wheat is further complicated by the presence of both applied mineral N and organic N fractions from applied organic manures. Ammonium is subject both to rapid nitrification to NO₃ while organic N requires an initial mineralization step to be utilized by plants. Because both nitrification and mineralization are microbially mediated in soil, they are influenced by substrate characteristics of different organic manures. The available N content of the soil during wheat growth increased significantly with application of manures (FYM, pressmud and poultry manure) (Table 16 and Fig. 13). The available N content of the soil increased significantly up to 24 days and decreased thereafter in all

manures treatment. The general trend was that N in the soil decreased trends was observed after the tillering and panicle stages. The results from the field seemed to be supported by the data from the experimental plots. The inorganic fertilizer N showed the highest peak of available at 48 days after sowing of wheat. This means that before 24 days after the application of inorganic fertilizer N, the N is already available for plant use. But decrease of N from the inorganic fertilizer N started after 24 days after the peak of N release into the soils. After 24 days of sowing of wheat, organic manures were low in N pools or may be immobilized and tied up by the microorganisms so N might be not available for plant uptake. The rate at which soil organic N is released is a function of the activity of microorganisms. The C: N ratio of the organic amendments largely regulated the accumulation or disappearance of nitrate in soil. Among the different manures, pressmud have narrow C: N ratio with high N content and followed by poultry manure and FYM. Mineralized N increased as days of incorporation of organic manure became longer than inorganic fertilizers. This is consistent with Javier and Tabien, 2003 concluded that the highest N was at 20 days after incorporation of poultry manure and 15 days after incorporation of inorganic fertilizer. This might be indicated that those 24 days to estimate maximum potential of soil N mineralization supported by our hypothesis. Total C, total N were found that 24-day incubation were found to have the strongest correlations with the 41-week, long-term incubation (Schomberg *et al.*, 2009). The rate of release decrease rapidly with time after the first 24 days and it also depends upon type and amount of crop residues recently added to soil are important factors determine N release. It also depends on the homogeneity of organic manures, if higher heterogeneity of organic manure like FYM takes more time to decomposition compared to pressmud and poultry. So that release of nutrients more consistent with the FYM than other organic manures, it all depends on C:N ratio of manures. Stockdale and Rees, (1995) showed that fresh poultry manure released N very quickly, compared to FYM, sludge and press mud where initial N release was slower but sustained over a longer period of time. A wide range of N compounds can be used by soil microorganisms, but availability of C to the soil microbial biomass is an important determinant of the dynamics of soil N transformations (Burger and Jackson, 2003). The available N content of the soil with application of half doses and full dose of NP fertilizers plot was less compared to manures. The immobilization of inorganic N is generally increased with increasing C availability. However, microbes may be N limited if C is in excess supply, leading to variations in the abundance and proportions of fungi and bacteria and thus differences in soil N cycling (Boyle *et al.*, 2008). Application of NP fertilizers in conjunction with organic manures (FYM, pressmud and poultry manure) resulted in significant increased in available N in soil over the application of NP fertilizers applied alone. The results of field experiment have shown that the transformation and the plant availability of N in soil were greatly influenced by the pressmud application.

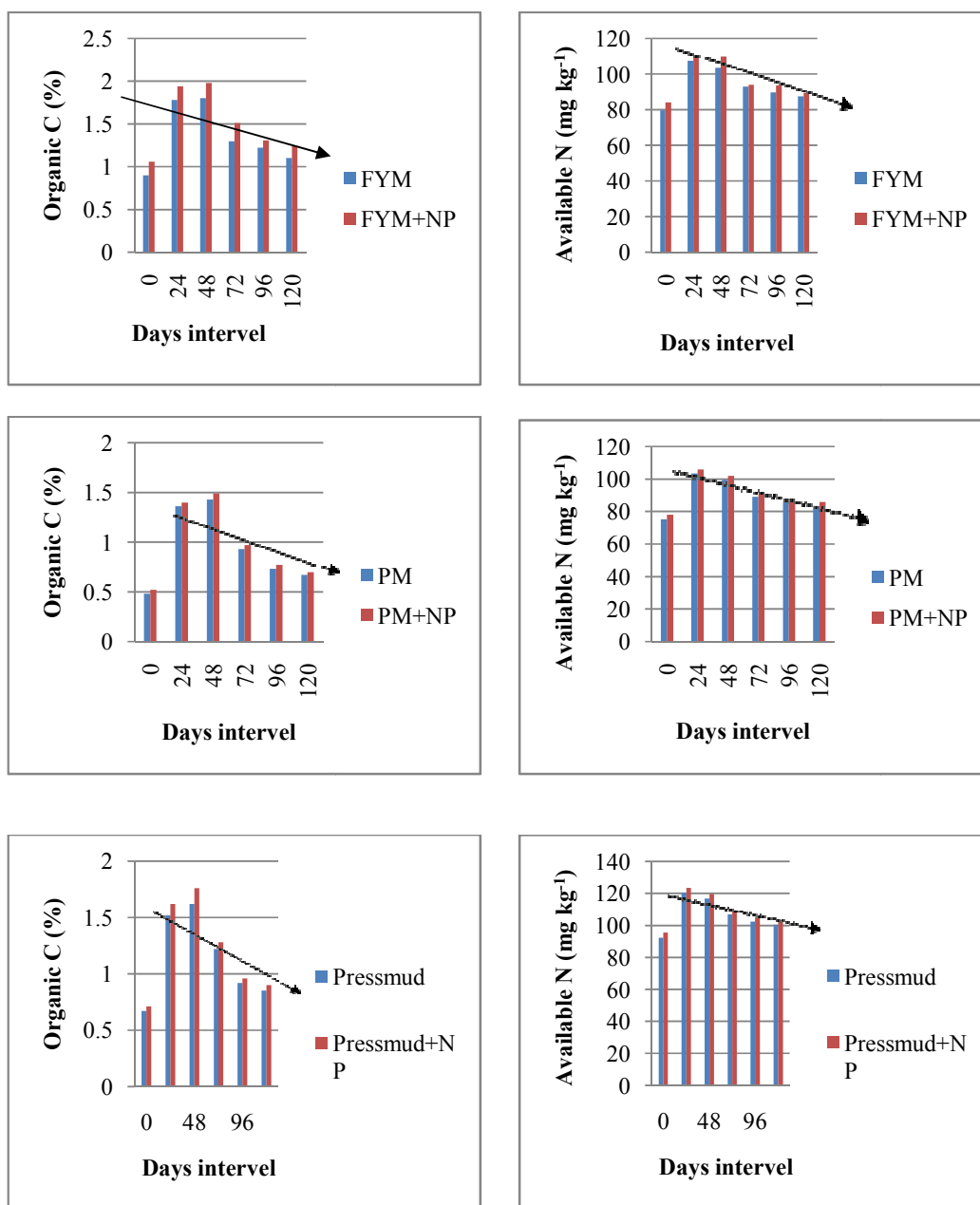


Fig. 13: Long-term effect of organic manures on periodical dynamics of organic C and available N under pearl millet –wheat cropping sequence

Application 7.5 Mg kg⁻¹ pressmud added large amount of N and increased the ammonification and nitrification, resulting in higher concentration of available N in soil. This may be attributed to highest N content in pressmud and narrow C: N ratio. Similar hypotheses stated by Kader *et al.* (2010) that the presumed stable chemical soil organic C fraction was found to be a relevant predictor indicating that this fraction contains bio-available N. Increase in the N availability in soil due to pressmud application was reported by (Baskar *et al.*, 2001). Account of available N and organic C pools reported that soils which received organic matter

inputs on a regular basis generally had greater labile C pools and greater N supplying ability than soils which received only mineral amendments (Gunapala and Scow, 1998).

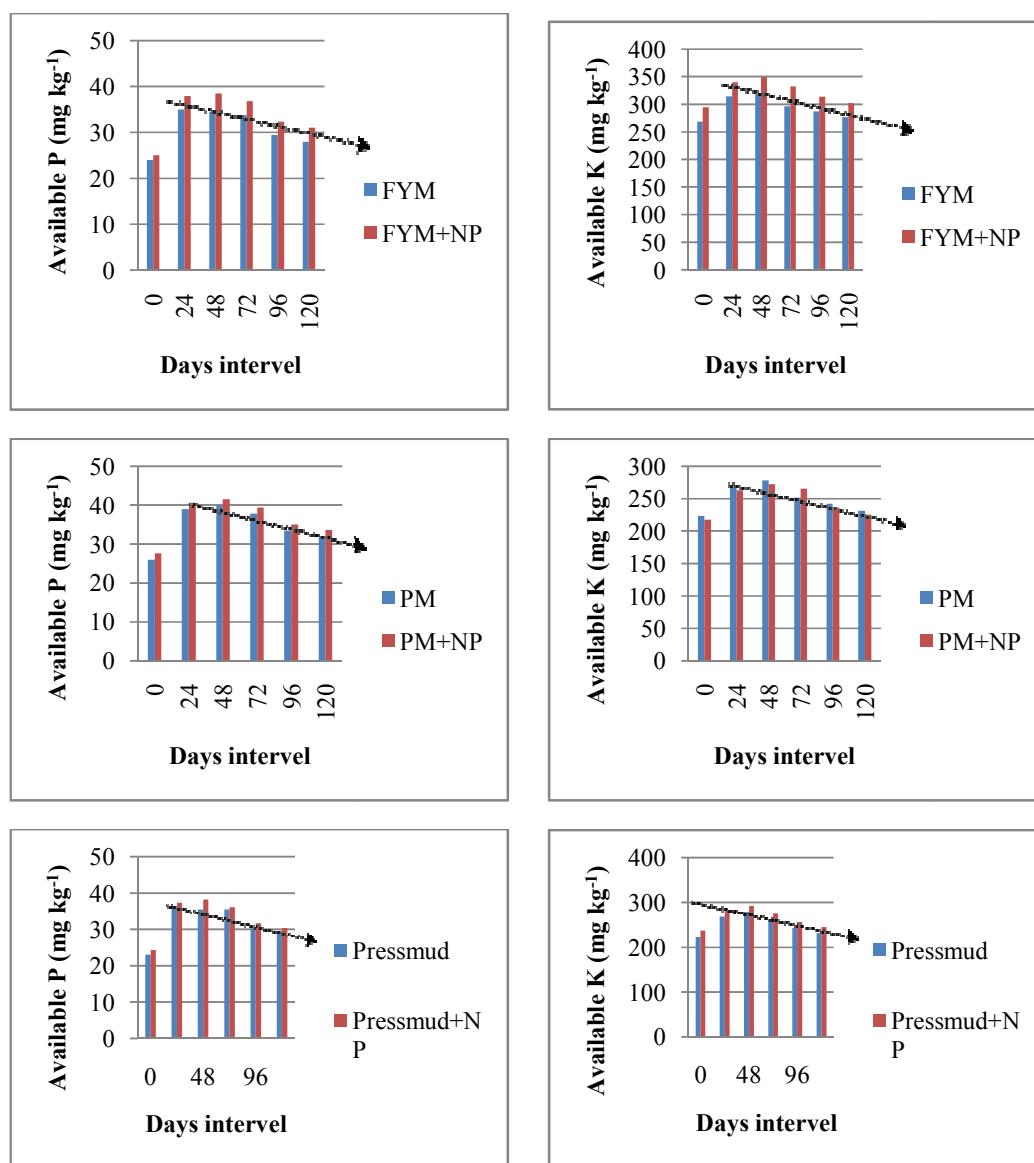


Fig. 14: Long-term effect of organic manures on periodical dynamics of available P and K under pearl millet –wheat cropping sequence

5.10.3. Available P

The available P content of the soil during wheat growth increased significantly with application of manures (FYM, pressmud and poultry manure) (Table 17 and Fig. 14). The available P content of the soil increased significantly up to 48 days and decreased thereafter in all manures treatments. Organic manures with low C: P ratio is usually considered to be more easily decomposable than those with high C: P ratio. Among the different manures where treatment receiving poultry manure was recorded higher available P followed by FYM and pressmud throughout wheat growing period. Application of NP fertilizers in conjunction with

organic manures (FYM, pressmud and poultry manure) resulted in significant increased in available P in soil over the application of NP fertilizers alone. Poultry manure showed superiority over other manures treatments in improving available P contents of soil. This effect has been attributed in part to increased CO₂ production and humic collides form a protective coating over base and insoluble phosphate salts and also over sequioxides, and thereby curtail the fixation of any phosphate that may be made available. Addition of manures and fertilizers to soils resulted in an increase in soluble P but this P is derived largely from organic materials and not from native soil P. Kaleem *et al.* (2007) reported that supply of NP fertilizers to crops and greater decomposition rate of organic manures resulted in greater availability of nutrients to crop growing period. Organic-phosphate is constantly being synthesized in soils by microorganisms that assimilate small amounts of inorganic P, microorganisms make these compounds available chiefly by secretion of numerous organic and inorganic acids that can under some conditions dissolve small amounts of phosphates and it made for available P.

5.10.4. Available K

The available K content of soil increased significantly with application of organic manures over inorganic fertilizers alone during wheat growing period (Table 18 and Fig. 14). The available K content of soil increased up to 48 days at all the treatment except in only NP fertilized plots where available K increase was very small. After 48 days of manures application, the available K content decreased in all the treatments. Among the different manures treatments the plots received FYM recorded higher available K compared to pressmud and poultry manure throughout the wheat growing period. Application of NP fertilizers in conjunction with organic manures (FYM, pressmud and poultry manure) resulted in significant increased in available K in soil over the application of NP fertilizers alone. Application of FYM₁₅N₁₅₀P₃₀ recorded highest available K throughout wheat growing period. The mineralization of manures not only depends on the quality of organic components, but also on amount and composition of manures. Organic substances are known to hold certain metallic cation very strongly, it is usually stated that organic substances holds di and trivalent metabolic cations much more firmly for longer time than monovalant so that it made available K in soil solution. The tenacity with which organic substance hold K, thereby exchange complex (available form of K) it does decrease loss by leaching and prevents inorganic fixation. Furthermore, plant residues that are high in K also serve as excellent; readily available due to addition of extra inorganic N induces the more biomass crop return to the soil. Despite annual K additions at recommended rates through fertilizers and at more than the recommended rates through organic manures, available K content decreased due to continuous cropping at five locations reported by Yadav *et al.* (2000). These finding are in agreement with the observation of Varalakshmi *et al.*, (2005). Similar results were reported by

Bulluck *et al.* (2002) and Edmeades, (2003) who reported that increased K availability with organic amendments could be due to the release of K from organic material and lower fixation and leaching losses.

5.11. Soil pH, EC, Organic C, available N, P, and K and Micronutrients

5.11.1. Soil pH

Addition of organic manures (FYM, poultry manure, pressmud) alone or in combination with N or NP fertilizer for 16 years decrease the soil pH over the initial value (Table 19), due to the formation of organic acids during decomposition of organic matter. The decrease in soil pH with addition of FYM has also been reported by Laxminarayana and Patiram, 2005; Singh *et al.* 2012). The decrease in pH was more with the addition of FYM compared to poultry manure and pressmud. Highest soil pH (7.87) was observed with the application of NP fertilizers. Several researcher (Marschner, 1995; Walker *et al.*, 2004) observed significant changes in soil pH on addition of organic manure owing to organic matter oxidation and release of CO₂ in the soil. Soil pH was lower in sub-surface soil than in surface soil, irrespective of the treatments, it might be due to the leaching of soluble salts from surface soil. The effect of different treatments on pH of sub-surface soils was non-significant and lowest pH was recorded in FYM treated plots. Soil pH is greatly influenced by addition of organic matter through different organic amendments and change in pH varies with the nature of OM (Walker *et al.*, 2004). Similar results were reported by Bulluck *et al.* (2002). Walker *et al.* (2004) reported significant changes in soil pH on addition of organic manure owing to organic matter oxidation and release of CO₂ in the soil.

5.11.2. Soil EC

Continuous application of organic manures for 16 years (Table 19) increased the EC of the soil. However, an increase in soil EC with the continuous application of NP fertilizers over the initial value was marginal. A significant increase in EC of the soil was observed with the combined application of organic manures plus NP fertilizers over application of NP fertilizers alone, similar to finding of Balaguraviah *et al.*, (2005). Continuous application of organic manures alone or in conjunction with NP fertilizers for 10 years decreased the soil pH and reverse trend was observed in case of EC (Antil & Mandeep, 2007). The proportionate increase in EC was more with the addition of FYM than poultry manure and pressmud. It might be due to the supply of higher quantity of salts through FYM compared to pressmud and poultry manure. Soil EC was higher in surface soil than in sub-surface soil. Similar results were reported by Chang *et al.* (1991) and Eghball, (2002).

5.11.3. Soil Organic C

Addition of organic manures increases the organic matter contents of soils as compared to control and significant amount of organic matter was added, which increased the content of organic C (Agbede *et al.*, 2008). Organic C changes were observed in surface soil,

whereas differences were observed in sub-surface soil. The increases in organic C after due to addition of organic manures alone or with NP fertilizers for 16 years of pearl millet-wheat cropping sequences are given in Table 19. An increase organic C content was observed with the application of organic manure alone or with NP fertilizers over NP fertilizers for 16 years it may be due to addition of organic matter through organic manures. The highest build-up in soil organic C was observed with the addition of FYM followed by pressmud and poultry, which might be due to variation in their amounts applied, nutrient composition and their release pattern into soil. Increase or decrease in soil organic C was marginal from its initial value with the continuous application of NP fertilizers. However, recommended dose of NP fertilizers were tended to have more organic C in soil compared to half recommended dose of NP fertilizers. The increase in organic C content of soil with the addition of organic manure plus NP fertilizers may be due to better crop growth with concomitant higher roots biomass generation and higher return of left over surface plant residues. Golakiya *et al.*, (2006) reported that during the year 1980 and 2000, the FYM at 25 Mg ha⁻¹ treatment improved SOC content (0.45 and 0.66 %) as compared to that of NP (0.36 and 0.60 %), ½ NP+K (0.36 and 0.54 %), ½ NP (0.30 and 0.40 %) and control (0.30 and 0.36 %). Kukal *et al.* (2009) observed a higher C sequestration in a 33 year old rice–wheat system due to application of FYM. It may be postulated that more production of roots and their subsequent decomposition increased organic C content of soil (Narwal and Antil, 2005). The SOC concentration decreased with increase in soil depth. The addition of FYM, pressmud and poultry manure along with NP fertilizers resulted in significant increase in organic C even at lower depths of soil. Kanchikerimath and Singh, (2001) also found that inorganic fertilizers plus organic material increased the SOC content of the soil. The reasons for the higher SOC in manure soils the crop rooting depth between organic manure and inorganic fertilizer soils differ. The organic manure soils can be favorable for the growth of roots into deeper layers due to the relatively loose soil and high soil water content. The SOC in organic manure soils can also move to lower depths through earthworm burrows and leaching (Lorenz and Lal, 2005). This suggests that FYM is more effective in building soil C than poultry manures and pressmud, possibly due to the presence of more humified and recalcitrant C forms in FYM compared to pressmud and poultry manure.

The build-up in organic C was not in the proportion of quantity of organic manures applied. Taking into consideration the amount of FYM, poultry manure and pressmud added during the period of 16 years and assuming no loss of C, the organic C content of soil should have been approximately 73152, 14592 and 36480 kg ha⁻¹, respectively, but the overall corresponding increases only 0.62, 0.15 and 0.34 % C (over the initial level) and only about 17.0, 20.6 and 18.6% of added organic C was retained in the soil.

Application of organic amendments as a supplement with NPK not only added organic C in the soil but also increased plant C inputs in the soil through root residue, stubble, rhizodeposition etc. because of an increase in yield. A 20-40 % increase in organic C with continuous use of FYM was also reported by Ruhal and Shukla, (1979). Organic C content in the sub-surface layer of soil showed the same trend as observed in surface soil, but the increase was less pronounced compared to surface soil. Higher content of organic C in surface layer compared to sub-surface layer may be due to accumulation of crop residues in surface layer (Antil and Mandeep, 2007). Sub-soils contain a smaller concentration of C than the corresponding topsoil, generally reflecting root distribution (Carter and Gregorich, 2010). Similar finding reported by Rasool *et al.* (2008) that application of balanced fertilization improved the SOC till 45 cm depth and balanced fertilization results in better plant growth including the root biomass, which might have added to the soil organic C particularly as indicated in the lower layers.

5.11.4. Available N

The available (mineralizable) N content decreased from 98 to 64.5 mg kg⁻¹ due to cropping with N₇₅P₃₀ for 16 years (Table 20) whereas it was 82.6 mg kg⁻¹ was with 15 Mg FYM ha⁻¹. The depletion of available N in soil was less after FYM addition. A significant increase in available N was observed when organic manures were applied in conjunction with N or NP fertilizers over NP fertilizers applied alone. Increase in available N content with the addition of organic manures might be due to the release of N through the decomposition of organic manures (Narwal and Antil, 2005; Antil and Mandeep, 2007). Moreover, it could also be attributed to the greater multiplication of soil microbes, which could convert organically bound N into inorganic form. Among the different organic manures, pressmud registered more increase in available N content of soil compared to FYM and poultry manure. Available N decreased with soil depth in all the treatments. Considering the amount total N added through FYM, poultry manure and pressmud during the period of 16 years of experimentation (approximately 2266, 1632 and 2976 kg N ha⁻¹, respectively), no residual effect was observed. Sixteen years of continuous cultivation of pearl millet-wheat cropping system could not sustain the initial level of N. Besides, a part of the N might have been converted to such forms, which were not extracted in alkaline KMnO₄. Twenty years of continuous application of pearl millet-wheat rotation in sequence with different amounts of FYM fertilizer N could not sustain the initial concentration of N in surface (0-15 cm) soil (Gupta *et al.* 1992)

5.11.5. Available P

Available P content of the soil decreased from 12.6 to 8.9 mg P kg⁻¹ in soil with applying with 75 kg N + 30 Kg P₂O₅ ha⁻¹ for 16 years by growing pearl millet-wheat crops in sequence (Table 20). There is increasing evidence that organic amendments at high rates of application can cause dramatic increases in soil nutrients, particularly N, P and K, leading to

increased leaching of these elements and associated off-site impacts (Amlinger *et al.*, 2007; Kundu *et al.*, 2009). A significant build up in available P was observed in all plots which received the organic manures alone or in combination with N or NP fertilizers. Higher build-up in available P was observed with the addition of poultry manure compared to FYM and pressmud, which might be due to variation in their P contents and amounts applied. Similar results revealed by Aziz *et al.* (2010) that organic matter content, P bioavailability in soil and their uptake by plants were increased by organic manure application irrespective of the source (poultry manure, FYM and pressmud). The build-up of available P in sub-surface soil was lower compared to surface soil. Our hypotheses are that the less deeper root systems of wheat crop and lower amount of litter inputs in the sub-surface would lead to substantial lesser amounts of available P through translocation process in the deep soil (Iversen, 2010), and lesser organic P inputs through litter decomposition processes in sub surface soil (Moore *et al.*, 2010; Achat *et al.*, 2012). The increase in available P of the soil with the addition of organic manures may be due to the mineralization of organic P, the production of organic acids which have a solubilizing effect on soil P and the organic aminos which retard the fixation phosphorus in soil (Narwal and Antil 2005; Antil and Mandeep, 2007) The critical evaluation of the data indicated that considering the amount of total P added through FYM, poultry manure and pressmud during the tenure of experiment (1152, 1126 and 864 kg P ha⁻¹, respectively) but the overall corresponding increase in available P was only 16.4, 16.0 and 14.5 mg kg ha⁻¹ (over the initial level) and about 2.8, 3.2 and 3.4 % available P was retained in the soil. P is relatively immobile nutrient in soil and diffusion is the major process controlling its movement. Hence indirectly soil moisture regulates soil P mobility (Marschner, 1995). Addition of organic manure increased soil moisture contents (Boateng *et al.*, 2006), which may be the reason of improved P availability in soil. Nonetheless organic manures after decomposition may also have played role in carbonic acid driven increased P bioavailability (Marschner, 1995; Mengel & Kirkby, 2001). Production of organic legends in soil by increased microbial activity (Marschner, 1995) might be responsible for desorption of P from mineral compounds. The results suggested by Ali *et al.* (2012) that integration of organic (poultry manure) and inorganic source of P can improve maize growth and enhance yield over sole application of inorganic source as a cost effective and environmentally benign nutrient management approach. Soil P mineralization increases with increasing organic P content from organic matter, while the amount of inorganic P immobilization ion is inversely associated with soil organic P in such a way that, as the ratio of soil organic C:P ratio increases, P immobilization increases (Ahmed *et al.*, 2010). High C:P ratios are considered to facilitate soil organic matter buildup because metabolic needs of microbes immobilized P in microbial biomass, as C:P ratios increases within microbial biomass. Cavigelli and Thien, (2004) also found increased bioavailability of P in soils by addition of organic matter. Similar results

were found in our study and around the world (Havlin *et al.*, 2005; Cleveland and Liptzin, 2007; Ahmed *et al.*, 2010).

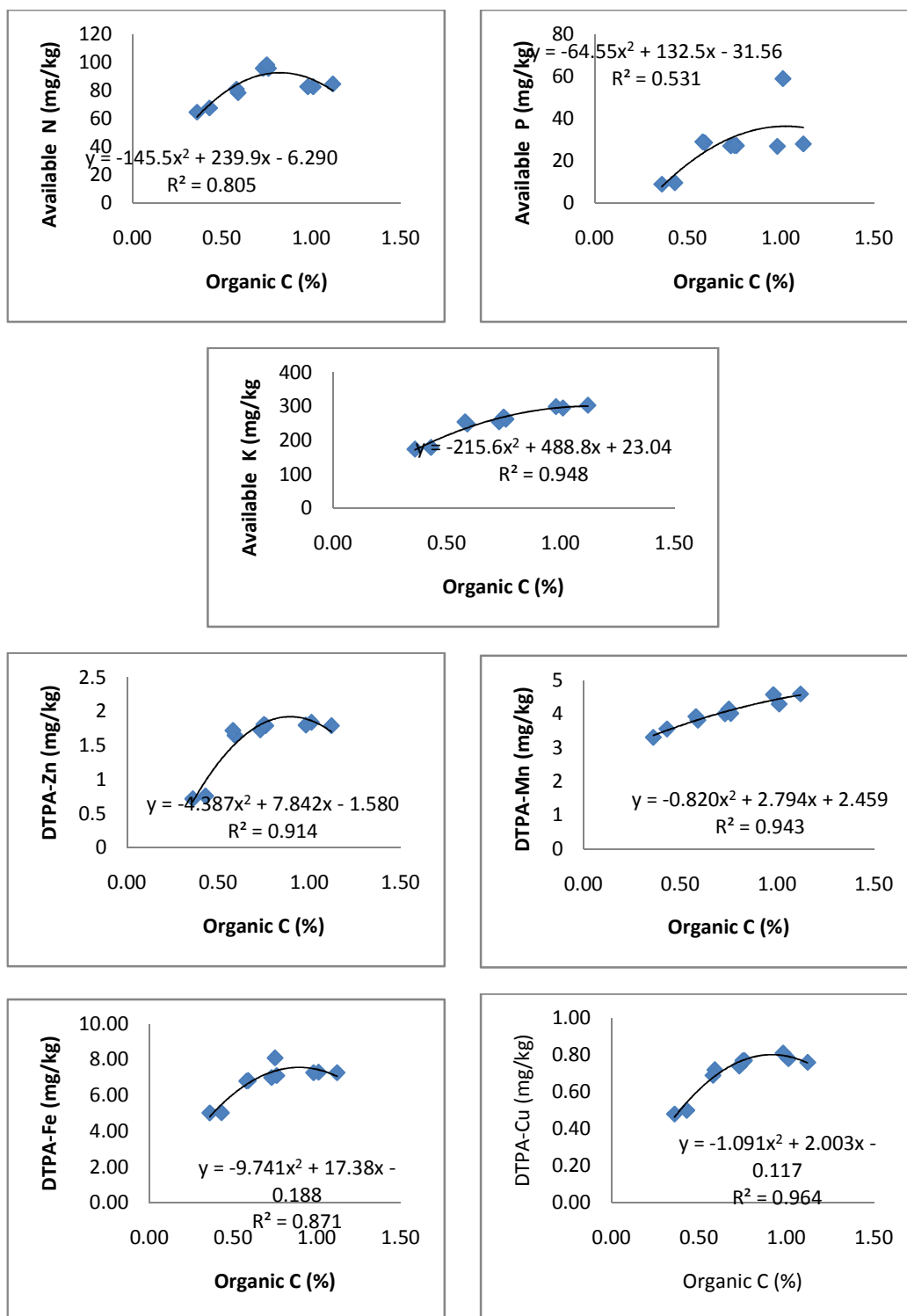


Fig. 15: Relationship between organic C and available nutrients status in soil

5.11.6. Available K

The available K content decreased from 217 to 173.4 mg kg⁻¹ to 16 years cropping where 75 kg N + 30 Kg P₂O₅ ha⁻¹ fertilizers were applied, whereas it increased to 294.4 mg kg⁻¹ with 15 Mg FYM ha⁻¹ yr⁻¹ (Table 20). Addition of organic manures resulted in significant higher build up in available K over NP fertilizers applied alone. Application of organic manures in conjunction with N or NP fertilizers, significant increase in available K of soil over the organic manures applied alone. The proportionate increase in available K was apparently more with FYM addition followed by pressmud and poultry manure. Similar results revealed by Aziz *et al.* (2010) that organic matter content, K bioavailability in soil and their uptake by plants were increased by organic manure application irrespective of the source (poultry manure, FYM and pressmud). Comparing different sources, P and K concentration in plants were maximum in poultry manure treatment and farm yard manure, respectively. It might be due to the variation in K content and the amounts of organic manures applied. The available K content in sub-surface layer was less as compared to the surface layer. There is increasing evidence that organic amendments at high rates of application can cause dramatic increases in soil nutrients, particularly N, P and K (Amlinger *et al.*, 2007; Kundu *et al.*, 2009). Considering the amount of total K added through FYM, poultry manure and pressmud during the 16 years of experimentation, total K content of soil should have been approximately 3686, 736 and 768 kg N ha⁻¹, respectively, but the overall corresponding increase in available K was only 77.4, 30.4 and 36.4 mg kg⁻¹ (over the initial level). About 5.8, 8.2 and 9.5 % of available K was retained in soil during the period of 16 years added through FYM, poultry manure and pressmud. Cavigelli and Thien, (2004) also found increased bioavailability of P in soils by addition of organic matter. Higher P contents were observed in soil previously added with poultry manure, while higher K contents were recorded in soil receiving FYM and pressmud. This happened possibly due to the higher contents of respective mineral in the respective source.

5.11.7. Micronutrients

The lowest DTPA extractable Zn, Mn, Fe and Cu concentrations was observed where only NP fertilizers were applied (Table 21). A significant increase in DTPA extractable Zn, Mn, Fe and Cu was observed with the application of organic manures over no manure was applied. Application of NP fertilizers along with organic manures over only manures were applied had no effect on DTPA extractable Zn, Mn, Fe and Cu in soil. The proportionate increase in DTPA extractable Zn, Mn, Fe and Cu was recorded with the application of FYM followed by pressmud and poultry manure. DTPA extractable Zn, Mn, Fe and Cu was higher in the surface soil than sub-surface soil. In the sub-surface layer, a similar trend of increase was observed but the rate of increase was less than the surface layer.

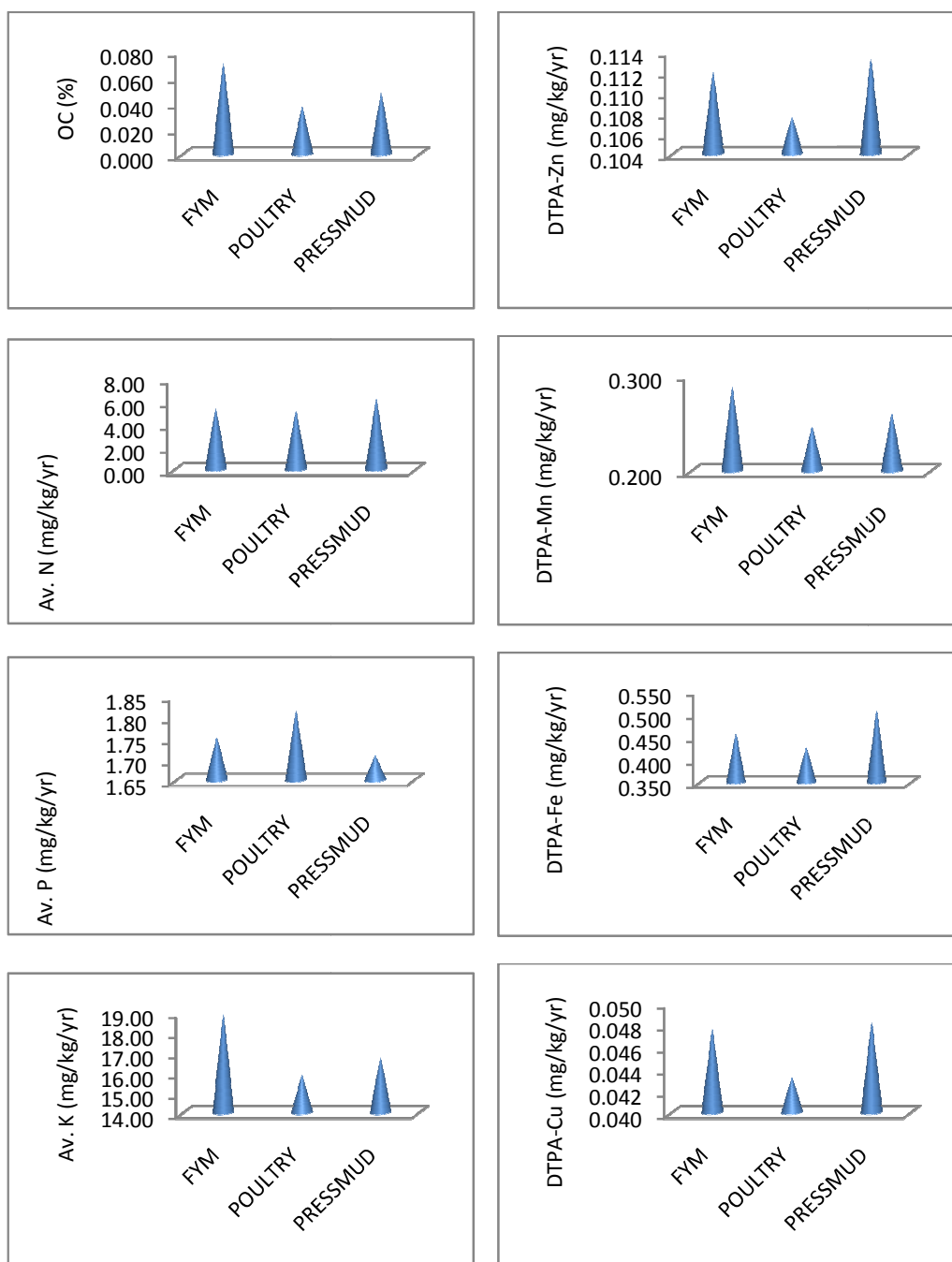


Fig. 16. Influence of organic manures on build up (per year) of soil organic C, available NPK and micronutrients contents as a component of integrated nutrient management

Build-up of organic matter under continuous manuring possibly results in higher DTPA extractable Zn, Mn, Fe and Cu in soil. Chaudhary and Narwal, (2005) reported that application of FYM significantly increased the DTPA extractable Zn, Mn, Fe and Cu at 0-15, 15-30 and 30-45 cm soil depths. The increase was higher in the surface layer than in lower depths. The application of organic manures with or without NP fertilizers increased the DTPA

extractable Zn, Fe, Mn and Cu content of soil (Narwal and Antil, 2005; Antil and Mandeep, 2007).

A polynomial relationship was observed between organic C and DTPA extractable micronutrients (Zn, Mn, Fe and Cu) (Fig. 6). The DTPA extractable Zn, Mn, Fe and Cu contents of soil increased with increasing soil organic C content of soil due to the application of organic manures.

The effect of organic manures on the build-up of soil organic C and available nutrient contents per year as a component of integrated nutrient management were calculated as the difference between organic C build-up due to the addition of organic manure plus NP fertilizers minus NP fertilizers alone divided by 16 numbers of years of experimentation. The organic C, available N, P, K, DTPA extractable Zn, Mn, Fe and Cu contents of soils increased and ranged between 0.04-0.07 yr⁻¹, 5.1-6.1, 1.7-1.8, 15.8-18.9, 0.01-0.12, 0.25-0.29, 0.43-0.51 and 0.04-0.05 mg kg yr⁻¹, respectively, with the application of FYM, poultry manure and pressmud as a component of integrated nutrient management under pearl millet-wheat sequence (Fig. 10).

5.12. Grain yield of pearl millet and wheat

The lowest grain yield of both pearl millet and wheat crops was recorded when either 15 Mg FYM or 5 Mg poultry manure or 7.5 pressmud ha⁻¹ was applied alone (Table 22). With the application of NP in conjunction with organic manures, there was a significant increase in the crop yield which was comparable with recommended dose of applied NP alone or half dose of NP applied alone. There was an increase of about 66, 50 and 60 % in pearl millet grain yield and 126, 92 and 109 % in wheat grain yield upon application of 15 Mg FYM, 5 Mg poultry manure and 7.5 Mg pressmud ha⁻¹ along with recommended N and half of P over manures applied alone, respectively. The organically manures plots produced significantly higher crop yield as compared to NP fertilized treated plots, reflecting the positive interaction of integrating organic and inorganic fertilizers on crop yield. Increase in grain yield of pearl millet and wheat with the application of organic manures along with NP fertilizers may be due to additional supply of plant nutrients and nutrients mineralized from the organic manures meeting the need of the crop slowly but continuously along with readily available macro and micronutrients. The addition of FYM and other organic materials had directly added an appreciable amount of major nutrients which contributed to the enhanced yield. In contrast, Edmeades, (2003) stated that relative to the same amounts of nutrients application as chemical fertilizers, applying organic manures had no obvious advantages to soil productivity, measured as crop yields, despite the positive effects of these organic manures on soil physical and biological properties. Linear regressions fitted to pooled data across the locations revealed highly significant ($p < 0.01$) annual increase in yield of rice with integrated supply of nutrients through fertilizers and manures, indicating thereby the advantage of combined use of

manures plus fertilizers over fertilizers applied alone in sustaining crop yields reported by Yadav *et al.* (2000). The increasing C sequestration was observed by increasing C input through crop residues and organic manures. The higher magnitude of residual effect of FYM may be due to the higher quantity of FYM application. The increase in soil organic C pools and N fractions with application of manures could be attributed to an increase in belowground biomass production compared to fertilizers N or NP applied plots. Continual addition of FYM increases MBC, which could lead to a positive effect on both soil aggregation and macro porosity and it improves the growth and development of crop. DOC and LFC are active C is a small fraction of soil organic manures, it acts as a buffering agent in replenishment of all bioavailability of nutrients to crops. Integration of organic and inorganic sources resulted in higher biological yield in sunflower that is attributed to more availability of nutrients and their uptake, which increased flowering, leaf area index, biomass (Munir *et al.*, 2007). Increase of nutrients, structural development and changes in soil health might have collectively contributed to improve in crop yields. Large increase the yield with integrated use of FYM and inorganic fertilizers have been reported by Yadvinder-Singh *et al.*, 2004. Increase in yield of crops with FYM application is expected due to its favorable effect on physical, biological and chemical properties of the soil (Edmeades, 2003). Amujoyegbe *et al.*, (2007) found highest grain yield and biomass of maize and sorghum with the combined application of inorganic fertilizer + poultry manure followed by inorganic fertilizer. Tahir *et al.* (2011) recommended that organic matter alone with synthetic fertilizers could be helpful for enhancing stagnant wheat grain yield. Similar report of combined application of organic manures and inorganic fertilizers by Rasool *et al.* (2008) that grain yield and uptake of N, P and K by both maize and wheat were higher with the application of FYM and inorganic fertilizers than in control plots.

5.12.1. Wheat grain and straw NPK (%) contents

Data presented in Table 23 revealed that when organic manures (FYM, poultry manure and pressmud) applied alone resulted in less NPK (%) content of wheat grain. When organic manures were applied in conjunction with N or NP fertilizers, there was significant increase in grain NPK content over N or NP fertilizers applied alone. The increase in N, P and K content in wheat grain was 2.06, 0.42, and 1.60; 1.34, 0.48 and 1.44; and 2.11, 0.31 and 1.53 % with the application of 15 Mg FYM, 5 Mg poultry manure and 7.5 Mg pressmud ha⁻¹ along with recommended dose of N and half of P over 15 Mg FYM, 5 Mg poultry manure and 7.5 Mg pressmud ha⁻¹, respectively. The content of N by wheat grain ranged from 0.89 (N₇₅P₃₀) to 2.11 % (pressmud_{7.5}N₁₅₀P₃₀). Favorable effect of pressmud on N content is attributed to fast release of N during decomposition due their narrow C: N ratio and highest N content. The lowest contents of NPK were observed in only NP fertilizers applied plots which attributed to the lower yields obtained in these plots. Sunil *et al.* (2012) showed that the

application of pressmud equivalent to N content of recommended FYM along with RDF recorded maximum N, P and K, which was followed by combined application of 12.5 t FYM ha⁻¹ + 100% RDF.

Regression equations predicts highly significant relationship between N content in wheat with acid insoluble-N ($R^2=0.95$), hydrolysable NH₃-N ($R^2=0.87$), amino acid-N ($R^2=0.94$), amino sugar-N ($R^2 = 0.93$), hydrolysable unknown-N ($R^2 = 0.97$) and total hydrolysable-N ($R^2 = 0.97$). Sharma and Verma, (2001) reported that important variable contributing to the total variation in the regression of available N was amino acid-N. The all N fractions were contributing to the total variation in available N in the soil.

The increased content of P may be ascribed to more availability of these nutrients added through organic and inorganic sources, and solubility action of organic acids produced during the decomposition of organic materials. Sharma *et al.* (2001) reported that uptake of P by rice as well as wheat was highest with combined addition of inorganic and organic in ratio of 50:50. Singh *et al.* (2001) reported that application of FYM significantly enhanced the uptake of P by the wheat crop. Hence, plants grown with organic manures accumulate more NPK than without organic amendments (Mujeeb *et al.*, 2008). The results suggested by Ali *et al.* (2012) that integration of organic (poultry manure) and inorganic source of P can improve maize growth and enhance yield over sole application of inorganic source as a cost effective and environmentally benign nutrient management approach.

The K content of wheat grain ranged from 1.53 (pressmud_{7.5}N₁₅₀P₃₀) to 1.60 (%) (FYM₁₅N₁₅₀P₃₀). Identical trends were observed with respect to K content in wheat straw. Higher wheat biomass and yield production may also have resulted in increased K content in organic manures plus recommended NP fertilizers treated plots. Shaktawat, (2002) reported that the effect of poultry manure and pig manure in relatively lower than FYM in respect of yield and nutrient uptake, which might be due to variation in their nutrient composition and their release pattern into soil.

5.12.2. Pearl millet grain and straw NPK (%) contents

The results pertaining to grain and straw NPK (%) content of pearl millet is presented in Table 24. Data revealed that when organic manures (FYM, poultry manure and pressmud) applied alone resulted in less NPK (%) content of pearl millet grain as compared to organic manures applied along with NP fertilizers. The content of NP in grain of pearl millet was higher than straw, but higher K content was recorded in straw. Among different manures applied alone, N content was highest in pressmud (1.25%) followed by FYM (1.20 %) and poultry manure (1.00 %). K content in pearl millet grain was highest with FYM (1.34 %) followed by pressmud (1.28 %) and poultry manure (1.23 %). But in case of P, highest P content was observed with poultry manure (0.35 %) followed by FYM (0.28 %) and pressmud (0.25 %). The increase in N, P and K content in pearl millet straw was 0.85, 0.28,

and 3.81; 0.54, 0.34 and 3.25; and 0.91, 0.27 and 3.54 % with the application of 15 Mg FYM, 5 Mg poultry manure and 7.5 Mg pressmud ha⁻¹ with recommended dose of N and half of P over 15 Mg FYM, 5 Mg poultry manure and 7.5 Mg pressmud ha⁻¹, respectively. This may be attributed to that pearl millet crop considered as a drought resistant crop so that K content of straw in pearl millet is higher than grain. Increased NPK content in FYM, pressmud and poultry manure applied plots may be due to additional amount of nutrients supplied through these organic manures. This might be attributed to decaying organic matter increase soil CO₂ concentrations and liberates H⁺ when dissolves in water. The released H⁺ enhances dissolution of plant nutrients contained minerals and releases more nutrients to exchange complex to soil solution. Moreover, organic materials improve the soil physico-chemical properties that accelerate exchange of nutrients on soil solids and leaching of salts from the root zone. K content in pearl millet grain was highest with FYM (1.34 %) followed by pressmud (1.28 %) and poultry manure (1.23 %). But in case of P, highest P content was observed with poultry manure (0.35 %) and followed by FYM (0.28 %) pressmud (0.25 %). This may be due to the synergistic effect of organic manures addition of the availability of native and applied nutrients, thereby enhancing the yield of crop and hence the content of macronutrients. The analysis of soil for plant available plant nutrients revealed that organic manures, major source of NPK into the soil solution which is contributed more in plant uptake. The plants grown with addition of organic manures accumulate more NPK than without organic amendments and it contributed more plant available NPK in soil (Mujeeb *et al.*, 2008 and Rasool *et al.*, 2008).

CHAPTER-VI

SUMMARY AND CONCLUSION

Long-term experiments are providing the best practical approximation to test of sustainability. Hence, a study had been planned to observe the changes that were brought about in the labile soil organic matter pools and N fractions in soils after forty three years of FYM application with supplementation by fertilizer N and their effect on yield, nutrients uptake and soil organic matter pools and N fractions. An ongoing long-term field experiment with pearl millet-wheat cropping sequence which was established in 1967 on a coarse loamy, Typic Ustochrept soil at CCS Haryana Agricultural University, Hisar, India was selected for the present study. The experimental site is located between 29.16° N latitude and 75.75° E longitude with a mean annual precipitation of 443 mm. The experimental treatment consisted of 3 levels of FYM (15, 30 and 45 Mg ha⁻¹ till 2007-08) and 5, 10 and 15 Mg ha⁻¹ from 2008-09 onwards); three modes of application: every kharif crop (summer season), in every rabi crop (winter season) and in both (kharif and rabi) the crops. An absolute control with application of FYM in any of the seasons was maintained as control. These 10 treatments (3 FYM levels X 3 modes of application + 1 FYM control) were allocated in the main plots and each main plot was subdivided into two sub-plots receiving fertilizer N at 0 and 120 kg N ha⁻¹ in each season through urea using split plot design.

The DOC, MBC, LFC and HFC content of soil increased significantly increasing levels of FYM. However, increase in DOC, MBC, LFC and HFC was highest in 15 Mg ha⁻¹ followed by 10 and 5 Mg ha⁻¹ and values were 362.7, 245.9 and 160.2 mg kg⁻¹; 708.8, 529.0, and 410.8 mg kg⁻¹; 0.46, 0.41 and 0.34 g kg⁻¹; and 1.45, 1.15 and 1.05 g kg⁻¹, respectively. Increasing levels of FYM from 0 to 15 Mg ha⁻¹ increased amino acid-N, amino sugar-N, hydrolysable NH₃-N, hydrolysable-N, total hydrolysable unknown-N and acid insoluble-N from 68.3 to 144.1, 21.2 to 45.8, 62.9 to 143.6, 155.2 to 464.3, 67.3 to 159.3 and 77.1 to 159.0 mg kg⁻¹, respectively.

There was a significant difference in organic C pools and N fractions of soil receiving 0 and 120 kg N ha⁻¹. A significant increase in DOC (114.8 %), MBC (131.0 %), LFC (108.1 %) and HFC (113.1) was observed with application of 120 kg N ha⁻¹ over 0 kg N ha⁻¹. Similarly, N fractions (amino acid-N, amino sugar-N, hydrolysable NH₃-N, hydrolysable-N, total hydrolysable unknown-N and acid insoluble-N) also increased significantly. Highest organic C pools and N fractions were observed where 15 Mg FYM ha⁻¹ was applied in both the seasons (rabi and kharif) in conjunction with 120 kg N ha⁻¹. Highest organic C pools and N fractions were recorded when FYM was applied in both seasons as compared to applied

either in rabi or kharif season. However, application of FYM in rabi season was found more beneficial than its application in kharif season.

The grain yield of pearl millet and wheat increased significantly with the application of FYM from 0 to 15 Mg FYM ha⁻¹ and N from 0 to 120 kg ha⁻¹. Highest grain yields was recorded when FYM applied at 15 Mg ha⁻¹ followed by 10 and 5 Mg ha⁻¹ and values were 25.57, 27.02 and 28.60 q ha⁻¹ of pearl millet and 43.49, 45.34 and 47.72 q ha⁻¹ of wheat, respectively. The increase in pearl millet grain yield was about, 23, 30 and 37 % and that of wheat grain was 28, 34 and 41 % upon application of FYM at 5, 10 and 15 Mg ha⁻¹ over the control, respectively. Application of FYM in both the seasons (kharif and rabi) gave maximum yield followed by rabi and kharif applications. Increase in NPK content in wheat grain was highest with addition of 15 Mg FYM ha⁻¹ followed by 10 and 5 Mg ha⁻¹ and values were 1.94, 1.86 and 1.78 % N; and 0.84, 0.76 and 0.71 % P and 1.44, 1.36 and 1.28 % K, respectively. The corresponding values in pearl millet grain with addition of 15, 10 and 5 Mg FYM ha⁻¹ were 1.32, 1.23 and 1.15 % N; 0.49, 0.43 and 0.37 % P; and 2.24, 2.16 and 2.08 % K. Highest N, P and K content in both pearl millet and wheat grains was recorded when FYM was applied in conjunction with 120 kg N ha⁻¹ in both seasons.

The organic C, available N, P and K contents of soil decreased from its initial values after 43 cycles of pearl millet-wheat cropping system due to continuous cropping without FYM and N. Continuous application of FYM for a period of 43 years increased EC, organic C, available N, P, K, Zn, Mn, Fe and Cu content of soil. However, a reverse trend was observed in case of soil pH. Application of FYM in rabi season was found to be more beneficial in increasing organic C, available N, P, K and Zn, Mn, Fe and Cu contents as compared to its application in kharif season.

An ongoing long-term experiment initiated in 1995 was selected to investigate the effect of organic manures (FYM, poultry manure and pressmud) and fertilizers on changes of soil organic C pools, N fractions, soil pH, EC, organic C and available nutrients (N, P, K, Zn, Mn, Fe and Cu) after 16 cycles of pearl millet-wheat cropping system. The experiment was laid out with the following treatments in a randomized block design with three replications; 75 kg N + 30 Kg P₂O₅ ha⁻¹, 150 kg N + 60 Kg P₂O₅ ha⁻¹, 15 Mg FYM ha⁻¹, 15 Mg FYM + 150 kg N ha⁻¹, 15 Mg FYM + 150 kg N + 30 Kg P₂O₅ ha⁻¹, 5 Mg poultry manure ha⁻¹, 5 Mg poultry manure + 150 kg N + 30 Kg P₂O₅ ha⁻¹, 7.5 Mg press mud ha⁻¹, 7.5 Mg press mud + 75 kg N + 30 Kg P₂O₅ ha⁻¹, 7.5 Mg press mud + 150 kg N + 30 Kg P₂O₅ ha⁻¹. FYM, poultry manure and pressmud were applied once a year in winter at time of wheat planting.

The lowest grain yield of pearl millet and wheat crops was recorded when either 15 Mg FYM or 5 Mg poultry manure or 7.5 pressmud ha⁻¹ was applied alone. However, a significant increase in yield was obtained when organic manures were applied in conjunction

with recommended dose of N for these crops and that was comparable with recommended dose of applied NP alone or NP applied in combination with organic manures.

Application of FYM, poultry manure and pressmud along with NP fertilizers increased the organic C pools and N fractions over the recommended dose of N fertilizers. Highest organic C and N fractions were recorded with 15 Mg FYM+150 kg N + 30 Kg P_2O_5 ha⁻¹. The build-up of organic C and N fractions and nutrient contents were higher in surface (0-15 cm) soil as compare to sub-surface (15-30 and 30-45 cm) soil. Application of FYM along with NP fertilizers led to the greatest increase in various N fractions followed by pressmud and poultry manure. The organic C, available P and K during wheat growth increased significantly up to 48 days in all the treatments received organic manures alone or in combination with N or NP fertilizers over NP fertilizers (without organic manures) and decreased thereafter. However, the available N content of soil increased only up to 24 days. Organic C, available N, P, K, Zn, Mn, Fe and Cu contents of the soil decreased from its initial value, when only NP fertilizers were applied and increased significantly with the application of organic manures applied alone or applied in conjunction with NP fertilizers.

Based upon the observations made on the different aspects of the present study, the following inferences may be drawn:

- Combined application of FYM and fertilizer N increased the productivity of pearl millet-wheat cropping system and maintained soil fertility.
- Both seasons (kharif and rabi) applications of FYM have been able to sequester more C and maintain more labile soil organic matter pools and N fractions than other modes (rabi and kharif) of FYM.
- Highest organic C pools and N fractions were observed where 15 Mg FYM ha⁻¹ was applied in conjunction with 120 kg N ha⁻¹ followed by 10 and 5 Mg ha⁻¹ FYM.
- Increase in organic C, available N, P, K, Zn, Mn, Fe and Cu contents was observed when FYM applied in both the seasons compared to applied either in rabi or kharif season. However, FYM applied in rabi season shown higher build up as compared to applied in kharif season.
- Incorporation of FYM with fertilizers resulted in highest increase in soil organic C pools and N fractions followed by pressmud and poultry manures.
- Soil fertility with respect to P, K and micronutrients (Zn, Cu, Mn and Fe) can be maintained with the application of organic manures but not N.
- Organic C, available N, P, K, Zn, Mn, Fe and Cu contents of the soil decreased from its initial value, when only NP fertilizers were applied and increased significantly with the application of organic manures applied alone or applied in conjunction with NP fertilizers.

- Under pearl millet-wheat cropping sequence, application both organic manures (FYM, pressmud and poultry manure) and fertilizers maintained better crop productivity and C-sequestration.
- Under pearl millet-wheat cropping sequence, combined application of both organic manures and fertilizers on higher consistence maintained in periodical changes of organic C, available N, P and K throughout wheat growth period as compared to NP fertilizers applied alone.
- These results indicate that instead of using chemical fertilizer alone, the integrated use of organic manures and fertilizer may be more effective in ensuring soil health and in sustaining crop productivity on a long-term basis.

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ABSTRACT

- a) Title of thesis: **Long-term effects of organic manures and fertilizers on soil organic carbon pools and nitrogen fractions**
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Keywords: Long term, Organic Manures, Fertilizers, C pools and N fractions

An ongoing long-term experiment on the integrated nutrient management (FYM and fertilizer N) under pearl millet-wheat cropping sequence was selected which has been running at the research farm of CCS Haryana Agricultural University since October, 1967. The experimental treatments consisted of 3 levels of FYM at 15, 30 and 45 Mg ha⁻¹ till 2007-08 and 5, 10 and 15 Mg ha⁻¹ from 2008-09 onwards; there modes of application: every kharif crop (summer season), in every rabi crop (winter season) and in both (kharif and rabi) the crops. An absolute control with application of FYM in any of the seasons was maintained as control. These 10 treatments (3 FYM levels X 3 modes of application + 1 FYM control) were allocated in the main plots and each main plot was subdivided into 3 sub-plots receiving fertilizer N at 0 and 120 kg N ha⁻¹ in each season through urea using split plot design. Keeping the results of the above long-term experiment in mind, another long-term experiment was planned in 1995, to test/validate the results of above experiments by using different kinds of organic manures in combination with fertilizers under pearl millet-wheat cropping system. The experiment was laid out with the following treatments in a randomized block design with three replications; 75 kg N + 30 Kg P₂O₅ ha⁻¹, 150 kg N + 60 Kg ha⁻¹ P₂O₅ ha⁻¹, 15 Mg FYM ha⁻¹, 15 Mg FYM + 150 kg N ha⁻¹, 15 Mg FYM + 150 kg N+30 Kg P₂O₅ ha⁻¹, 5 Mg poultry manure ha⁻¹, 5 Mg poultry manure +150 kg N+30 Kg P₂O₅ ha⁻¹, 7.5 Mg press mud ha⁻¹, 7.5 Mg press mud +75 kg N + 30 Kg P₂O₅ ha⁻¹, 7.5 Mg press mud +150 kg N + 30 Kg P₂O₅ ha⁻¹.

The changes in soil organic C fractions (DOC, MBC, LFC and HFC) and N fractions (acid insoluble-N, hydrolysable NH₃-N, amino acid-N, amino sugar-N, hydrolysable unknown-N and total hydrolysable-N) were more dynamic in various treatments consisting of modes and levels of FYM and fertilizer N. A significant increase in soil organic C pools and N fractions when FYM applied at 15 Mg ha⁻¹ followed by 10 and 5 Mg ha⁻¹. Highest increase in soil organic C pools and N fractions were noticed when 15 Mg FYM ha⁻¹ was applied along with 120 kg N ha⁻¹ in both the seasons compared to applied in rabi or kharif seasons. Increased organic C, available macro (N, P and K) and micronutrients (Zn, Mn, Fe and Cu) and concentration of nutrients (NPK) contents were affected by the degree of change from the historical (43 years of experiments) amendment of FYM in different modes and levels of the intervention and fertilizer N levels. Increase in organic C, available N, P, K, Zn, Mn, Fe and Cu, and concentration of nutrients contents was observed, when FYM applied at 15 Mg ha⁻¹ followed by 10 and 5 Mg ha⁻¹ and highest were noticed when FYM applied in both the seasons compared to applied either in rabi or kharif season.

Continuous application of organic manures alone or in conjunction with NP fertilizer for 16 years led to resulted increase in the contents of various pools/form of organic C and N. The highest organic C and N fractions were recorded with 15 Mg FYM+150 kg N + 30 Kg P₂O₅ ha⁻¹. The build-up of organic C and N fractions and nutrient contents were higher in surface (0-15 cm) soil as compare to sub-surface (15-30 and 30-45 cm) soil. Application of FYM along with NP fertilizers led to the greatest increase in various organic N fractions followed by pressmud and poultry manure. Organic C, available N, P, K, Zn, Mn, Fe and Cu contents of the soil decreased from its initial value, when only NP fertilizers were applied and increased significantly with the application of organic manures applied alone or applied in conjunction with NP fertilizers.

Application of organic manures (FYM, pressmud and poultry manure) along with NP fertilizers produced significantly higher grain yield of pearl millet and wheat. Integrated use of fertilizers with organic manures maintained the sustainability of the pearl millet-wheat cropping system.

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“I **Kumara, B. H.** Admission No. **2010A34D** undertake that I give copy right to the CCS HAU, Hisar of my thesis entitled “**Long-term effects of organic manures and fertilizers on soil organic carbon pools and nitrogen fractions**”

I also undertake that, patent, if any, arising out of the research work conducted during the programme shall be filed by me only with due permission of the competent authority of CCSHAU, Hisar.

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