

**Soil nitrogen transformation under long term INM  
practices in an acid *Inceptisols***

**ANINDITA JANA  
Adm. No. 18122025**



**DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL  
CHEMISTRY  
COLLEGE OF AGRICULTURE  
ODISHA UNIVERSITY OF AGRICULTURE AND TECHNOLOGY  
BHUBANESWAR, ODISHA-751003  
2020**

# **Soil nitrogen transformation under long term INM practices in an acid *Inceptisols***

**A**

*Thesis submitted to the  
Odisha University of Agriculture and Technology  
in Partial fulfilment of the Requirement for the degree of*

*Master of Sciences in Agriculture  
(Soil Science and Agricultural Chemistry)*

**By**

**ANINDITA JANA  
Adm. No. 18122025**



**DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL  
CHEMISTRY  
COLLEGE OF AGRICULTURE  
ODISHA UNIVERSITY OF AGRICULTURE AND TECHNOLOGY  
BHUBANESWAR, ODISHA-751003  
2020**



**ODISHA UNIVERSITY OF AGRICULTURE AND TECHNOLOGY**  
**DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY**  
**COLLEGE OF AGRICULTURE**  
**BHUBANESWAR, ODISHA-751003**

**Dr. (Mrs.) Mitali Mandal**  
Assistant Professor and OIC  
AICRP ON LTFE  
Department of Soil Science and  
Agricultural Chemistry, C.A., O.U.A.T.

Bhubaneswar  
Date:

**CERTIFICATE-I**

This is to certify that the thesis entitled “**Soil nitrogen transformation under long term INM practices in an acid *Inceptisols***” submitted in partial fulfilment of the requirements for the award of the degree of **MASTER OF SCIENCE IN AGRICULTURE (SOIL SCIENCE AND AGRICULTURAL CHEMISTRY)** to the **ODISHA UNIVERSITY OF AGRICULTURE AND TECHNOLOGY**, Bhubaneswar, is a faithful record of bonafide and original research work carried out by **Ms. ANINDITA JANA, ADM. NO. 18122025** under my guidance and supervision. No part of this thesis has been submitted for the award of any other degree or diploma.

It is further certified that the assistance and help received by her from various sources during the course of investigation has been duly acknowledged.

.....  
**Chairman**

**Advisory Committee**



## CERTIFICATE-II

This is to certify that the thesis entitled “**Soil nitrogen transformation under long term INM practices in an acid *Inceptisols***” submitted by **ANINDITA JANA** to the Odisha University of Agriculture and Technology, Bhubaneswar in partial fulfilment of the requirement for the degree of **MASTER OF SCIENCE IN AGRICULTURE (SOIL SCIENCE AND AGRICULTURAL CHEMISTRY)** has been approved by the students’ advisory committee and the external examiner.

### Advisory Committee

**Chairman**     **Dr. (Mrs.) Mitali Mandal**  
Assistant Professor and OIC  
AICRP ON LTFE  
Department of Soil Science &  
Agricultural Chemistry,  
C.A., O.U.A.T., Bhubaneswar

---

- Members**
- 1. Dr. R. K. Patra**  
Professor and H.O.D  
Department of, Soil Science and  
Agricultural Chemistry,  
C.A., O.U.A.T., Bhubaneswar
  - 2. Dr. S. N. Jena**  
Professor,  
Department of Agronomy  
C.A., O.U.A.T., Bhubaneswar
  - 3. Dr. Narayan Panda**  
Assistant Professor  
Department of Soil Science &  
Agricultural Chemistry,  
C.A., O.U.A.T., Bhubaneswar
  - 4. Dr. S. K. Pattanayak**  
Former Professor and Head  
Department of Soil Science &  
Agricultural Chemistry,  
C.A., O.U.A.T., Bhubaneswar

---

---

---

---

**External Examiner**

---

(Name and designation)

# ACKNOWLEDGEMENT

No one can get around pain and opposition, but one can try to be joyful in the trial and I thank myself for the trial, and thank God for he has given me the strength and courage to go through it.

This M.Sc. thesis is the result of a challenging journey, upon which many people have contributed and given their support. It is indeed a great privilege to explicit my deepest gratitude, respect and indebtedness towards my major advisor and chairman of the advisory committee, Dr. (Mrs.) **Mitali Mandal**, Assistant Professor and OIC, AICRP ON LTFE, Department of Soil Science and Agricultural Chemistry, Odisha University of Agriculture and Technology, College of Agriculture, for her utmost counsel, concrete suggestions, constructive criticism, her inspiring, meticulous and affectionate guidance, constant help and persistent encouragement during the course of my study and prosecution of research work. I am highly grateful and proud to have an opportunity of working under her supervision and knowledge moulded with unending inspiring and indomitable spirit which she provided me throughout the course of investigation and made the work completely successful.

I am thankful to **Dr. R. K. Patra**, Professor and Head, Dept. of Soil Science and Agricultural Chemistry and member of the Advisory committee for being affectionate always and helping with his valuable advice which led to successful completion of the research work. I am heartily grateful to him for sharing his useful and illuminating views on a number of issues related to the project.

I am highly thankful to **Dr. S.N. Jena**, Professor, Department of Agronomy, O.U.A.T, Bhubaneswar for his close monitoring guidance, constant inspiration and kind interest in this work.

I convey my sincere gratitude to **Dr. Narayan Panda**, Assistant Professor, Dept. of Soil Science and Agricultural Chemistry and member of the Advisory committee, for his scholarly guidance, admirable patience and giving valuable suggestions in my research work.

I would like to extend my heartfelt thanks in expressing my deep sense of reverence and gratitude and indebtedness to **Dr. S.K. Pattanayak**, former Prof. and Head, Dept. of Soil Science and Agricultural Chemistry and member of Advisory Committee for his guidance, valuable suggestions, critical comments, careful and reasoned criticism, diligent support and meticulous attention to the details and in preparation of the manuscript of this thesis.

I would like to express my special appreciation and thanks to **Dr. K. K. Rout**, Professor, AICRP on LTFE, Dept. of Soil Science and Agricultural Chemistry Dean C.A., OUAT, Bhubaneswar and member of my advisory committee, for his valuable guidance and suggestions in my post-graduation research work.

Most humbly and respectfully I wish to express my gratitude to **Dr. A. K. Dash, Dr. A. Mishra, Dr. K. N. Mishra, Dr. R.K. Nayak, Dr. S. Soren, Mrs. Bandita Jena and Dr. G.H. Santra** for their valuable suggestions and cooperation igniting curiosity throughout my research work.

I sincerely furnish my profound gratitude and appreciation to **Debdatta bhai, Avisek bhai** and **Bhuban bhaina** for their affection and unconditional support for successful completion of my thesis. I would like to express my special thanks to **Payal didi, Lavanya didi, Prava didi, Himani didi, Kshitipati bhai** and **Sanjib bhai** for their practical guidance, sincere cooperation, moral support and encouragement till the end. My sincere thanks goes to Nirmal bhaina and Laxmi bhaina for helping me with all soil sampling related work and practical suggestions during my reaserch work. I also thank Snigdha mam, Sasmita mam, Bubu bhaina, Srinibas bhaina and Ujwal bhaina for their timely help on my road to the work. I would like to extend my appreciation for the selfless effort and constant help provided by Debdatta bhai amid the Covid-19 pandemic situation.

I would like to thank all other non-teaching staffs of the Department of Soil Science and Agricultural Chemistry for their help in making my thesis.

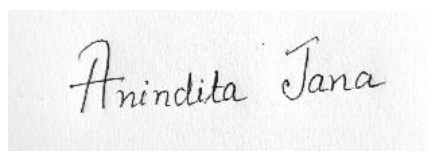
I express heartfelt thankfulness to my friends Soumyadeep, Supriya and Smita for being my companion of pain and pleasure, without whom my journey at OUAT would have been incomplete. I would also like to thank Puja, Yeti, Rutuparna, Shibani, Srilaxmi, Payal,

Meghna, Lalita, Sucharita, Swagatika, Sakshi, Sunishita, Kamesh, Ketan, Amit, Avisek, Athul, Devabrat, Pratyush, Hari om, Soumyakant, Sanjay, Srikant, Shashank, Nihar, Subrat for their help, affection, unsolicited assistance and pleasant company. I must express my gratitude to AICRP LTFE and STCR project of the Department of Soil Science and Agricultural chemistry and Central Library, O.U.A.T. for providing all sorts of facilities, physical conditions needed during the course of my study.

All languages fall short of to express my unboundful gratitude, indebtedness, love and affection to my beloved and venerable parents **Smt. Sephali Jana** and **Sri. Tapan Kumar Jana** for bringing me up in the best education, for nurturing in me the best of ideals and for helping me to see the best of times. It is time to surface out my love and affectionate gratitude to my younger sister **Joyeeta**, my seniors **Moumita didi**, **Bitasta didi** and my friend **Sagnika** for their everlasting love, encouragement and needy inspiration during the course of my life.

Finally, the financial assistance provided by the ICAR during the tenure is greatly acknowledged.

**Place: Bhubaneswar**

A rectangular box containing a handwritten signature in cursive script that reads "Anindita Jana".

**Dated:**

**(ANINDITA JANA)**

# CONTENTS

<b>CHAPTER</b>	<b>PARTICULARS</b>	<b>PAGE NO.</b>
<b>I</b>	<b>INTRODUCTION</b>	<b>1-4</b>
<b>II</b>	<b>REVIEW OF LITERATURE</b>	<b>5-19</b>
<b>III</b>	<b>MATERIALS AND METHODS</b>	<b>20-27</b>
<b>IV</b>	<b>RESULTS</b>	<b>28-51</b>
<b>V</b>	<b>DISCUSSION</b>	<b>52-62</b>
<b>VI</b>	<b>SUMMARY AND CONCLUSION</b>	<b>63-68</b>
	<b>REFERENCES</b>	<b>i-xix</b>

# LIST OF FIGURES

<b>Figure No.</b>	<b>PARTICULARS</b>	<b>Page No.</b>
<b>1</b>	Layout of treatments in the experimental field	22
<b>2</b>	Non hydrolysable N of soil total N at different soil depth influenced by long term INM practices	46
<b>3</b>	Relative proportion of hydrolysable N fractions (HAN, AAN, ASN and UHN) to THN (a) and contribution of Inorganic N, THN and NHN to soil Total N (b) influenced by long term INM practices	46

## LIST OF TABLES

Table No.	Particulars	Page No.
1	Physico-chemical properties of the initial surface soil	21
2	Meteorological data during crop season	21
3	Influence of organics, inorganics, biofertilizers and INM practices on Crop productivity, Harvest index and Relative Agronomic Efficiency	30
4	Influence of organics, inorganics, biofertilizers and INM practices on Concentration (%), Uptake ( $\text{kg ha}^{-1}$ ) and Recovery Efficiency (%) of N by Black gram crop	31
5	Influence of organics, inorganics, biofertilizers and INM practices on depth wise distribution of soil pH and EC in soil	33
6	Influence of organics, inorganics, biofertilizers and INM practices on depth wise distribution of Soil Organic Carbon (SOC) and Available Nitrogen content in soil	35
7	Influence of organics, inorganics, biofertilizers and INM practices on depth wise distribution of Available Phosphorous and Potassium content in soil	37
8	Influence of organics, inorganics, biofertilizers and INM practices on depth wise distribution of Total Nitrogen and Inorganic N content in soil	38
9	Influence of organics, inorganics, biofertilizers and INM practices on depth wise distribution of Total Hydrolysable Nitrogen (THN) and Non Hydrolysable Nitrogen (NHN) content in soil	41
10	Influence of organics, inorganics, biofertilizers and INM practices on depth wise distribution of Hydrolysable Ammonia Nitrogen (HAN) and Amino Acid Nitrogen (AAN) content in soil	43
11	Influence of organics, inorganics, biofertilizers and INM practices on depth wise distribution of Ammonia Sugar Nitrogen (ASN) and Unidentified Hydrolysable Nitrogen (UHN) content in soil	45
12	Cumulative amount of N mineralized in soils ( $\text{mg kg}^{-1}$ ) in INM package of practices	47
13	Different parameters of Potential Mineralizable N ( $N_0$ ) estimated according to the first order equations using the NLLS technique to describe the net N mineralization and comparison of experimental with predicted values	48
14	Correlation coefficients (r) between seed yield, SOC content and N fractions at different soil depth	50
15	Step-wise multiple regression analysis of dependent variables (Seed yield and N uptake) and independent variables (forms of N)	51

# ABSTRACT

The study on N transformation and quantifying N balance under intensive cropping system enables optimal N fertilization management practice for reducing environmental risks and improving N supplying capacity of soil. New cultivation strategies like incorporation of biological fertilizers with chemical and organic fertilizers are required to reduce environmental risk with an increasing yield. Blackgram is one of the most important pulse crops in India. Therefore, a long term field experiment was conducted during the *summer* season of 2019 to study the “Soil nitrogen transformation under long term INM practices in an acid *Inceptisols*” at College of Agriculture, O.U.A.T., Bhubaneswar. The test crop blackgram of present study was the 25<sup>th</sup> crop in sequence. The experiment was initiated with 10 different INM treatments, namely : (1) absolute control, (2) STD + FYM, (3) STD + VC, (4) STD + F + BFs, (5) STD + VC + BFs, (6) STD + F + L + BFs, (7) STD + VC + L + BFs, (8) STD (100 % NPK) (9) BFs alone, (10) 50 % STD + BFs. Biofertilizers like *Rhizobium* was seed inoculated @ 50 g kg<sup>-1</sup> seed and PSB for soil application was applied @ 4 kg ha<sup>-1</sup> as per treatment inoculated to 5 % limed vermicompost, incubated for 7 days and applied as basal. The soil test dose of N-P-K-S for the test crop was 30-13-30-30 kg ha<sup>-1</sup> supplied through Navaratna (20-20-0-13), urea and MOP. The doses of FYM and vermicompost were 5 and 2.5 t ha<sup>-1</sup> respectively. Long term INM package of practices significantly influenced inorganic N, organic N fractions, and total N in soil. Organic N fractions constituted 90.9 to 94.9% of total N as compared with 5.1 to 9.1% share of Inorganic N. Integration of inorganics with organics, biofertilizers and lime helped to significant increase in the total soil N, total hydrolysable- N (THN) (amino acid-N, ammonia-N, amino sugar-N, hydrolysable unknown-N) and non-hydrolysable-N (NHN). All the nitrogen fractions decreased with increase in depth. Of the total hydrolysable-N fraction in soil, ammonia-N constituted 25.4%, amino acid-N 38%, amino sugar-N 6.6%, and hydrolysable unknown-N 30%. A trend towards increasing potential mineralizable N (N<sub>0</sub>) by adoption of INM package of practices was observed. There was 72% yield loss in sole application of inorganic fertilizers as compared to unfertilized control. Even 50% reduced inorganic fertilization recorded 109% significant yield increment over STD when combined with biofertilizers. Conjunctive application of biofertilizers, inorganics and various organic inputs increased total yield maximum up to 133% over unfertilized treatment whereas, lime inclusion held significant variation in total crop productivity by adding extra 42% yield. N uptake by crop, maintenance of soil acidity at lower level (higher pH), higher available nutrients and higher organic carbon status in post-harvest soil were influenced by INM practices. All the nitrogen fractions except NHN were positively and significantly correlated with Crop yield and Nutrient uptake in surface layer.

## **CHAPTER-1**

---

### **INTRODUCTION**

# INTRODUCTION

---

Blackgram is the oldest and well-known principal pulse crop of Asia (Kokani *et al.*, 2014), the crop was originated in India and secondary origin was Central Asia which later spread throughout the Asia and other parts of the world as staple food grain legume. Blackgram ranks as the third most important pulse crop (Selvakumar *et al.*, 2012) since India alone produce more than two-third of the world production (Saini and Jaiwal, 2002) as food, feed and industrial raw material. It is sown in the area of 50.31 lakh ha in India with the productivity of 651 kg ha<sup>-1</sup> (Ministry of Agriculture and Farmers Welfare). Total blackgram production was 3280 thousand tonnes of which percentage share in 13.48% during 2017-18.

Due to its wider adaptability, blackgram is grown across a wide range of agro-ecological zones. This drought resistant crop is considered as a staple food for about 900 million consumers and about one third of all underfed children. As a highly nutritious crop, blackgram contains three times higher percentage (26%) of quality protein (albumin and globulin) than cereals, also rich in dietary fibres (Kokani *et al.*, 2014), carbohydrates (56-60%), fat (1.5%), oil (1.5%), fiber (4.5%) and is the richest in phosphoric acid among pulses being five to ten times richer than others on the basis of dry weight consumed per capita globally. It is an excellent soil nourishing grain legume crop which fixes nitrogen from the atmosphere through symbiotic nitrogen fixation. After the removal of pods, the green plants can be used as fodder. Blackgram is an eco-friendly crop, good for organic agriculture and has the capacity to produce consistent yield, even without special care and requires less nutrients as compared to many cereals and pulses. Amruta *et al.* (2016) reported that blackgram is a high energetic fodder which holds ample amount of calorie contents as 347 calories per 100 gm.

This is well established that chemical fertilizers or organic manures alone cannot sustain the desired levels of crop production under continuous cropping as observed in many long term fertilizer experiments (Singh and Wanjari, 2013). In this emerging scenario, there is a necessity to adopt the practices like integrated nutrient management which maintain soil health and environmental quality in a more sustainable production system and provide quality food for nutritional requirements of human and animals. The practices of integrated nutrient management relies on crop rotations and use of crop

residues, animal manures, legumes, green manures, organic farm wastes, crop residue, biofertilizers and minerals as natural fertilizer sources for supplying nutrients. Amongst the organic manure, FYM is one of the most traditional source, most readily available and widely used by the farmers since time immemorial. It increases soil microbiological activities, plays key role in transformation, recycling and availability of nutrients to the crop (Collins *et al.*, 1992). Through optimization of on-farm resources, maximum use of crop residues towards building soil fertility and minimum use of off-farm resources can meet the aim of sustainable nutrient management.

Therefore, new cultivation strategies like incorporation of biological fertilizers are required to reduce environmental risk with an increasing yield trend (Hedge *et al.*, 1999). Being cost effective, biofertilizer is eco-friendly and renewable source of plant nutrients to supplement chemical fertilizers in sustainable agricultural system by boosting farm productivity (Thavaprakash *et al.*, 2005). Inoculation of seeds with PSB plays a vital role in supplementing phosphorus requirements of crop and brings out more amount of fixed or unavailable native phosphorus into soluble and available form. *Rhizobium* are a group of gram-negative soil bacteria that are well-known for their symbiotic relationship with various leguminous crops (soybean, blackgram, alfalfa etc.). Inoculation of *Rhizobium* gave an additive effect over FYM, nitrogen and phosphorus application alone and its application with micronutrients increased grain yield and yield attributes in blackgram (Rathi *et al.*, 2009). Both, enzymatic activities as well as microbial population of bacteria, fungal and actinomycetes are improved with integrated use of concentrated manure and chemical fertilizers. Vermicomposting is one such viable technique for augmentation of organic source in soil. Application of vermicompost influences the physical, chemical and biological properties of soil and improves the water holding capacity as well. Use of vermicomposting is being proposed for sustaining soil fertility in various field crops. Integration of recommended doses of fertilizer along with farmyard manure or vermicompost would result in better yield of blackgram under rainfed condition (Sutaria *et al.*, 2010).

In the terrestrial eco-system, nitrogen is the most important essential major nutrient required for plant growth. It is an integral component of all amino acids, nucleic acids,

proteins, nucleotides, chlorophyll, chromosomes, ribosome, also a constituent of all enzymes and one of the major nutrients affecting soil fertility. The soil nitrogen system being a dynamic one, its content varies widely depending on soil texture, clay minerals, cropping pattern and use of manures and fertilizers. The nitrogen found in soil can generally be classified into inorganic and organic forms.

In most soils, 95–98% of total N is tied up in the organic compounds which are unavailable to plants. Only a smaller portion about 2 % of total N was in the inorganic forms like  $\text{NH}_4^+$ -N,  $\text{NO}_3^-$ -N and  $\text{NO}_2^-$ -N that are readily available to plants but are liable to different types of losses like denitrification, ammonia volatilization, runoff, leaching, and fixation by soil clay minerals. The efficiency of fertilizer N in upland crops generally ranges 40-50%. Traditionally, hot acid hydrolysis method quantifies and characterizes different organic N fractions (Bremner, 1965). Acid insoluble N or non-hydrolysable N (20–25% of the total N), ammonium-N (20–25%), amino acid N (30–45%), amino sugar N (5–10%) and hydrolysable unknown N (10–20%) are five main N fractions, commonly obtained (Stevenson, 1994). It is estimated that about half of the total N is yet to be properly identified after adding various proportions of N found in acid insoluble and hydrolysable unknown fractions.

In tropical and subtropical soils, unless replenished efficiently from unavailable forms, plant available N such as  $\text{NH}_4^+$  and  $\text{NO}_3^-$  are rarely adequate for crop production. Fertilizer application has a great impact on the fractions of soil organic N, directly through changing the composition of soil N and indirectly through affecting crop growth (Bird *et al.*, 2002). Gonzalez-Prieto *et al.* (1997) reported that major source of plant available N was hydrolysable organic N fractions, added recently through urea-N. Influence of several management practices like cropping system and inorganic and organic fertilization on changes of soil organic N can be broadly assessed from these fractions (Wander *et al.*, 2007). Increment in the proportion of amino acid-N and amino sugar-N is seen through variable N inputs while other soil humus fractions such as hydrolysable unknown N and non-hydrolysable N are reportedly decreased (Allen *et al.*, 1973). Transformation of nitrogen is a complex biochemical process brought about by a succession of different micro-organisms related to soil fertility. Particularly, the hydrolysable organic form of N is

mineralized slowly through aminization, ammonification and nitrification processes and become available to crops. As a readily available fraction of total N, PMN is an important potential source of N for crop growth and yield. In well drained soils, PMN is made available to plants and microorganisms, mostly in the form of nitrate, through aerobic mineralization. Significant effect of nitrogen in enhancing yield of blackgram has been reported by many workers (Hussain *et al.*, 2011 and Athokpam *et al.*, 2009).

On a long term basis, INM is an essential step to address yield trends and changes in nutrient dynamics and balances. The study on N transformation and quantifying N balance under intensive cropping system enables optimal N fertilization management practice for reducing environmental risks and improving N supplying capacity of soil. In comparison to the effects of different fertilization regimes on SON under wetland paddy fields, only a few studies have been conducted on irrigated upland crops. Moreover, most of the N transformation studies have largely been confined to the top soil, although plants also utilize N from deeper horizons. In tropical and subtropical climatic conditions, the SON transformation as affected by conjunctive use of chemical and biological fertilizers with lime, FYM and vermicompost is yet to be explored in blackgram crop to mitigate nutritional imbalance particularly in acidic soils. Hence, the research work was initiated with the following objectives:

- To study the availability of nitrogen in soils in relation to its nutrition to crops grown under long term INM practices.
- To monitor changes in nitrogen fractions of soil under long term INM practices.
- To determine the effect of long term INM practices on potentially mineralizable nitrogen status in different depths of soil under intensive cropping system.
- To evaluate the impact of long term INM practices on crop productivity.

## **CHAPTER-2**

---

### **REVIEW OF LITERATURE**

# REVIEW OF LITERATURE

---

Organic matter mineralization is one of the key processes affecting N cycling in agro-ecosystems (Janzen, 2004). Microorganisms are the mediators of soil N transformations, including biological N fixation, nitrification, and denitrification (Müller *et al.*, 2007). The distribution of N among inorganic and organic fraction, their relative abundance and contribution to crop yield and N uptake were studied by different scientists. Here, in this chapter, an attempt is being made to collect the available information pertinent to the present study entitled “Soil nitrogen transformation under long term INM practices in an acid *Inceptisols*”.

## **2.1. An overview of Integrated Nutrient Management**

The main challenges facing agricultural planners and farming decision makers in the coming few years' lies in vision world without hunger and zero poverty intensified with food security worldwide (Wheller and Braun, 2013). Recently, escalated call emerged, invited farmers and agricultural specialists to change their awareness towards substituting a part of inorganic fertilizers by cheaper, more sustainable, ecofriendly and efficient nutrients originating from natural resources under the bold strategy of integrated nutrient management. Assessment of basic soil fertility in relation to climate and nature of crop, not in isolation but as a part of cropping system and yield targets are the principles of INM which includes providing 30% of total nutrient levels in the organic form also. Intensive cropping system can remove annually 500-900 kg of NPK/hectare/year along with substantial quantities of secondary and micro-nutrients, thus increasing scope of balanced nutrient supply in relation to the expected yields. The major sources of organic which need to be harnessed into integrated plant nutrient supply system are crop residues, dung and urine from domesticated animals, waste from slaughter houses, human excreta, sewage, biomass of weeds, organic wastes from fruits and vegetables production, household wastes, sugarcane trash, oilcakes, press mud, basic slag, phosphogypsum, and fly ash from thermal power plants.

## **2.2. Soil nitrogen fractionation**

Organic compounds shares around 95 to 98 % of total N in most of the soils and the remainder of about 2-5 % is in inorganic forms that are readily available to plants.

### **2.2.1 Soil inorganic nitrogen**

Das *et al.* (1997) reported that the main type of soil N is Inorganic Nitrogen that can be directly absorbed and utilized by plants, but only accounting 1% in the Total Soil N.

The rate of inorganic N added also enhanced the nitrate-N possibly due to the conversion of applied inorganic N via nitrification process as revealed by Yadav and Singh (1991). Higher content of  $\text{NO}_3^-$ -N in soil as a result of increased N addition has been reported by Brar and Brar (2002).

Inorganic N fertilizer is one of the most important anthropogenic inputs related to biological turnover and abiotic cycling of N in agricultural ecosystems (Bol *et al.*, 2005 and 2008).

Yang *et al.* (2008) concluded that organic nitrogen mineralization from plant residues can increase soil inorganic nitrogen concentrations. Mineralization of soil organic N to inorganic N includes ammonification and nitrification with former providing readily available N for plant uptake and substrates for latter and latter influencing plant N uptake and N losses from soil-plant system through leaching and conversion to gaseous N compounds.

A comparative study was conducted by Li-Lin *et al.* (2008) to determine the  $\text{NH}_4^+$  and  $\text{NO}_3^-$  concentrations in soil profiles in adjacent forest, grassland, and cropland soils on the Tibetan Plateau. The concentration decreased sharply with increasing soil depth. The  $\text{NH}_4^+$ -N concentration did not show significant changes with soil depth except at 0–20 cm depth in the forest soil where the  $\text{NH}_4^+$ -N concentration was slightly higher than in the deeper layers.

Nitrate and ammonium are major form of inorganic N in soil and as a source of inorganic N absorbed by crop, help to determine the fertility of the soil. However, nitrate can easily leach into deeper layer soil and escape as runoff with precipitation (Kunrath *et al.*, 2015).

### **2.2.2. Soil organic nitrogen**

Stevenson (1982) concluded that amino acids comprise the largest hydrolyzed N pool, varying from 20-45%. Amino sugars, identified mainly as glucosamine, galactosamine and muramic acids by using gas chromatography, represent between 5 %

and 10 % of SON. Amino sugars contributed a small percentage in the total soil residual fertilizer N, but its direct effect was significant indicating that a portion of fertilizer N could be directly immobilized and stabilized as microbial residues (He *et al.*, 2011).

The amounts of all four hydrolysable N fractions [amino acid-N (AAN), amino sugar-N (ASN), ammonia-N (HAN), hydrolysable unknown N (HUN)] and non hydrolysable N (NHN) decreased significantly in unfertilized treatment. Amino acids are closely associated with microbial metabolism, simultaneously serving as an important storage pool for the immobilized N (Amelung, 2001) and a main source of available N for soil microorganisms and plants (Werdin-Pfisterer *et al.*, 2009).

The total hydrolysable N (THN) was accounted for 75.8 to 82.8 % of the total N content of the soil and was constituted by 32.7 % of AAN and 30.4 % of HAN in the long term fertilizer plots after 13 years of cropping on an acid soil of Palampur (Kher and Minhas, 1992).

Researchers have attempted to examine specific organic N fractions that may become plant available throughout the growing season. Amino compounds are reportedly sensitive to organic amendments, such as manure and may affect the native N fertility of a soil (Wander, 2004).

Exchangeable  $\text{NH}_4^+$  and some of the different fraction from the breakdown of amines, hydroxyamines and other aminoacids such as aminosugars, purines and pyrimidines (Schnitzer and Hindle, 1980) and some release from fixed  $\text{NH}_4^+$  are the main sources of Hydrolyzable ammonium nitrogen in soil hydrolysis (Stevenson, 1982). Rate of mineralization of the protein fraction of added organic material affects the build-up of total amino acid-N in the soil (Sihag *et al.*, 2005).

The classical theory of Soil Organic Nitrogen (SON) availability for crops indicates the biochemical transformation of SON to release inorganic N ( $\text{NO}_3^-$  and  $\text{NH}_4^+$ ), which is generally preferred for uptake. The direct absorption of dissolved organic nitrogen (DON) is an important source of Nutrition, particularly in sandy soils low in N-supplying capacity and in the absence of external chemical sources (Jones *et al.*, 2005).

Rilling *et al.* (2007) concluded that NHN has been primarily identified as structural components which are either N-phenoxy amino acid or largely non-protein compounds. Therefore, enrichment of NHN probably resulted from the stabilization process of fertilizer

derived organic N fractions. The NHN was lower than THN portions suggesting the preferential conversion of residual fertilizer N into the fraction with high availability during rice growing season.

Gajbhiye and Bhoje (2014) reported that the nitrogen forms viz., total hydrolysable N, amino acid N, acid insoluble N, ammonical N and nitrate N is higher in *Vertisols* compared to *Inceptisols*. Comparatively higher values of different forms of nitrogen under *Vertisols* and *Inceptisols* may be due to greater heterogeneity in content of organic matter and high organic carbon content were reported by Singh and Singh (2007).

### **2.3. Effect of fertilization and manure application in the distribution of different forms of soil nitrogen**

#### **2.3.1. Distribution of soil inorganic nitrogen**

The combined application of 100 % NPK+ FYM resulted higher  $\text{NO}_3^-$ -N content of soil as compared to control. It could be due to increased microbial activity and resultant enhanced nitrification process (Khankhane and Yadav, 2000)

Duraisami *et al.* (2001) reported that the increasing rates of NPK application had a favourable influence on exchangeable  $\text{NH}_4^+$ -N in soil. Exchangeable  $\text{NH}_4^+$ -N contents was low in the treatments where nitrogen applied only through fertilizers, probably because of leaching loss.

Duhan *et al.* (2005) concluded that the increase of  $\text{NH}_4^+$ -N and  $\text{NO}_3^-$ -N content in soil over control throughout the incubation period was attributed to increased microbial population and N content due to application of FYM.

Gupta *et al.* (2005) studied distribution of mineral N in soil profile at different growth stages of wheat and reported that nitrate contents in different soil layers was more than that of  $\text{NH}_4^+$ -N at each growth stage of wheat and total mineral N content at different depths was influenced by the total quantity of N applied irrespective of the source.

Increase in inorganic forms of N with integrated use of manure and fertilizers were also reported by Manivannan and Sriramachandrasekharan (2009). Incorporation of organic residues helped enhance N content in an *Alfisols* (Sharma *et al.*, 2014).

Kurrey (2014) reported the combined effect of dose of fertilizer and green manure in *Vertisols*. Study revealed that during entire growing period,  $\text{NH}_4^+$ -N was recorded highest in 50% recommended dose of fertilizer (RDF)+green manure (GM) treated plot and

highest value of  $\text{NH}_4^+\text{-N}$  was recorded at 52 days after transplanting ( $50.97\text{kg ha}^{-1}$ ) while  $\text{NO}_3^-\text{-N}$  release from 16 to 97 days after transplanting and it was more in 50% RDF+GM dose.

Recently a long-term experiment was conducted by Suzuki *et al.* (2017) on soil N dynamics in the rainy season which focused on the effects of soil management with sole and combined applications of mineral and organic fertilizers and observed that inorganic N ( $\text{NO}_3\text{-N} + \text{NH}_4\text{-N}$ ) increased in the soil surface right after fertilizer application but its effect disappeared in a few weeks.

### **2.3.2. Distribution of soil organic nitrogen**

In a long term field experiment conducted on nitrogen fractions and their relationship with mineralizable N and its uptake by crops in a sandy clay loam soil of New Delhi, under maize-wheat-cowpea (fodder) cropping system, Sarawad *et al.* (2001) observed that application of graded levels of fertilizer application for 27 years significantly increased in hydrolysable N, amino acid N, amino sugar N, exchangeable  $\text{NH}_4^+\text{-N}$  and mineralizable N. They concluded that application of either fertilizers alone or their conjunctive use with FYM leads to an improvement in the organic fractions which are considered active pools of available N. They also observed that mobilization of N through microbial decomposition of organic source results in an increase in non-Hydrolyzable Nitrogen in the soil.

Sihag *et al.* (2005) concluded that application of chemical fertilizers alone or their combined use with organic manures significantly increased all the forms of nitrogen except unidentified hydrolysable-N both over control and their initial status. They further observed that among various N fractions, amino acid N was the dominant N fraction

Sarawad and Singh (2005) studied that long-term application of 100 per cent NPK + FYM resulted in highest amount of total-N in soil which was closely followed by 150 per cent NPK while application of 150 per cent NPK resulted in the highest amount of hydrolysable  $\text{NH}_4^+\text{-N}$  and of  $\text{NO}_3^-\text{-N}$ . Amino acid N content was highest in soils under 100 per cent NPK+S treatment. AAN and HAN were dominant fractions of N in soil irrespective of treatment. Long-term use of optimum dose of NPK either alone or in

conjunction with FYM+S resulted in a significant increase in the amount of hydrolysable N fraction in soil.

Ravankar *et al.* (2005) reported the higher content of total hydrolysable nitrogen and amino acid N in the treatment with 100 per cent recommended doses of NPK with FYM while least was observed in control plot in the soils of Vidarbha. Amino acid N, amino sugar N, amine N and hydrolysable NH<sub>4</sub>-N can provide an assessment of soil organic N changes induced by management such as cropping system and inorganic and organic fertilizations Wander *et al.* (2007) .

Sekhon *et al.* (2011) found that THN increased significantly from its initial level of 319 mg/kg soil to 352 mg /kg soil and also an increase in NHN and total N with the application of mineral fertilizer while studying the effect of long-term application of manure and mineral fertilizer application on the distribution of organic nitrogen fractions in soil after 7 year under a rice–wheat cropping system at Hissar. The magnitude of the increase in THN over its initial level, however, was more with a combined application of organic manure.

Bharti (2013) reported that the continuous use of chemical fertilizers and amendments for thirty six years in an acid *Alfisols* brought out marked increase in the organic and inorganic fractions of N, total N and organic carbon content compared to the untreated plots. Also, inorganic N and organic N contributed 4.3 and 95.7 per cent, respectively towards total soil nitrogen (Subehia and Dhanika, 2013). It was further reported that non hydrolysable and amino acid N were dominant organic fractions. Similarly, among all the fractions, hydrolysable ammonical-N was found to play major role in the supply of nitrogen. Similar results were observed by (Kaur and Singh, 2014).

The long-term use of fertilizers and organic manures differentially influenced mineral N (NO<sub>3</sub><sup>-</sup>-N and NH<sub>4</sub><sup>+</sup>-N), organic N fractions, and total N in soils (Durani *et al.*, 2016). They also observed that organic N fractions constituted about 94.2 % of total N as compared with 5.8 % share of mineral N. Nitrate N was 4.4 times higher than NH<sub>4</sub><sup>+</sup>-N fractions. Application of fertilizers improved available N in soil. On an average, amino acid-N (AAN), amino sugar-N (ASN), ammonia-N (AN), and hydrolyzable unknown-N (HUN) constituted about 27.9, 10.5, 28.7, and 32.7 % of the total hydrolyzable-N, respectively. The magnitude of increase in all the hydrolysable N fractions over the initial

level was higher with combined application of inorganic fertilizers and organic manures as compared with inorganic fertilizers alone. Combined application of manures and mineral fertilizers compared with mineral fertilizer treatments increased THN and NHN because of the mineralization and release of N contained in the manures (FYM, green manure and straw) on their decomposition caused by a favourable environment provided by the former compared with the latter.

### **2.3.3. Distribution of soil available nitrogen and total nitrogen**

Organic carbon and available N status were reportedly increased with an increase in urea N on rice-wheat sequence after two years experimentation at Ludhiana (Gupta *et al.*, 2000). Leinweber and Schulten (2000) concluded that primary source of potentially available N in various soils was organic matter bound to the heavy soil fraction. Combined application of NPK at 100 % and FYM increased the total nitrogen content in soil. It has also been reported that increase in the level of applied N along with FYM, there would be corresponding increase in organic matter in turn the total N content of soil (Prabhugouda, 2001).

A study conducted on the influence of integrated nutrient management on nitrogen and phosphorus under wheat-mungbean-maize cropping system demonstrated that the available N increased with increased application of fertilizer during all the sampling stages of maize (Begum *et al.*, 2007).

In a long-term fertilizer experiment Jagadamma *et al.* (2007) studied the comparative effect of five graded doses of N and two different cropping systems [continuous corn (*Zea mays* L.) (CC), and corn-soybean (*Glycine max* (L.) Merr.) rotation (CS)] on total nitrogen (TN) concentrations and pools. They found that the long-term N fertilization and cropping systems significantly influenced TN concentrations and pools which increased significantly up to 30 cm depth. However, TN concentration below 30 cm depth was statistically similar among different rates of N. The highest TN concentration was noticed in 0-10 cm depth for all N rates, and it gradually decreased with soil depth, but not below 20 cm depth.

In another experiment, Whalen *et al.* (2008) reported the effect of compost application on nitrogen pools where composted cattle manure was applied to each plot with

supplemental NPK fertilizers to meet crop requirements. The total N and  $\text{NO}_3^-$ -N pools were greater in plots that received the highest rate of compost.

Katkar *et al.* (2011) concluded that combined application of FYM with 100 % NPK recorded highest soil available nitrogen as compared to the plots where only 100 % NPK was applied. Such increase in available N might be due to multiplication of microbes leading to mineralization and enhanced conversion of organically bound N into inorganic forms thus, made available to crops. Soil organic carbon and total nitrogen of soil varied significantly with long-term application of manure and mineral fertilization.

Another comparative study on pools of different fertilizer grades of nitrogen per year basis found no significant effects on soil TOC (total organic carbon) and TN (total nitrogen) concentrations (He *et al.*, 2012) though significant increase was seen in soil  $\text{NO}_3^-$ -N and  $\text{NH}_4^+$ -N concentrations compared with the control. Nayak *et al.* (2013) reported that total N significantly increased with integrated nutrient management. The highest values for total N content were recorded in integrated treatment with inorganic fertilizer and organic manures.

#### **2.4. Depth wise distribution of organic and inorganic forms of nitrogen**

Application of recommended rate of 120 kg/ha fertilizer nitrogen to both rice and wheat in split doses for 4 years resulted in a significant increase of 35 kg/ha  $\text{NO}_3^-$  over control while 74 % of this increase occurred in the 90 to 150 cm soil depth (Aulakh *et al.*, 2000)

Bhandari *et al.*, (2002) reported that total N content in the surface layer (0–15 cm) increased over its initial values with continuous rice-wheat cropping system except in unfertilized plots. The amounts of total N were lower in sub-surface soil (15–30 cm) than in surface soil.

Long-term cropping without fertilization led to a decline in the amino sugar-N content by 19 % and 12 % in surface and subsurface layer, respectively. The content of unidentified-N in surface and subsurface layer decreased by 12 % and 7 %, respectively due to continuous cropping without fertilization. Total hydrolysable-N followed almost similar trend as its constituent fractions. Unlike hydrolysable fraction, non-hydrolysable-N was not influenced significantly by the use of chemical fertilizers alone or in combination with amendments (Bharti, 2013).

Bhattacharyya *et al.* (2013) demonstrated that application of FYM, along with NPK as balanced fertilization resulted in higher labile N pools as compared to the application of NPK alone in a 39 years long term fertilizer experiment under rice-rice cropping system. There was a decrease in soil available N status with increasing soil depths in all the fertilizer treatments because of a decrease in root bio mass and additional flower amount of root biomass, root exudates etc., as compared to surface soil.

## **2.5. Influence of biofertilizers on nitrogen fractions and mineralization**

Shinde *et al.* (2006) reported the increase of ammonical nitrogen in saline sodic soil by the use of urea+FYM+Azotobacter which may be associated with slow rate of mineralization of nitrogen. The increase in nitrate nitrogen in saline sodic soil by urea+FYM+Azotobacter might probably be due to increased process of nitrification. The nitrate nitrogen remains available for longer period due to combined application of urea and FYM.

Das *et al.* (2013) conducted an experiment on finger millet in red lateritic sandy loam soil in Odisha and showed that soil available N was reportedly increased to about 278 kg ha<sup>-1</sup> due to application of *Azotobacter* and PSB, along with increase in root and shoot biomass, available P, K and SOC content.

In a study of long term effect of organic manures and biofertilizers on dynamics of carbon and nitrogen under rice-wheat cropping system, Kumar (2015) stated that application of green manure, farm yard manure and biofertilizer showed higher amount of total carbon and total soil nitrogen in all three depths of soil. He also concluded presence of higher acid insoluble nitrogen than the rest of the treatments.

## **2.6. Biological fertilizers on soil nutrient availability and crop productivity**

The combined inoculation of Rhizobium and PSB imparted favourable effect due to synergistic interaction among phosphate solubilizing microorganism and *Rhizobium*, which lead to increased availability of nutrients (Khatkar *et al.*, 2007).

Positive effects of phosphobacterium (*Bacillus megatherium var.phosphaticum*) inoculation on nodule numbers, grain yield and P uptake by cowpea and available P status of soil after cowpea harvest were observed by Duraisami and Mani (2001).

Sharma and Sharma (2002) stated that available N, P and K status of soil was significantly increased with application of fertilizers, FYM and BGA either separately or

in combination over the unfertilized and unmanured plots in a long-term experiment based on rice based cropping systems while no significant effect on available N was observed with application of different combinations of NPK.

Gautam and Pant (2002) studied that significantly higher N content in soil at harvest was due to co-inoculation of phosphate solubilizing bacteria (PSB) with *Bradyrhizobium japonicum* which also increased nodule number and nodule dry weight of soybean at various growth stages. Synergistic effect of phosphorus rate and *Pseudomonas* species in combination with *Bradyrhizobium japonicum* and farmyard manure was suggested on seed yield and yield attributes of soybean (*Glycine max*) (Gautam *et al.*, 2003). Also, Seeds per plant were significantly higher in the PSB treated plot. Jain and Trivedi (2005) reported that inoculation of *Bradyrhizobium* and PSB alone or in combination markedly increased the N, P content and uptake in grain and straw yield. Sanjeev Chauhan *et al.* (2006) suggested that drymatter accumulation increased with increasing levels of nitrogen and phosphorus in soybean which could be ascribed to increased cell division and cell enlargement and better root growth.

Patel and Thakur (2003) observed that yield attributes and yield of urdbean were significantly influenced with phosphorus levels, PSB and FYM. They also observed an increasing trend in harvest index with increasing levels of phosphorus and application of PSB and FYM. Tomar *et al.* (1998) noticed that P application and inoculation treatments increased the nodulation, plant biomass, grain and straw yields, N and P content in blackgram. They also reported that residual effects of inoculation with *Rhizobium*, VAM and PSB individually or in combination and phosphorus applied to blackgram were significant on wheat. Plant dry weight, grain and straw yields and N and P uptake by wheat increased significantly.

Singh *et al.* (2007) reported that the inoculation, nitrogen and phosphorus application enhanced the nodulation, weight of nodules, growth and yield of cowpea in an experiment conducted on effect of nitrogen and phosphorus levels on inoculated cowpea. *Rhizobium* significantly increased N, P content, uptake of N and P by grain and straw as well as availability of nutrient and their translocation in Cowpea which might be due to nitrogen fixation by *Rhizobium* that makes plant roots more efficient to absorb the nutrient and producing chelating compounds (Dekhane *et al.*, 2011).

## **2.7. Effect of long term nutrient management on crop quality and crop productivity**

Nagarajan and Balachandar (2001) at Pudukkottai (Tamil Nadu) revealed that application of FYM @15 t ha<sup>-1</sup> significantly improved nodulation of blackgram and greengram over control. They further reported that number of nodules per plant was found at par with control in black gram as well as in green gram in acidic soils.

Singh and Singh (2006) at Pantnagar (Uttaranchal) reported that application of FYM @ 5 t ha<sup>-1</sup> recorded significantly higher grain yield of urdbean over no application. The per cent increase was 6.54 and 13.40 over no FYM during 2002 and 2003, respectively.

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.

Ren *et al.* (2014) reported that if no organic manure is applied, SOC concentration, especially for total organic carbon, will decline significantly. Therefore, integrating nutrient management, including optimized N fertilizer input enhanced the soil organic matter content, which should be considered to maintain soil fertility and productivity.

Yang *et al.* (2015) studied the combination of inorganic and organic fertilizer can substantially increase SOC and crop yields and concluded that SOC decreased with less inorganic fertilizers application and SOC increased with the addition of corn stalks. Also, there was a trend that the crop yields had a relationship with SOC. More than twenty years of continuous winter wheat–summer corn rotation cultivation revealed a significant correlation at  $p < 0.05$  level between crop yields and SOC. The mineralization amount of SOC had a significant correlation at  $p < 0.05$  level with wheat yield which can confirm the result of crop yield related to SOC.

## **2.8. Relationship of different forms of nitrogen with N availability, N uptake and crop yield**

Singaram and Kamalakumari (2000) reported that the increased N uptake in treatments receiving 100 % NPK+ FYM in an *Inceptisols* may be due to beneficial effects of organic manure in increasing and sustaining the availability of nutrients in soil.

Grain and straw yields of sorghum were significantly correlated with  $\text{NH}_4^+\text{-N}$  and  $\text{NO}_3^-\text{-N}$  while the same fractions with hexosamine and amino acid N enhanced N uptake at different growth stages (Duraismi *et al.*, 2002).

When N-fertilizers, particularly urea, are applied as top dressing to crops, fertilizer recoveries may be high usually in humid climates. Nevertheless, very low fertilizer recovery may also result from delayed application because of ammonium volatilization of the applied-N or because of dry conditions following application particularly in arid and semi-arid climates (Bacon and Freney, 1989).

Application of imbalanced nutrients could lead to declining nutrient-use efficiency making fertilizer consumption uneconomical and adversely affecting the atmosphere (Aulakh and Adhya, 2005).

Salvogiotti *et al.* (2008) observed that the on average,  $\text{N}_2$  fixation accounted 52% of total N uptake but the proportion of fixed N decreased with increasing fertilizer N-additions. Soybean in which less than 10kg N/ha as fertilizer this relative contribution of  $\text{N}_2$  fixation increased up to 58%. While negative exponential relationship was observed between N- fertilizer and  $\text{N}_2$  fixation.

Snyder (2009) and Ladha *et al.* (2005) suggested values of Recovery efficiency of N between 30–50% as typical for N recovery in cereals and values between 50–80% as achieved in the best management in cereals. However, the efficiency of nutrient use may be enhanced by the combined use of organic and inorganic fertilizers (Kumar *et al.*, 2014).

Sharma *et al.* (2014) concluded that all fractions of N, except HUN, NHN, and SON, were strongly interdependent and had a positive influence on grain yield and N uptake by rice and wheat crops.

## **2.9. Potentially mineralizable nitrogen**

Potentially mineralizable N is often measured to assess the capacity of soil organic matter to supply inorganic N as it plays a dominant role in N nutrition of crops. 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).

In an incubation study in the laboratory, Duhan *et al.* (2005) showed that the  $\text{NH}_4\text{-N}$  content in soil increased upto one week of incubation in all treatments and then declined

thereafter. The  $\text{NO}_3\text{-N}$  content in soil increased after first week of incubation under all treatment. Increase was relatively higher between 5<sup>th</sup> and 7<sup>th</sup> week of incubation under all the treatments and it became stable onwards. Application of N and FYM increased  $\text{NO}_3\text{-N}$  content in soil and maximum increase was observed between 1<sup>st</sup> and second week of incubation. However, Jagtap *et al.* (2007) noticed that the  $\text{NH}_4^+\text{-N}$  content was increased significantly with an increase in incubation period upto 20 days. Thereafter it was drastically reduced at 20 and 30 days of incubation in medium black *Vertic Ustrocrept*. The drastic reduction might be associated with transformation of the  $\text{NH}_4^+\text{-N}$  to  $\text{NO}_3\text{-N}$ .

Goel and Duhan (2011) observed that  $\text{NH}_4^+\text{-N}$  content of incubated soil increased upto first week, thereafter, it decreased during all the incubation periods. Application of organic manures at higher rates released significantly higher contents of  $\text{NH}_4^+\text{-N}$  over lower rates of organic manures throughout the incubation study.  $\text{NO}_3^-\text{-N}$  contents increased significantly in control as well as in organic manures treated soils throughout the incubation study. Swarnam (2013) reported that there was a significant increase in the rate of N mineralization in the first one week in which the highest rate of N mineralization of 0.24 and 0.23  $\text{mg day}^{-1}$  respectively, from 48<sup>th</sup> day after incubation.

In an experiment on nitrogen mineralization in loam soil, Abbasi *et al.* (2016) found that the N mineralization of the soil amended with full dose of poultry manure (PM) was almost negligible at the start (2.3  $\text{mg kg}^{-1}$ ), but progressively increased with time, and the highest concentration of 105.1  $\text{mg kg}^{-1}$  was attained at day 63. Thereafter, the concentration remained statistically unchanged. The soil amended with urea N (UN) exhibited the highest N mineralization during the initial phase, and the maximum N release of 193.3  $\text{mg kg}^{-1}$  was observed at day 6. Thereafter, the concentration tended to decline with time, most likely because of simultaneous nitrification-denitrification processes in the system in addition to possible chances of immobilization.

## **2.10. Effect of manures and fertilizers on mineralization potential of nitrogen in soil**

Zhang *et al.* (2012) concluded that repeated applications of mineral and/or organic fertilizer enhanced mineralization from recalcitrant organic N, the application of organic fertilizers stimulated the mineralization of labile organic N. Gross  $\text{NO}_3^-\text{-N}$  production solely resulted from  $\text{NH}_4^+\text{-N}$  oxidation.

Mariano *et al.* (2013) reported the nitrogen mineralization potential at different depths (0-20, 20-40 and 40-60 cm) of soil and observed an abrupt increase in mineralized N (Nm) during the initial periods of long-term aerobic incubation, especially for the soil samples in the 0-20 cm depth as compared to those from subsurface depths. A subsequent reduction and relative stabilization of Nm was observed after the 6th week.

Shahid *et al.* (2017) in a recent study investigated the effect of long-term application of manure and fertilizer on nitrogen mineralization in a field experiment started in 1969 in rice-rice mono-crop (from July–November in wet season followed by January–May in dry season) per year. Higher cumulative nitrogen mineralization (Nmin) was observed in NPK+FYM treatment which was significantly greater than rest of the treatments except N+FYM. Additions of N and NPK have resulted in significantly higher Nmin over control, but no significant difference was observed among them. The data further revealed that Nmin in N, NPK and FYM were statistically at par. In a meta-analysis, Chen *et al.* (2018) studied on the effect of nitrogen addition on net N-mineralization rate and found that it was significantly increased by  $76.6 \pm 25.5$  %, in response to nitrogen addition.

### **2.11. Relationship among different fractions of nitrogen**

Sharifi *et al.* (2007) concluded 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). Singh and Singh (2007) found that total N as is evidenced by highly significant positive correlation of organic N with total N. Total N with inorganic N showed positive correlation.

Findings from the experiment conducted by Martin and Kachhave (2009) observed significant positive relationship between available N and hydrolysable ammonium, acid insoluble N and nitrate N. However there was no positive significant correlation showed between total hydrolysable N and ammonical N. Similarly, total N, ammonical N, and nitrate N, total hydrolysable N, hydrolysable ammonium and acid insoluble N was positively correlated with available nitrogen (Nayak *et al.*, 2013).

Tabassum *et al.* (2010) revealed that total hydrolysable N, amino acid N, hydrolysable ammonium and non-hydrolysable N in surface soils and total hydrolysable N, amino acid –N, hydrolysable ammonium and hexoseamine N fractions of sub surface soils

were significantly related to the mineralizable N. However, best correlation of mineralizable N was found with hexoseamine-N followed by amino acid-N in surface soil and for hydrolysable ammonical N followed by amino acid- N in sub-surface soil. Similar observation was also accorded by Bharti (2013) that different organic and inorganic fractions were significantly and positively correlated with available N at 0-15 cm and 15-30 cm the depths. However, the highest value of correlation (r) was found in case of hydrolysable ammonical-N and lowest in case of non-hydrolysable-N. Stepwise multiple regression analysis revealed that about 54% and 56% variation in available N at surface and subsurface soil layer, respectively, was explained by hydrolysable ammonical-N alone.

## **CHAPTER-3**

---

### **MATERIALS AND METHODS**

# MATERIALS AND METHODS

---

In order to achieve the objectives of present investigation entitled “**Soil nitrogen transformation under long term INM practices in an acid *Inceptisols***”, the long term integrated nutrient management practices was conducted with the help of a field experiment at Odisha University of Agriculture and Technology (OUAT), Bhubaneswar. The details of materials used and methods adopted during the course of experiment are described in this chapter.

## **3.1 Field experiment:**

### **3.1.1 Location of experimental site**

The long term field trial is in continuation in the Department of Soil Science and Agricultural Chemistry since 2010. The site is located at 25°15' N latitude and 80°52' E longitude and altitude of 25.9 m above mean sea level (MSL) which is 60 kms west of the Bay of Bengal. The present crop blackgram was 25<sup>th</sup> crop in the sequence. This crop inherited residual effects of 24 crops grown in succession. Every year three succeeding crops are grown viz., cereal-vegetable-pulse in sequence. The crop residues are incorporated in situ.

### **3.1.2 Climate and Weather condition**

During the growing period of the crop, the minimum temperature ranged from 26°C during July-August 2019 to 27.4°C during May 2019 and the maximum temperature ranged from 32.1°C during August 2019 to 37.1°C by May 2019.

The test crop black gram (cv. PDM-139) received 144.6 mm rainfall during June to 341.7 mm during July 2019. During the crop growth period, the relative humidity ranged from 68 to 92.4 per cent. The data related to weather condition during the study period from May 2019 to August 2019 is presented in Table 2.

### **3.1.3 Soil of the experimental site**

The soil was loamy sand texture in the beginning. The initial physico-chemical properties of the soil as measured during 2010 are listed in Table 1.

**Table 1: Physico-chemical properties of the initial surface soil**

SL. No	Properties	Value
1	Textural class	loamy sand
2	pHw (1:2.5)	5.14
3	Organic Carbon (g kg <sup>-1</sup> )	2.7
4	Available N (alkaline KMnO <sub>4</sub> ) (kg ha <sup>-1</sup> )	207
5	Bray's 1 phosphorus (kg ha <sup>-1</sup> )	37
6	Available K (neutral normal Ammonium Acetate) (kg ha <sup>-1</sup> )	84
7	CaCl <sub>2</sub> extractable sulphur (kg ha <sup>-1</sup> )	25

**Table 2: Meteorological data during crop season:**

Month	Temperature (°C)		Rainfall Monthly (mm)	Relative Humidity (%)		Bright sunshine hours (hr)	Evaporation (mm)	Total Rainy days per Month
	Max	Min		7hr (AN)	14hr (FN)			
May	37.1	27.4	197.7	91.9	54.5	7.9	8.1	2
June	35.5	26.6	144.6	90.7	63.6	6.4	6.5	9
July	32.9	26.0	341.7	92.4	73.7	4.4	3.4	17
August	32.1	26.0	319.4	94.5	78.5	2.6	3.1	15
Mean	34.4	26.5	250.9	92.4	68	5.3	5.3	11

Source: Meteorological Observatory, College of Agriculture, OUAT.

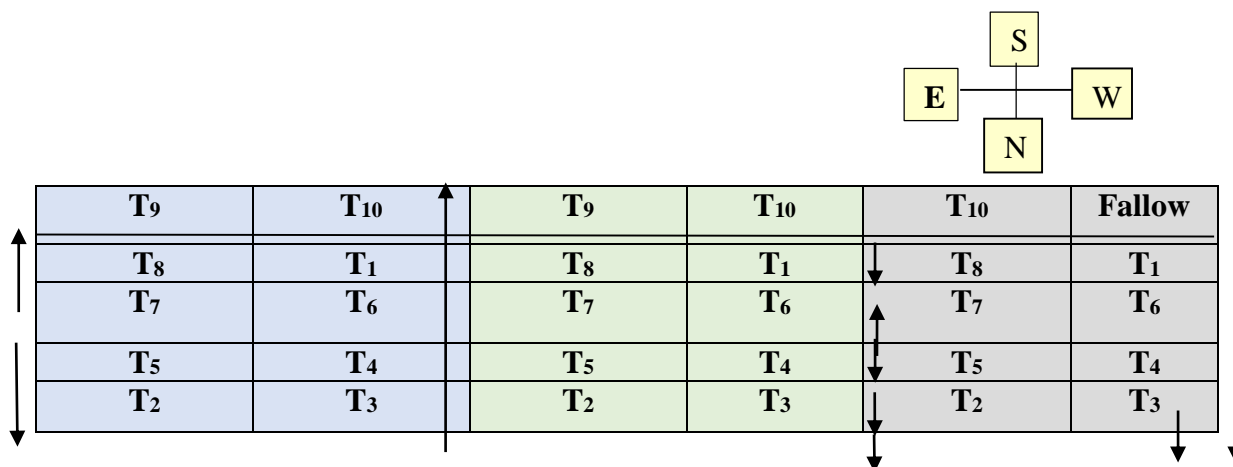
### 3.1.4 Treatment details

T <sub>1</sub>	Absolute control	T <sub>6</sub>	STD + FYM + L+ BF
T <sub>2</sub>	STD + FYM	T <sub>7</sub>	STD + VC + L + BF
T <sub>3</sub>	STD + VC	T <sub>8</sub>	STD
T <sub>4</sub>	STD + FYM + BF	T <sub>9</sub>	BF
T <sub>5</sub>	STD + VC + BF	T <sub>10</sub>	50%STD + BF

\* STD = soil test dose, FYM = farm yard manure, VC = vermicompost,

BF= biofertilizer and L = lime.

Each treatment was replicated three times and imposed over a statistically laid out field with RBD design (Fig-1)



**Fig- 1 Layout of treatments in the experimental field**

(Arrows indicate the direction of irrigation applied)

### 3.2. Materials

#### 3.2.1 Recommended dose of nutrients, liming material and fertilizer and biofertilizer sources

The test crop received N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O-SO<sub>4</sub> @ 30-13-30-30 kg ha<sup>-1</sup> in the form of urea, navaratna (20-20-0-13) and MOP respectively. The FYM and vermicompost were applied @ 5 t ha<sup>-1</sup> and 2.5 t ha<sup>-1</sup>, respectively. Biofertilizers like *Rhizobium* was seed inoculated @ 50 g kg<sup>-1</sup> seed and PSB for soil application was applied @ 4 kg ha<sup>-1</sup> as per treatment. The inorganic nutrients as fertilizers were applied in two splits and organics and biofertilizers as basal. Lime was applied @ 0.2 LR as paper mill sludge as per the treatment specificity.

#### Mode of fertilizers application

	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	SO <sub>4</sub>
	%			
<b>Basal</b>	100	100	50	100
<b>20days after sowing</b>	-	-	50	-

#### Nutrients added in respective treatments (kg ha<sup>-1</sup>)

INM packages	N	P	K	SO <sub>4</sub>	Total
	(kg ha <sup>-1</sup> )				
STD	30	13.1	32	20	95.1
STD+F	55	25.1	48	29	167.1
STD+VC	60	31.1	54	24	169.1

#### 3.2.2 Intercultural operations and plant protection measures

Intercultural operations like hoeing, weeding, irrigation and plant protection measures were carried out as and when required to raise a good crop. The crop was sprayed with chloropyriphos @ 1% five days after sowing and another with monocrotophos @ 0.1% before flowering.

### **3.2.3 Collection and processing of soil samples**

Representative composite soil samples were collected before initiation of the experiment from the depth of 0-15 cm and 15-30 cm after harvesting of blackgram from all the treatments and its residue was incorporated during 2019-20.

The collected soil samples were then dried under shade, grinded with wooden hammer and sieved through 2 mm (100 mesh) sieve. The samples were preserved in polythene bags with proper labels for analysis.

### **3.2.4 Collection of plant samples**

The different plant parts like seed, stover and siliqua were collected after the harvest of the crop and kept in envelopes separately and labeled accurately. These envelopes were dried in hot air oven till a constant weight was recorded. Each sample was grinded separately and used for of different element analysis.

## **3.3. Methods of soil analysis**

The processed soil samples were subjected to various physicochemical analysis following standard methods which are given below:

### **I. Soil pH (w):-**

The soil pH was determined in 1:2.5 soil and water suspension by using glass electrode pH meter (Jackson, 1973).

### **II. Electrical conductivity (EC) :-**

The EC (dS/m) of the soil was determined in 1:2.5 soil and water suspension by using conductivity meter (Jackson, 1973)

### **III. Organic carbon content of soil:**

The Organic carbon content of soil was determined by wet oxidation and heat of dilution procedure of Walkley and Black as outlined by Page *et al.*, 1982.

### **IV. Available nitrogen (N):-**

Available nitrogen in soil (easily oxidizable) was determined by alkaline  $\text{KMnO}_4$  method (Subbiah and Asija, 1956).

**V. Available phosphorous (P):-**

Available phosphorous in the soil was determined by Bray's 1 method (Bray and Kurtz, 1945) as outlined by Page *et al.*, (1982).

**VI. Available potassium (K):-**

Available potassium was determined by extracting the soil with neutral normal ammonium acetate ( $\text{NH}_4\text{OAC}$ ) solution and estimated by flame photometer as described by Jackson, 1973.

**VII. Total nitrogen (N):**

Total nitrogen was determined by standard Kjeldahl's method described by Page *et al.* (1982) in digestion block at reactor digestion system with controlled temperature.

**VIII. Soil nitrogen fractionation**

The fractionation of soil nitrogen was carried out by an adopted version of the procedure given by Page *et al.* (1982).

**(a) Inorganic fractions of Nitrogen**

**1)  $\text{NH}_4^+$  and  $\text{NO}_3^-$  forms of Nitrogen**

It was determined by following the procedure given by Bremner and Keeney (1996). Soil samples were subjected to 2M KCl extraction and extract was analyzed for  $\text{NH}_4^+$ -N using MgO and  $\text{NO}_3^-$ -N with *de varda's* alloy by steam distillation. The distillate was collected in a 2% boric acid medium containing mixed indicator and titrated against 0.02 N  $\text{H}_2\text{SO}_4$ .

**(b) Organic nitrogen fractions**

Different fractions of the soil organic nitrogen were analyzed using the procedure prepared by Stevenson (1996).

**1) Preparation of soil hydrolysate**

Soil samples after extraction with 2 M KCl were digested with 40 ml 6 N HCl and 2 drops of n-octyl alcohol by heating on water bath under reflux for 12 hours. On cooling, hydrolysate mixture was filtered through Whatman filter paper into a 200 ml beaker marked at 50 ml capacity. The residue was washed with 5 ml portions of distilled water until the filtrate reached 50 ml mark. Then the beaker was put into a tray containing cold water and the pH of the filtrate was neutralized to 5.0 by adding 5 N NaOH. Finally pH was adjusted to  $6.5 \pm 0.1$  by adding drop-wise 0.5 N NaOH. The neutralized hydrolysate was transferred to 100 ml volumetric flask and diluted with distilled water.

## 2) Analysis of the hydrolysate for various organic fractions

- i. Total Hydrolysable Nitrogen (THN): 5 ml of neutralized hydrolysate was digested with 2 ml conc.  $H_2SO_4$  and  $K_2SO_4$  catalyst mixture and Nitrogen content was determined by steam distillation and ammonia liberated was determined by absorbing in boric acid and titrating with standard acid solution.
- ii. Hydrolysable Ammonium Nitrogen (HAN): It was determined with steam distillation of 5 ml hydrolysate with MgO. The ammonia liberated was determined by absorbing in boric acid and titrating with standard acid solution.
- iii. Amino Sugar Nitrogen (ASN) + HAN: It was determined with steam distillation of 5 ml hydrolysate with phosphate borate buffer (pH 11.2). The ammonia liberated was determined by absorbing in boric acid and titrating with standard acid solution.
- iv. Amino Sugar Nitrogen (ASN): This was calculated by the difference between above two fractions  $[(ASN + HAN) - (HAN)]$ .
- v. Amino Acid Nitrogen (AAN): 5 ml hydrolysate and 1 ml 0.5 N NaOH was taken in 50 ml conical flask, one ml 0.5 N NaOH was added and the content were heated in a water bath at  $100^\circ C$ , until volume got reduced to 3 ml. After cooling, 0.5 g of citric acid and 100 mg of Ninhydrin were added and flasks were kept immersed in water bath at  $100^\circ C$ . After 1 min, the flask were swirled for a few seconds without removing it from the water bath and then allow to remain in water bath for additional 9 minutes. The contents were transferred to distillation flask by giving washing with distilled water. To this 10 ml of phosphate borate buffer (pH 11.2) and 1 ml of 5 N distilled water. To this 10 ml of phosphate borate buffer (pH 11.2) and 1 ml of 5 N NaOH were added and steam distillation was carried out. The

ammonia liberated was determined by absorbing in boric acid and titrating with standard acid solution.

- vi. Unidentified Hydrolysable Nitrogen (UHN): This was determined by the difference of THN and (HAN+ASN+AAN).
- vii. Non Hydrolysable-N (NHN): This was determined by the difference of Total Nitrogen and (THN+Inorganic Nitrogen form).

#### IX. **Potential mineralizable nitrogen**

It was determined by long term aerobic incubation method proposed by Sharifi *et al.* (2007) and modified by Curtin and Campbell (2007). To a soil sample of 10 g in 50 ml centrifuge tube, water was added to reach 50% water filled pore spaces. Tubes were placed in a large incubation chamber at 25°C. The top stoppers were removed 2-3 times per week for few minutes to allow aeration and positions of tubes were re-randomized in the vial. The soil moisture was maintained throughout the incubation period at field capacity by frequently weighing containers and adding water whenever necessary. Samples were incubated at 25°C for 0, 2, 4, 6, 8, 10, 12, 14, 16 weeks and analyzed for mineral N (NH<sub>4</sub>-N + NO<sub>3</sub>-N) at each incubation interval. To avoid soil disturbance due to sampling, independent sets were run concurrently for each incubation period. At the end of each incubation period, NH<sub>4</sub>-N and NO<sub>3</sub>-N from soil samples were extracted with 40 ml 2 M KCl followed the same procedure as outlined for inorganic nitrogen. Cumulative N mineralized in a soil at a given time was calculated by subtracting mineral-N content of the soil at the start of incubation i.e. zero day time and then the mineral N data was fitted to first order kinetic model to work out the nitrogen mineralization potential.

First order kinetic model;  $N_{\min} = N_0 (1 - e^{-kt})$  (Stanford and Smith, 1972).  $N_{\min}$  = Cumulative N mineralized (mg N kg<sup>-1</sup> soil) at time 't' (weeks),  $N_0$  = Nitrogen mineralization potential (mg N kg<sup>-1</sup> soil),  $k$  = First order rate constant (week<sup>-1</sup>).

#### 3.4 **Plant analysis:**

The seed, siliqua and stover samples were analyzed for determination of nitrogen concentration. The method employed is given below:

**Nitrogen:** Nitrogen in the processed sample was determined by Kjeldahl digestion method as described in AOAC (1984).

### 3.5 Yield

**a) Biological yield:** Black gram crop was harvested at maturity, the plants were then oven dried at 70°C temperature, weight was taken and the data was expressed in kg ha<sup>-1</sup> for biomass calculation.

**b) Seed yield:** The sun dried (14% moisture) seed weight was measured in an electric balance and expressed in kg ha<sup>-1</sup>. Similarly, siliqua and stover yield were also collected.

### 3.6 Empirical formulae used

**(a) Nutrient uptake (kg ha<sup>-1</sup>) =**

Dry matter (q/ha) x nutrient concentration (%)

**(b) Relative Agronomic Efficiency (RAE) =**

$$\frac{(\text{Total Biomass production in treatment}) - (\text{Total Biomass production in Absolute Control})}{(\text{Total Biomass production in STD}) - (\text{Total Biomass production in Absolute Control})} \times 100$$

**(c) Apparent Recovery of Nutrient (%) =**

$$\frac{(\text{Uptake of nutrient in desired treatment}) - (\text{Uptake in absolute control})}{\text{Amount of nutrient added (kg ha}^{-1}\text{)}} \times 100$$

**(d) Harvest index (HI) =**

$$\frac{\text{Economical yield}}{\text{Total Biomass production}} \times 100$$

### 3.8 Statistical analysis

Individual character data sets were statistically analyzed and mean comparison between treatments was established by the statistical package SPSS (SPSS Inc., Chicago IL). The two factor analysis of variance was performed to test for difference between depth of soil and treatment mean. Simple correlation and regression were analyzed between various soil attributes, crop yield and nutrient uptake and nonlinear least-square regression was the preferred statistical technique to estimate potentially mineralizable N (N<sub>0</sub>) and mineralization rate constant (*k*) in the first-order kinetic model.

## **CHAPTER-4**

---

### **RESULTS**

# RESULTS

---

This chapter deals with the results of the experiment following as per objectives of the present study which are demonstrated in tabulated and graphical forms.

## **4.1 Influence of organics, inorganics, biofertilizers and INM practices on Crop productivity, Harvest index and Relative Agronomic Efficiency**

The experimental results of crop productivity in terms of seed, stover and siliqua yield, harvest index and agronomic efficiency are presented in Table 3. Appraisal of data revealed that total dry matter production due to INM practices varied between 191 kg ha<sup>-1</sup> and 1080 kg ha<sup>-1</sup>, lowest with STD and highest in STD+FYM+BF+Lime. Influence of different integrated nutrient management practices resulted significant variation among the treatments. There was a 72% yield loss in sole application of inorganic fertilizers as compared to unfertilized control. Even 50% reduced inorganic fertilization recorded 109% significant yield increment over STD when combined with biofertilizers. If no nutrient was added through external source, only biofertilizers was able to produce similar level of total blackgram yield. Conjunctive application of biofertilizers, inorganics and various organic inputs increased total yield maximum upto 133% over unfertilized treatment whereas, lime inclusion held significant variation in total crop productivity by adding extra 42% yield. Extra yield of 77% were obtained when all sources of organics, inorganics and biofertilizers were applied in comparison to organics and inorganics only. Non application of organics with STD caused a reduction of 386% in potential seed yield. This signifies the importance of organics in package of practices (POP). Inclusion of lime in INM treatments recorded marked increase in seed yield over unfertilized control and contributed 55% more in yield economics of other biofertilized INM plots receiving full STD. Thus the set of treatment combinations with different organics, inorganics, biofertilizers and soil ameliorant either alone or in combination followed the order of seed yield as STD+FYM+BF+Lime > STD+VC+BF+Lime > STD+VC+BF > STD+FYM+BF > STD+FYM > STD+VC > 50% STD+BF > BF > Absolute Control > STD in descending manner. Similar pattern was noticed in case of total yield except STD+VC recorded little more total yield over STD+FYM which were statistically at par though.

Overall, integration of organics not only influenced the seed yield but also the stover and siliqua biomass in black gram crop. STD+VC+BF+Lime registered highest stover yield (263 kg ha<sup>-1</sup>) while maximum quantity of siliqua biomass (153 kg ha<sup>-1</sup>) was obtained from STD+FYM+BF+Lime treatment with STD recording lowest yield (127 kg ha<sup>-1</sup> stover yield and 13 kg ha<sup>-1</sup> siliqua yield) in both cases. Conjunctive application of vermicompost with inorganics showed marked increase (58%) in stover yield as compared to STD; with biofertilizer addition alone or in combination with lime contributed 14.4% and extra 14.3% more significant variation respectively.

Experimental data from Table 3 revealed that harvest index of blackgram varied from 27% to 63%. Significant variation was noticed as harvest index was affected by input integration. The treatment (STD+FYM+BF+Lime) recording maximum blackgram seed (678 kg ha<sup>-1</sup>) also exhibited highest harvest index (63%). Lowest HI was recorded in STD with minimum economic yield (51 kg ha<sup>-1</sup>).

Considering the performance of STD+FYM as 100, efficiency of other package of practices can be arranged as: BF's (10) < 50% STD+BF's (30) < STD+VC (84) < STD+FYM+BF (226) < STD+VC+BF (309) < STD+VC+BF+Lime (559) < STD+FYM+BF+Lime (573). These results clearly indicated greater agronomic performance of STD+FYM+BF+Lime over other INM treatments.

#### **4.2 Influence of organics, inorganics, biofertilizers and INM practices on concentration (%), uptake (kg ha<sup>-1</sup>) and recovery efficiency (%) of N by Black gram crop**

The data related to N nutrition of blackgram crop has been presented in Table 4. The highest concentration of N was found in seed (varying 4.15% to 5.12%) than its stover (ranging from 2.57% to 4.13%) and siliqua (ranging from 1.67% to 4.03%); the latter recording lowest N concentration and treatment receiving biofertilizers alone resulted maximum seed N concentration (5.12%) in blackgram. Such differential N distribution resulted in uptake of N ranging from 3.8 kg ha<sup>-1</sup> to 9.2 kg ha<sup>-1</sup> through stover and 0.3 kg ha<sup>-1</sup> to 6.16 kg ha<sup>-1</sup> through siliqua of blackgram.

**Table 3:- Influence of organics, inorganics, biofertilizers and INM practices on Crop productivity, Harvest index and Relative Agronomic Efficiency**

	Treatments	Productivity (kg ha <sup>-1</sup> )				Harvest index (%)	RAE (%)
		Seed	Stover	Siliqua	Total		
<b>T<sub>1</sub></b>	Absolute Control	157	147	22	326	48	-
<b>T<sub>2</sub></b>	STD+F	248	179	87	514	48	100
<b>T<sub>3</sub></b>	STD+VC	233	201	82	516	45	84
<b>T<sub>4</sub></b>	STD+F+BF	363	184	90	637	57	226
<b>T<sub>5</sub></b>	STD+VC+BF	438	230	92	760	58	309
<b>T<sub>6</sub></b>	STD+F+BF+L	678	249	153	1080	63	573
<b>T<sub>7</sub></b>	STD+VC+BF+L	666	263	135	1064	63	559
<b>T<sub>8</sub></b>	STD	51	127	13	191	27	-
<b>T<sub>9</sub></b>	BF	166	147	27	340	49	10
<b>T<sub>10</sub></b>	50%STD+BF	184	181	35	400	46	30
	LSD ( <i>P</i> =0.05)	27.66	21.67	9.86	32.41	-	-

It was evident that N uptake in seed was more, varying from 2.28 kg ha<sup>-1</sup> to 34.56 kg ha<sup>-1</sup>. Total uptake varied from 6.8 mg kg<sup>-1</sup> in sole inorganic fertilized plot to the maximum 49.2 kg ha<sup>-1</sup> in lime applied INM treatment receiving FYM as organic input. Integration of biofertilizers with STD+FYM/VC increased total uptake by 36% to 59% and further addition of lime (PMS) as acid soil ameliorant manifested 49% to 84% (46.4 kgha<sup>-1</sup>, 49.2 kg ha<sup>-1</sup>) marked increment on biofertilized treatments receiving full dose (26.8 kgha<sup>-1</sup>, 31.1 kgha<sup>-1</sup>).

The apparent recovery of either applied 30 kg N (STD alone), 55 kg N (STD+FYM) or 60 kg N (STD+VC) ha<sup>-1</sup> under the influence of INM packages varied between 15% (STD+VC) and 70% (STD+FYM+BF+Lime). Organic integration alone with STD could able to recover only 16.4% N, with biofertilizers 34% and further to 70% with addition of lime in acid soil. The recovery of N with 50% STD+BFs package was only 35%, much less as compared to lime treated packages like STD+FYM/VC+BF+Lime (Table 4).

**Table 4:- Influence of organics, inorganics, biofertilizers and INM practices on Concentration (%), Uptake (kg ha<sup>-1</sup>) and Recovery Efficiency (%) of N by Black gram crop**

Treatments		Concentration (%)			Uptake (kg ha <sup>-1</sup> )				NRE
		Seed	Stover	Siliqua	Seed	Stover	Siliqua	Total	
T <sub>1</sub>	CONTROL	4.15	2.57	1.67	6.50	3.8	0.36	10.7	-
T <sub>2</sub>	STD+F	4.27	3.68	2.77	10.68	6.6	2.42	19.7	16.4
T <sub>3</sub>	STD+VC	4.59	3.27	2.80	10.70	6.6	2.30	19.6	15
T <sub>4</sub>	STD+F+BFs	4.35	4.13	3.60	16.09	7.5	3.23	26.8	29
T <sub>5</sub>	STD+VC+BFs	4.66	3.29	3.63	20.35	7.4	3.33	31.1	34
T <sub>6</sub>	STD+F+BF+L	5.08	3.65	4.03	34.56	8.5	6.16	49.2	70
T <sub>7</sub>	STD+VC+BF+L	4.86	3.51	4.03	32.21	9.2	5.02	46.4	59.5
T <sub>8</sub>	STD	4.55	3.53	2.33	2.28	4.2	0.30	6.8	-
T <sub>9</sub>	BF	5.12	3.20	2.60	8.54	4.8	0.71	14.1	-
T <sub>10</sub>	50%STD+BF	4.90	3.49	2.87	8.99	6.0	1.00	16.0	35
	LSD ( <i>P</i> =0.05)	-	-	-		1.321	0.426	1.94	

#### **4.3 Effect of Integrated Nutrient Management practices on pH, EC content of surface (0-15 cm) and sub-surface (15-30 cm) layers of soil**

The experimental results regarding the influence of integrated nutrient management practices on pH and EC content upto 30 cm soil depth has been depicted in Table 5. In 2010, before the commencement of experiment, initial status of soil sample was acidic (pHw: 5.14). After the harvest of 25<sup>th</sup> crop i.e. blackgram, the pH of the surface soil (0-15 cm) varied from 4.43 to 5.83 with a mean value of 5.13. In comparison to initial status, soil reaction decreased among all the treatments except that receiving sole biofertilization and inclusion of lime as soil ameliorant. Regarding pH of the soil in INM treatments, except application of lime in organics and inorganics integrated plots or that receiving only biofertilization, there was no significant variation. Though increment in soil reaction was seen in STD excluded treatment receiving only biofertilizers, addition of half dosed inorganic fertilizers recorded no significant variation over STD and yield significantly lower pH value as compared to the treatments ameliorated with lime. There was no

significant difference in soil reaction in INM package of practices and control plot receiving absolutely no nutrients from external source. Lowest pH was observed in STD in 0-15 cm. Results demonstrated that soil reaction values followed an increasing trend in deeper soil layer (15-30 cm) in all treatments except that receiving STD, FYM and biofertilizers combinedly. In 15-30 cm soil pH varied from 4.63 to 5.93 with a mean value of 5.33. The treatments receiving lime as soil ameliorant showed significantly higher soil reaction value over the integrated treatment of mineral and organic fertilizers or mineral fertilizers alone. A drastic increase in soil pH was recorded in biofertilized treatment combined with 50% STD in the sub-surface layer.

Calculation of data pertaining to electrical conductivity of soil, presented in Table 5 clearly indicated decrement in soil EC as compared to initial value of  $0.18 \text{ dS m}^{-1}$ . After the harvest of blackgram, EC in the surface soil varied from  $0.075 \text{ dS m}^{-1}$  to  $0.1 \text{ dS m}^{-1}$  with a mean value of  $0.085 \text{ dS m}^{-1}$ . The highest EC value ( $0.1 \text{ dS m}^{-1}$ ) was recorded in STD which was statistically similar with the treatments receiving inorganic fertilization combined with vermicompost, biofertilizers either including lime or not. No significant variation in EC was noticed among the treatments except that included lime in organics and inorganics integrated plots, also in the biofertilizer treated plot receiving vermicompost with inorganic fertilization and only STD treated plot. The treatment receiving sole biofertilization recorded the lowest EC value ( $0.075 \text{ dS m}^{-1}$ ) showing no significant difference with control and also with the biofertilized plot including 50% STD.

Regarding EC of the sub-surface soil (15-30 cm) in INM practice, the values varied from  $0.063 \text{ dS m}^{-1}$  to  $0.109 \text{ dS m}^{-1}$ . The control plot, receiving no external inputs, recorded the lowest EC value showing significant variation with all other treatments. Application of 50% reduced inorganic fertilization caused no appreciable variation with 100% inorganics combined with various organic fertilized plots except STD treatment alone and STD in conjunction with vermicompost and biofertilizer. The latter recorded the highest soil EC value showing synergistic effect of vermicompost and biofertilizers affecting mobility of soil ions in sub-surface layer. Experimental results indicated that soil EC values followed an increasing trend in deeper soil layer except in STD treatment combined with vermicompost and control.

**Table 5:- Influence of organics, inorganics, biofertilizers and INM practices on depth wise distribution soil pH and EC in soil**

Treatments		pH			EC (dSm <sup>-1</sup> )		
		Soil Depth (cm)					
		0-15	15-30	Mean	0-15	15-30	Mean
<b>T<sub>1</sub></b>	Absolute Control	5.83	5.92	5.88	0.078	0.063	0.070
<b>T<sub>2</sub></b>	STD+F	4.94	5.41	5.18	0.080	0.086	0.083
<b>T<sub>3</sub></b>	STD+VC	4.85	4.97	4.91	0.084	0.077	0.080
<b>T<sub>4</sub></b>	STD+F+BF	4.92	4.87	4.89	0.08	0.093	0.086
<b>T<sub>5</sub></b>	STD+VC+BF	4.75	4.89	4.82	0.096	0.109	0.103
<b>T<sub>6</sub></b>	STD+F+BF+L	5.71	5.82	5.77	0.089	0.099	0.094
<b>T<sub>7</sub></b>	STD+VC+BF+L	5.50	5.66	5.58	0.09	0.101	0.095
<b>T<sub>8</sub></b>	STD	4.43	4.63	4.53	0.100	0.103	0.102
<b>T<sub>9</sub></b>	BF	5.45	5.75	5.60	0.075	0.092	0.084
<b>T<sub>10</sub></b>	50%STD+BF	4.92	5.4	5.16	0.076	0.089	0.083
	Mean	5.13	5.33	5.23	0.085	0.091	0.088
	<b>Initial</b>	<b>5.14</b>			<b>0.18</b>		
LSD ( <i>P</i> =0.05)		Treatment-0.22 Depth-0.099 Treat x Depth-0.32			Treatment-0.012 Depth-0.05 Treat x Depth-0.018		

#### **4.4 Influence of organics, inorganics, biofertilizers and INM practices on depth wise distribution Soil Organic Carbon (SOC) and Available Nitrogen content in soil**

Perusal of data revealed (Table 6) that nine long years of balanced mineral fertilization either alone or in combination with organic manure and soil ameliorant helped in improvement of SOC status from its initial value (2.7 g kg<sup>-1</sup>). The SOC in 0-15 cm depth ranged from 4.37 to 5.5 g kg<sup>-1</sup> with a mean value of 5.17 g kg<sup>-1</sup>. Application of lime, vermicompost and biofertilizers have no significant effect on SOC content. Integrated application of inorganic, organic and biofertilizers over the years increased organic carbon content from 62% to 104% over the initial soil status. The maximum organic carbon build up was recorded in the treatment receiving combination of organics (VC), inorganics, biofertilizers and lime which was 24% increment over STD. A significant variation was

seen in only-biofertilized plot which showed 20% increase in organic carbon content over the treatment receiving mineral fertilizers alone. Reduced (50%) inorganic fertilization recorded no significant variation in organic carbon content in comparison with other fully inorganic fertilized treatments.

In sub-surface soil, SOC followed a decreasing trend ranging from 2.98 g kg<sup>-1</sup> to 3.79 g kg<sup>-1</sup> with a mean of 3.47 g kg<sup>-1</sup>. In 15-30 cm depth SOC content in INM treatments improved by 3.65% to 15.7% over STD except STD+FYM+BF+Lime as compared to 18% to 24% increment in 0-15 cm depth showing pronounce effect of INM treatments in building up SOC in upper soil layer. Surprisingly, conjunctive application of FYM, biofertilizers and lime with inorganics recorded depletion in organic carbon content in deeper soil layer as compared to STD showing only 1.5% variation from surface soil. Also, application of half dosed inorganic fertilizers in sub-surface soil held appreciable organic carbon build up than all other treatments having inorganic fertilization with full dose except the treatment receiving lime, biofertilizers and vermicompost with full inorganic fertilization. All treatments showed significant depth-wise variation in SOC content, the highest (64.4%) being recorded in lime treated plot combined with inorganics, FYM and biofertilizers. In deeper soil layer, magnitude of decrement in mean SOC was recorded as 1.7 g kg<sup>-1</sup> exhibiting 49% depth-wise variation.

The data related to N availability was presented in Table 6. Appraisal of results in the present study clearly indicated that all the treatments which received any kind of fertilizer and manure in the surface and sub-surface layer improved nitrogen content of soil as compared to initial status (207 kg ha<sup>-1</sup>). In both soil layers, maximum available N (463 kg ha<sup>-1</sup> in 0-15 cm and 435 kg ha<sup>-1</sup> in 15-30 cm) were attained in the treatment receiving lime and organic manure in the form of vermicompost, biofertilizers along with STD followed by STD+vermicompost+biofertilizers (460 kg ha<sup>-1</sup>) in surface layer and STD+vermicompost (426 kg ha<sup>-1</sup>) in sub-surface layer which were statistically at par. Mean soil N varied from 305 kg ha<sup>-1</sup> to 449 kg ha<sup>-1</sup> with absolute control registered lowest N Status (305 kg ha<sup>-1</sup>). In 0-15 cm depth, inclusion of organic inputs like FYM, vermicompost, biofertilizers either alone or in combination increased the N content, ranging from 5.5% to 10.05% over sole inorganic fertilization while lime addition recorded greater increase in N

content showing a variation of 10.76%. Appreciable increment in available N was observed in all treatments receiving full inorganics as compared to 50% reduced inorganic fertilization except STD treated plot along with FYM and STD alone. Also, treatment receiving sole biofertilization registered second lowest available N content exhibiting only 17.83% increase in surface and 29.5% in sub-surface soil over absolute control. Overall available N content in lower depth was lower in all the treatments as compared to surface soil.

**Table 6:- Influence of organics, inorganics, biofertilizers and INM practices on depth wise distribution Soil Organic Carbon (SOC) and Available Nitrogen content in soil**

Treatments		SOC (g Kg <sup>-1</sup> )			Av. N (Kg ha <sup>-1</sup> )		
		Soil Depth (cm)					
		0-15	15-30	Mean	0-15	15-30	Mean
<b>T<sub>1</sub></b>	Absolute Control	4.37	2.98	3.68	342	268	305
<b>T<sub>2</sub></b>	STD+F	5.28	3.45	4.36	441	391	416
<b>T<sub>3</sub></b>	STD+VC	5.35	3.40	4.37	459	426	442
<b>T<sub>4</sub></b>	STD+F+BF	5.24	3.61	4.42	458	417	437
<b>T<sub>5</sub></b>	STD+VC+BF	5.42	3.57	4.50	460	425	443
<b>T<sub>6</sub></b>	STD+F+BF+L	5.31	3.23	4.27	459	415	437
<b>T<sub>7</sub></b>	STD+VC+BF+L	5.50	3.70	4.60	463	435	449
<b>T<sub>8</sub></b>	STD	4.45	3.28	3.86	418	377	397
<b>T<sub>9</sub></b>	BF	5.35	3.79	4.57	403	347	375
<b>T<sub>10</sub></b>	50%STD+BF	5.39	3.72	4.56	435	366	401
	Mean	5.17	3.47	4.32	434	387	410
	<b>Initial</b>	<b>2.7</b>			<b>207</b>		
LSD ( <i>P</i> =0.05)		Treatment-0.22 Depth-0.10 Treat x Depth-0.32			Treatment-15.36 Depth-7.87 Treat x Depth-22.72		

**4.5 Influence of organics, inorganics, biofertilizers and INM practices on depth wise distribution of Available Phosphorous and Potassium content in soil**

The experimental findings (Table 7) revealed that available P status in surface soil depleted from initial content in all treatments except combination of inorganics, biofertilizers, vermicompost with or without lime and STD+FYM+biofertilizers+lime showing significant effect of biofertilizers on soil P availability. Treatment receiving STD+FYM+biofertilizers+lime developed maximum soil available P ( $38.12 \text{ kg ha}^{-1}$ ) in surface soil which was statistically significant with all other treatments in two layers. But in deeper soil, lime treated with vermicompost, biofertilizers and inorganics resulted the highest P availability ( $25.18 \text{ kg ha}^{-1}$ ) showing significant variation of 9% over other lime treated FYM applied plot. Treatment receiving biofertilization alone significantly decreased P content ranging from 23.5% to 204% in 0-15 cm and 38.3% to 224% in 15-30 cm soil. However, control recorded the lowest soil available P in both surface ( $7.84 \text{ kg ha}^{-1}$ ) and sub-surface layer ( $6.67 \text{ kg ha}^{-1}$ ). Soil P build-up in 15-30 cm depth was lower as compared to that of 0-15 cm layer in all treatments showing 43% significant depth-wise variation.

Regarding available K status in soil, it was clear from the Table 7 that after nine years of intensive cultivation, available K content in both soil layers increased drastically in all the treatments from its initial value of  $38.54 \text{ kg ha}^{-1}$ . Available K content in surface layer was varying from 159 to  $242 \text{ kg ha}^{-1}$  and it ranged from 143 to  $202 \text{ kg ha}^{-1}$  in sub-surface layer (15-30 cm). In 0-15 cm STD+VC+BF+Lime developed maximum K ( $242 \text{ kg ha}^{-1}$ ) showing no significant variation with inorganically fertilized treatments receiving only FYM or vermicompost as organic input. In deeper soil, STD+VC registered the highest available K ( $202 \text{ kg ha}^{-1}$ ) which was statistically significant with all other treatments except STD+FYM and STD+VC+BF. Inclusion of lime held no significant difference with other INM treatments in surface soil. Similarly, in 15-30 cm lime treated plots recorded lower soil available K which were statistically at par with all INM treatments except STD+VC. Application of biofertilizers alone increased the appreciable amount of available K which was closely followed by only inorganic fertilization in both soil layers. Minimum available soil K content was recorded in absolute control. Availability of Soil K in 15-30 cm depth was lower as compared to that of 0-15 cm layer in all treatments showing 26.6% significant depth-wise variation.

**Table 7:- Influence of organics, inorganics, biofertilizers and INM practices on depth wise distribution of Available Phosphorous and Potassium content in soil**

Treatments		Av. P (Kg ha <sup>-1</sup> )			Av. K (Kg ha <sup>-1</sup> )		
		Soil Depth (cm)					
		0-15	15-30	Mean	0-15	15-30	Mean
T <sub>1</sub>	Absolute Control	7.84	6.67	7.25	159	143	151
T <sub>2</sub>	STD+F	18.11	14.56	16.33	232	180	206
T <sub>3</sub>	STD+VC	21.69	16.1	18.89	230	202	216
T <sub>4</sub>	STD+F+BF	25.57	16.47	21.02	205	170	187
T <sub>5</sub>	STD+VC+BF	28.93	19.69	24.31	209	180	195
T <sub>6</sub>	STD+F+BF+L	38.12	23.10	30.61	213	159	186
T <sub>7</sub>	STD+VC+BF+L	30.1	25.18	27.64	242	158	200
T <sub>8</sub>	STD	25.01	16.28	20.65	213	156	185
T <sub>9</sub>	BF	12.54	7.76	10.15	213	164	188
T <sub>10</sub>	50%STD+BF	15.49	10.73	13.11	228	180	204
	Mean	22.343	15.65	18.99	214	169	192
	<b>Initial</b>	<b>28.55</b>			<b>38.54</b>		
LSD ( <i>P</i> =0.05)		Treatment-1.47 Depth-0.66 Treat x Depth-2.08			Treatment-26.03 Depth-11.64 Treat x Depth-36.82		

**4.6 Influence of organics, inorganics, biofertilizers and INM practices on depth wise distribution of total nitrogen content in soil**

Perusal of results (Table 8) revealed that distribution of total N content in soil was significantly affected by INM treatments, soil depth and their respective interactions. The magnitude of total N was higher in 0-15 cm which ranged from 235 mg kg<sup>-1</sup> to 692 mg kg<sup>-1</sup> and exhibited a gradual decrease with increasing depth, varying between 176 mg kg<sup>-1</sup> to 452 mg kg<sup>-1</sup> in 15-30 cm. Mean total N varied from 205.3 mg kg<sup>-1</sup> in unfertilized control to 572 mg kg<sup>-1</sup> in STD+VC+BF+Lime treatment and the latter of surface soil recorded maximum total N build-up. Long term integration for nine long years demonstrated that inorganic fertilizer application either singly or combinedly in half or full dose with various organic inputs and lime had significant increment on total N irrespective of soil depth. Application of vermicompost in place of FYM in lime added INM treatments resulted 4.8%

and 19.6% increase in surface and sub-surface soil respectively and its addition in STD+BF recorded 19.85% significant increase in surface total N also, showing greater effect of vermicompost as organic input over FYM in INM treatments, especially in upper soil layer. Adding biofertilizers exhibited synergistic effect in INM treatments with a variation of 15%-135% over only-biofertilized treatment in surface soil and maximum upto 100% in sub-surface layer. Total N increment as compared to unfertilized control were 25.5%, 44%, 61% and 195% with application of biofertilizers singly, 50% STD+BF, STD and STD+VC+BF+Lime respectively in 0-15 cm depth while 28%, 34%, 46.6% and 157% respectively in deeper soil. The treatment receiving 50% reduced inorganic fertilization in upper layer registered 11.5% significant depletion of total N over balanced fertilization with no significant variation in 15-30 cm depth.

**Table 8:- Influence of organics, inorganics, biofertilizers and INM practices on depth wise distribution of total nitrogen and inorganic nitrogen content in soil**

Treatments		Total N (mg kg <sup>-1</sup> )			Inorganic N (mg kg <sup>-1</sup> )		
		Soil Depth (cm)					
		0-15	15-30	Mean	0-15	15-30	Mean
T <sub>1</sub>	Absolute Control	235	176	205.33	12.06	9.05	10.55
T <sub>2</sub>	STD+F	420	282	351	28.65	19.12	23.89
T <sub>3</sub>	STD+VC	434	274	354	32.54	20.51	26.53
T <sub>4</sub>	STD+F+BF	534	332	433	41.51	25.92	33.71
T <sub>5</sub>	STD+VC+BF	640	336	488	56.32	29.56	42.94
T <sub>6</sub>	STD+F+BF+L	660	378	519	60.28	34.52	47.40
T <sub>7</sub>	STD+VC+BF+L	692	452	572	58.56	38.36	48.46
T <sub>8</sub>	STD	378	258	318	21.87	14.93	18.40
T <sub>9</sub>	BF	295	226	260	23.06	17.62	20.34
T <sub>10</sub>	50%STD+BF	339	236	288	26.53	18.50	22.51
	Mean	462.8	295.03	378.92	36.14	22.81	29.47
LSD ( <i>P</i> =0.05)		Treatment-26.66 Depth-11.92 Treat x Depth-37.22			Treatment-4.36 Depth-1.95 Treat x Depth-6.16		

#### **4.7 Influence of organics, inorganics, biofertilizers and INM practices on depth wise distribution of inorganic nitrogen content in soil**

The data related to inorganic N has been presented in the Table 8 and it is evident that the mineral fertilizer application either singly or combinedly with various organic

inputs in half or full dose had significant effect on inorganic nitrogen irrespective of soil depth. Inorganic nitrogen content in surface layer (0-15 cm) varied from 12.06 mg kg<sup>-1</sup> in unfertilized control to the maximum, 60.28 mg kg<sup>-1</sup> in treatment receiving FYM, biofertilizers, lime with STD where as in subsurface layer (15-30 cm) it varied from 9.05 mgkg<sup>-1</sup> in control to the highest, 38.36 mg kg<sup>-1</sup> in lime treated plot in combination with vermicompost, biofertilizers and STD. Long term application of mineral fertilizers in combination with various organic inputs and lime significantly increased the highest concentration of inorganic nitrogen in soil. Inclusion of lime exhibited significantly higher accumulation of inorganic-N over all other lime excluded treatments in both layers except STD+VC+BF in surface soil. Treatment having STD+FYM+biofertilizers+lime showed significant variation over all other biofertilized plots except that receiving combination of STD and vermicompost either with lime or without it in surface layer and STD+VC+BF+Lime in sub-surface soil. Use of biofertilizers either alone or in combination increased inorganic soil N content ranging from 5.4% to 176% over STD in 0-15 cm depth and it varied from 18% to 157% with a significant increase in 15-30 cm soil. In surface soil, biofertilized treatment having 50% reduced application of mineral fertilizers showed significant increase in inorganic N by 21.3% over treatment receiving only full dosed inorganic fertilization but no significant difference was seen in sub-surface soil while variations were noticeably significant for all INM treatments in both layers except STD+FYM in 0-15 cm depth and vermicompost or FYM included treatment with STD in 15-30 cm soil layer. There was 58.44% significant depth wise variation of inorganic nitrogen content and it decreased with increasing depth. Inorganic fraction comprised only 5.14 to 9.13% of total nitrogen content in soil (Fig 3).

#### **4.8 Influence of organics, inorganics, biofertilizers and INM practices on depth wise distribution of Total Hydrolysable Nitrogen (THN) and Non Hydrolysable Nitrogen (NHN) content in soil**

Results obtained from the recent study presented in Table 9 demonstrated that THN were strongly influenced by long term integrated nutrient management practices as well as the interactive effect of soil depth exhibiting 57.1% significant depth-wise variation. The magnitude of THN was maximum in surface layer of 0-15 cm depth and it decreased in deeper soil layer (15-30 cm). THN in surface soil (0-15 cm) ranged between 164.5 to 519

mg kg<sup>-1</sup> and 122.96 to 339 mg kg<sup>-1</sup> in sub surface soil (15-30 cm). In both layers the maximum THN were found in 100% STD+VC+BF+Lime treatment whereas control plot exhibited minimum THN. Addition of lime with vermicompost recorded 4.8% and 19.6% increment as compared to other treatment receiving lime with FYM in surface and sub-surface soil respectively. In 0-15 cm depth THN decreased significantly in unfertilized control as compared with single organics addition or inorganic fertilization alone or various INM treatments. However, the magnitude of the depletion varied markedly (81.3 to 215.5%) depending on the combination of nutrients applied in INM treatments followed by 63% and 29.4% depletion with respect to STD and treatment receiving only biofertilization. Similarly, significant variation range was seen in case of 15-30 cm also. Although, use of biofertilizers along with full STD showed vast improvement in THN ranging from 45.2% to 93.4% in surface soil and 32.3% to 85% in deeper soil over STD exhibiting prominence effect of biofertilizers in enhancing soil THN but its addition with 50% reduced inorganics registered marked decrement of THN over full inorganic fertilization (STD) varying 11.44% in 0-15 cm and 9.1% in 15-30 cm soil depth respectively. So the magnitude of changes of THN content in surface soil followed the order like STD+VC+BF+L > STD+FYM+BF+L > STD+VC+BF > STD+FYM+BF > STD+VC > STD+FYM > STD > 50%STD+BF > BF > absolute control where STD+FYM and STD+VC treatments were statistically at par. Also, THN contributed the major (70% to 75%) share of total N (Fig 3).

After nine years of integrated nutrient management, experimental findings indicated that the NHN content (Table 9) improved with different organic and inorganic fertilizer doses and the value ranged between 55.56 to 113.71 mg kg<sup>-1</sup> irrespective of soil depth under different treatments. With increasing depth, NHN content decreased showing significant variation among all except treatments receiving only biofertilizers and STD+VC+BF+Lime. In the surface soil layer (0-15cm) it varied from 58.43 mg kg<sup>-1</sup> in control to 116.48 mg kg<sup>-1</sup> in STD+VC+BF but in 15-30 cm depth highest NHN was recorded in STD+VC+BF+Lime (113 mg kg<sup>-1</sup>) and lowest content was found in control (52.7 mg kg<sup>-1</sup>). In surface soil, NHN content in STD+VC+BF+Lime was statistically at par with treatment recording maximum NHN but exhibited significant variation with other lime treated plot. Amount of NHN was improved significantly ranging from 6.1% to 32.8% in various INM treatments as compared to receiving only 100% inorganic fertilizers in surface

layer and deeper soil exhibit greater variation (9.3%-51%). In upper layer (0-15 cm) there was a significant depletion (25.8%) of NHN in STD treatment in comparison with 50% STD+BF whereas in 15-30 cm, slight NHN increase was noticed. As in case of treatment receiving biofertilizers alone, there was no significant depth-wise variation in NHN content. This acid insoluble nitrogen fraction comprised 19 to 27% of total N (Fig 3).

**Table 9:- Influence of organics, inorganics, biofertilizers and INM practices on depth wise distribution of Total Hydrolysable Nitrogen (THN) and Non Hydrolysable Nitrogen (NHN) content in soil**

Treatments		THN (mg/kg)			NHN (mg/kg)		
		Soil Depth (cm)					
		0-15	15-30	Mean	0-15	15-30	Mean
T <sub>1</sub>	Absolute Control	164.50	122.96	143.73	58.43	52.70	55.56
T <sub>2</sub>	STD+F	298.20	200.22	249.21	93.14	81.78	87.46
T <sub>3</sub>	STD+VC	312.48	197.28	254.88	88.97	76.72	82.84
T <sub>4</sub>	STD+F+BF	389.82	242.36	316.09	102.66	89.64	96.15
T <sub>5</sub>	STD+VC+BF	467.20	245.28	356.24	116.48	90.72	103.60
T <sub>6</sub>	STD+F+BF+L	495.00	283.50	389.25	104.72	94.50	99.61
T <sub>7</sub>	STD+VC+BF+L	519.00	339.00	429.00	114.43	113.00	113.71
T <sub>8</sub>	STD	268.38	183.18	225.78	87.74	74.82	81.28
T <sub>9</sub>	BF	212.88	162.72	187.8	59.72	59.72	63.28
T <sub>10</sub>	50%STD+BF	240.82	167.90	204.36	110.37	71.97	68.76
	Mean	336.82	214.44	275.63	93.67	89.83	80.59
LSD ( <i>P</i> =0.05)		Treatment-19.24 Depth-8.60 Treat x Depth-27.21			Treatment-7.29 Depth-3.26 Treat x Depth-10.31		

**4.9 Influence of organics, inorganics, biofertilizers and INM practices on depth wise distribution of Hydrolysable Ammonia Nitrogen (HAN) and Amino Acid Nitrogen (AAN) content in soil**

The experimental results of HAN and AAN content in soil were presented in Table 10. It was observed that long term integrated application of mineral fertilizers and organic manures resulted in significant build-up of HAN content over unfertilized control and also, it varied significantly along depth. Maximum HAN content was found in surface layer (0-15 cm) and then gradually depleted with deeper layer. In 0-15 cm HAN content varied from 40.02 mg kg<sup>-1</sup> in absolute control to 140.13 mg kg<sup>-1</sup> in treatment receiving conjunctive

application of biofertilizers, inorganics and organic input like vermicompost with lime (STD+VC+BF+Lime). Similarly, 15-30 cm soil recorded the highest HAN build up in STD+VC+BF+Lime treatment (29.94 mg kg<sup>-1</sup>) with lowest in unfertilized control (91.53 mg kg<sup>-1</sup>). In both layers significant variation was seen between two lime applied INM treatments. Using vermicompost instead of FYM as organic input in lime treated plots exhibited 11.8% and 27.4% HAN increment in 0-15 cm and 15-30 cm respectively showing significant synergistic effect of lime and vermicompost over FYM in HAN development. Inclusion of lime in INM treatments improved HAN content significantly varying 25% to 133% in surface soil and 56% to 119% in deeper layer. Reduced inorganic fertilization recorded significant depletion in HAN content varying 21% in surface and 18% in sub-surface soil over STD. The increase in surface HAN content with application of biofertilizers alone, 50% STD+BF, STD and STD+FYM+BF+Lime in comparison to control were to the tune of 38%, 50%, 81%, 250% respectively in surface layer while 41.2%, 40%, 65%, 206% respectively in deeper soil. Overall 57% significant variation was observed between two different depths. Among other organic N fractions, HAN shared 25.4% of THN content in soil (Fig 3).

The appraisal of the result related to amino acid nitrogen (AAN) in present study revealed that lowest AAN content was observed in control plot (62.51 mg kg<sup>-1</sup>) and maximum in STD+FYM+BF+Lime (207.9 mg kg<sup>-1</sup>) in 0-15 cm depth. In sub-surface soil, the highest AAN (135.6 mg kg<sup>-1</sup>) build-up was recorded in STD+VC+BF+Lime over 46.72 mg kg<sup>-1</sup> in unfertilized control. There was significant difference in AAN content in all treatments receiving organic and inorganic fertilizers with unfertilized control plot. The increase in AAN content with sole application of BF's, 50% STD+BF, STD, STD+FYM+BF+Lime as compared to control were 29.4%, 34.8%, 76%, 85.3% respectively in upper soil. Similarly, the orderly values for sub-surface soil were 32%, 26%, 61% and 155% respectively. Combination of biofertilizers with either various organics, inorganics and soil ameliorant like lime or without lime resulted 4.2% to 157% significant increment in surface AAN content over single biofertilization. Maintaining synergistic effect of biofertilizers in INM treatments, sub-surface soil improved 118% AAN content. In 0-15 cm depth, there was maximum 89% and 70 % increase in AAN content in INM treatments with lime and without lime over STD treatment whereas in 15-30 cm depth

80.6% and 30.6% significant variation were observed. Application of half dosed inorganic fertilizers caused significant depletion in AAN content, varying 30.5% and 27.8% over STD in surface and deeper soil respectively.

**Table 10:- Influence of organics, inorganics, biofertilizers and INM practices on depth wise distribution of Hydrolysable Ammonia Nitrogen (HAN) and Amino Acid Nitrogen (AAN) content in soil**

Treatments		HAN (mg/kg)			AAN (mg/kg)		
		Soil Depth (cm)					
		0-15	15-30	Mean	0-15	15-30	Mean
T <sub>1</sub>	Absolute Control	40.02	29.94	34.98	62.51	46.72	54.61
T <sub>2</sub>	STD+F	78.39	52.79	65.59	119.28	80.08	99.68
T <sub>3</sub>	STD+VC	74.99	47.34	61.17	112.49	71.02	91.75
T <sub>4</sub>	STD+F+BF	96.36	59.74	78.05	124.74	77.55	101.14
T <sub>5</sub>	STD+VC+BF	112.12	58.86	85.49	186.88	98.11	142.49
T <sub>6</sub>	STD+F+BF+L	125.40	71.82	98.61	207.90	119.07	163.48
T <sub>7</sub>	STD+VC+BF+L	140.13	91.53	115.83	207.60	135.60	171.60
T <sub>8</sub>	STD	72.46	49.45	60.96	110.03	75.10	92.56
T <sub>9</sub>	BF	55.30	42.27	48.78	80.89	61.8336	71.364
T <sub>10</sub>	50%STD+BF	60.04	41.83	76.21	84.28	58.76	71.52
	Mean	85.52	54.56	72.57	129.66	82.38	106.02
LSD ( $P=0.05$ )		Treatment-5.48 Depth-2.45 Treat x Depth-7.75			Treatment-7.38 Depth-3.30 Treat x Depth-10.44		

Highest build-up of AAN was observed in surface layer ( $207.9 \text{ mg kg}^{-1}$ ) and further decreased with increase in soil depth. There was significant 57.4% variation of amino acid nitrogen content as observed depth wise. Also, major share of THN (38%) was contributed by AAN in soil (Fig 3).

#### 4.10 Influence of organics, inorganics, biofertilizers and INM practices on depth wise distribution of Ammonia Sugar Nitrogen (ASN) and Unidentified Hydrolysable Nitrogen (UHN) content in soil

Experimental results of ASN and UHN content in soil were presented in the Table 11. Persual of results revealed that absolute control recorded significantly lower

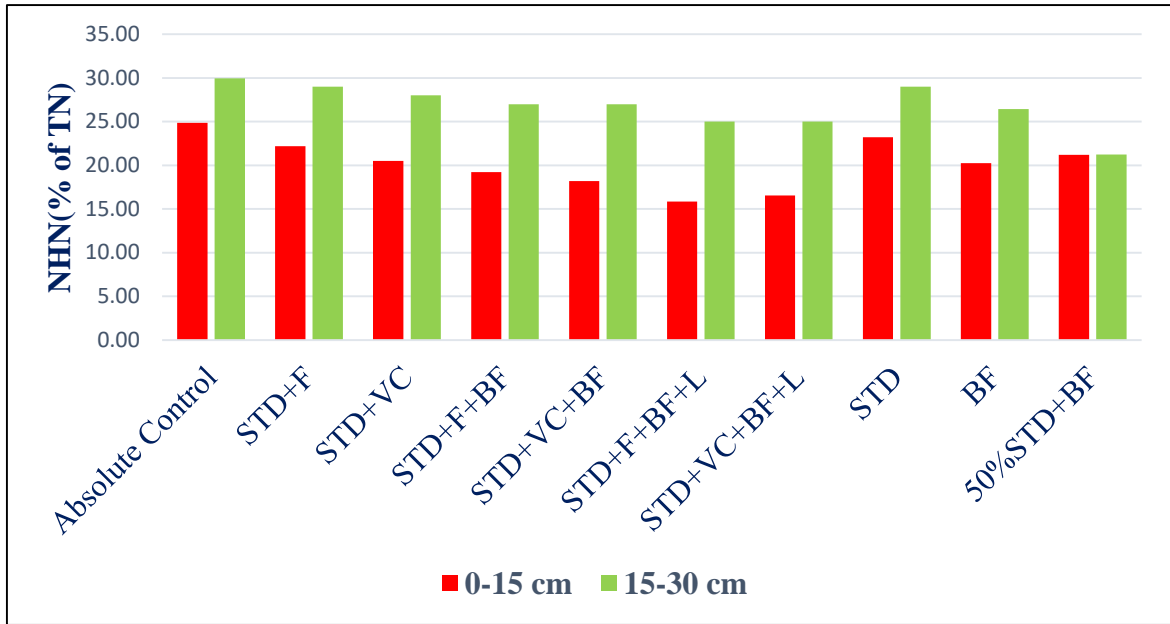
content of ASN than the plots treated with mineral fertilizer and organic manure. Long-term integrated nutrient management significantly increased ASN and it varied along the soil depth also. ASN content decreased with increase in depth. In 0-15 cm depth, it varied from 8.22 mgkg<sup>-1</sup> in unfertilized control to 34.65 mgkg<sup>-1</sup> in STD+FYM+BF+Lime. Highest ASN in 15-30 cm soil was observed in STD+VC+BF+ Lime (20.34 mgkg<sup>-1</sup>) followed by STD+FYM+BF+Lime (19.84 mgkg<sup>-1</sup>) and lowest (6.14 mgkg<sup>-1</sup>) was recorded in control. Biofertilizer inclusion in 0-15 cm layer increased 52.5% ASN in STD+FYM with extra 27% due to lime addition while in 15-30 cm depth, biofertilizers with STD+FYM exhibited 41.2% increment and 17% more with further addition of lime. The ASN build-up varied significantly from 117.6% to 321.5% in 0-15 cm and 92.7% to 231.3% in 15-30 cm depth among various INM treatments receiving full STD as compared to treatments excluding any fertilizers. It was observed that ASN contributed only 6% of THN (Fig 3).

Long term integrated nutrient management practices significantly affected UHN as compared to no-fertilization over the years. UHN content varied significantly along the soil depth. Maximum UHN content was observed in surface soil and then decreased towards deeper layer. In 0-15 cm UHN varied from 53.73 mg kg<sup>-1</sup> to 144.83 mg kg<sup>-1</sup> while in 15-30 cm it ranged between 40.14 mg kg<sup>-1</sup> and 91.53 mg kg<sup>-1</sup>. In surface soil, UHN was found to be the highest (144.83 mg kg<sup>-1</sup>) in STD+VC+BF followed by STD+FYM+BF (141.43 mg kg<sup>-1</sup>) and lowest (53.73 mg kg<sup>-1</sup>) was registered in control. Sub-surface soil exhibiting different pattern recorded maximum UHN accumulation in STD+VC+BF+Lime (91.53 mg kg<sup>-1</sup>) and lowest in unfertilized control (40.14 mg kg<sup>-1</sup>). The increase in surface UHN content over control treatment with sole application of biofertilizers, STD, 50% STD+BF, STD+VC+BF+Lime and STD+VC+BF were to the tune of 15%, 35%, 57.1%, 161% and 169.5% respectively. Following the same order, deeper soil recorded as 17.6%, 23%, 47%, 128% and 89% significant variation. Increment in UHN by 10.29% in surface and 25.8% in deeper layer were observed using vermicompost instead of FYM along with STD and biofertilizers in lime treated plots. Although, biofertilization in STD+FYM treatment increased UHN content by 71.16% in 0-15 cm and 59.23% in 15-30 cm depth but lime inclusion in STD+FYM+BF showed significant depletion in UHN varying 11.31% and 21.06% in surface and sub-surface soil respectively. Similarly, 36.32% in 0-15 cm and 13.35% in 15-30 cm increase in UHN were noticed due to addition of biofertilizers in

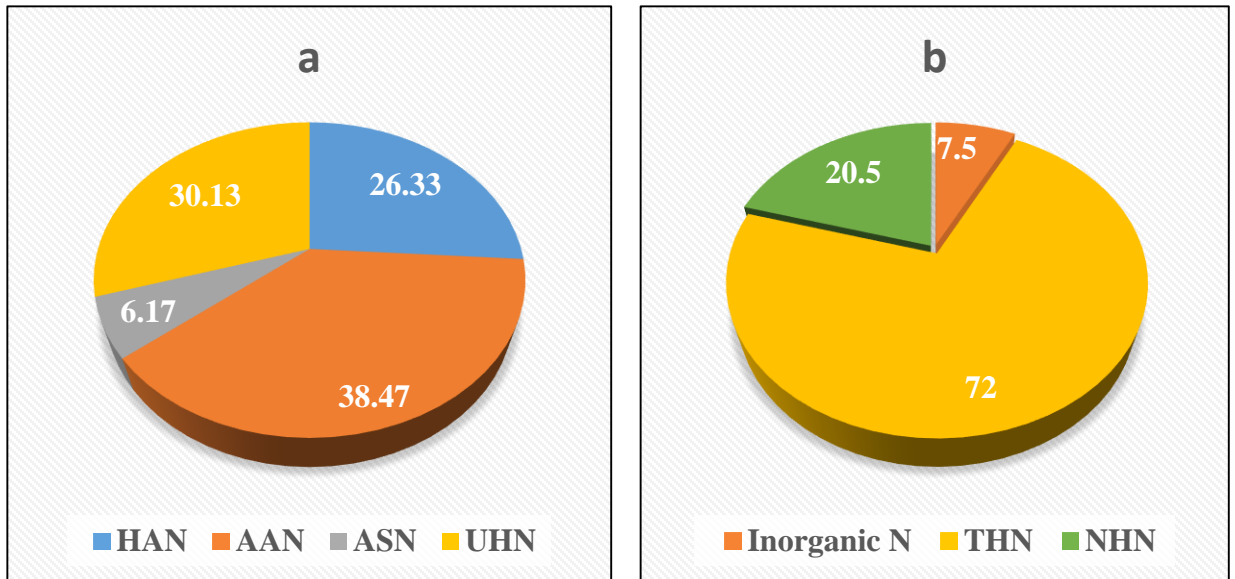
STD+VC over STD+FYM+BF. Among different organic nitrogen fractions 30% of THN remained still unidentified (Fig 3).

**Table 11:- Influence of organics, inorganics, biofertilizers and INM practices on depth wise distribution of Amino Sugar Nitrogen (ASN) and Unidentified Hydrolysable Nitrogen (UHN) content in soil**

Treatments		ASN (mg/kg)			UHN (mg/kg)		
		Soil Depth (cm)					
		0-15	15-30	Mean	0-15	15-30	Mean
<b>T<sub>1</sub></b>	Absolute Control	8.22	6.14	7.18	53.73	40.14	46.94
<b>T<sub>2</sub></b>	STD+F	17.89	12.01	14.95	82.63	55.32	68.98
<b>T<sub>3</sub></b>	STD+VC	18.74	11.83	15.29	106.24	67.07	86.65
<b>T<sub>4</sub></b>	STD+F+BF	27.28	16.96	22.12	141.43	88.09	114.76
<b>T<sub>5</sub></b>	STD+VC+BF	23.36	12.26	17.81	144.83	76.03	110.43
<b>T<sub>6</sub></b>	STD+F+BF+L	34.65	19.84	27.24	127.05	72.76	99.90
<b>T<sub>7</sub></b>	STD+VC+BF+L	31.14	20.34	25.74	140.13	91.53	115.83
<b>T<sub>8</sub></b>	STD	13.41	9.15	11.28	72.46	49.45	60.96
<b>T<sub>9</sub></b>	BF	14.90	11.39	13.14	61.78	47.22	54.50
<b>T<sub>10</sub></b>	50%STD+BF	12.04	8.39	15.27	84.45	58.91	71.68
	Mean	20.16	12.83	17.00	101.47	64.65	83.06
LSD ( $P=0.05$ )		Treatment-1.19 Depth-0.52 Treat x Depth-1.69			Treatment-6.82 Depth-3.05 Treat x Depth-9.64		



**Fig 2: Non hydrolysable N of soil total N at different soil depth influenced by long term INM practices**



**Fig 3: Relative proportion of hydrolysable N fraction (HAN, AAN, ASN and UHN) to THN (a) and contribution of Inorganic N, THN and NHN to soil Total N (b) influenced by long term INM practices**

#### 4.11 Influence of organics, inorganics, biofertilizers and INM practices on Potential Nitrogen Mineralization (PMN)

The amounts of mineralized N differed significantly in the treatments at each incubation period (Table 12). The total N mineralized after two week varied from 14.01 to 74.07 mg kg<sup>-1</sup>. The INM treatments released more N compared to only mineral fertilizer, or only biofertilizer or without any fertilizer or manure i.e. control. The increment was more prominent in INM treatments and it increased to 41 to 90 mg kg<sup>-1</sup> after 8 weeks of incubation.

**Table 12:- Cumulative amount of N mineralized in soils (mg kg<sup>-1</sup>) in INM package of practices.**

Treatments	Release of mineral Nitrogen (mg kg <sup>-1</sup> )								
	Period of incubation (weeks)								
	0	2	4	6	8	10	12	14	16
Absolute Control	12.06	14.01	15.05	16.22	17.42	17.93	18.34	19.06	19.98
STD+F	28.65	33.84	37.09	38.18	41.03	41.89	42.06	43.10	45.94
STD+VC	32.54	39.20	45.12	47.01	48.20	51.40	53.08	56.30	60.90
STD+F+BF	41.51	43.20	52.10	57.10	59.01	62.30	66.00	67.01	67.90
STD+VC+BF	56.32	68.90	72.41	75.09	79.12	81.02	83.21	87.29	90.94
STD+F+BF+L	60.28	74.07	84.20	88.12	90.99	91.23	92.32	93.89	94.20
STD+VC+BF+L	58.56	67.12	69.29	71.38	73.07	74.01	75.00	75.90	76.90
STD	21.87	22.07	24.21	25.07	25.89	26.06	26.77	27.00	27.70
BF	23.06	25.41	26.93	27.34	27.45	28.04	30.89	31.00	32.22
50%STD+BF	26.53	29.10	30.14	30.65	31.00	31.98	32.43	32.93	33.02

A nonlinear least square (NLLS) regression analysis was used to calculate number and rate constant from the 16 weeks data. The NLLS method was used to reduce the error imposed by the logarithmic transformation of low value mineralization data (Smith *et al.*, 1980). N-Mineralization rate constant (k), Potential Mineralizable N (N<sub>0</sub>), Half-life (T<sub>1/2</sub>), active fraction of N (N<sub>0</sub>/N), coefficient of determination (R<sup>2</sup>) were presented in Table 13. Highest PMN (119.7 mg kg<sup>-1</sup>) and k value (0.101 mg kg<sup>-1</sup> week<sup>-1</sup>) were observed in integration of organic manure, biofertilizers, lime with mineral fertilizer and lowest PMN (23.18 mg kg<sup>-1</sup>) and k (0.063 mg kg<sup>-1</sup> week<sup>-1</sup>) in control. Time taken to reduce the half of the substrate were lowest in INM treatments (6-8 weeks). But mineral fertilizer takes 3

weeks (11weeks) more time to decompose half of the substrate. The proportion of  $N_0$  to total N which ranged from 9.0 to 18.0 %. The active fraction of N which readily decomposable dominates in INM treated plots. There was overestimation and underestimation of N mineralization after 16 weeks of incubation. But the estimation were very similar with predicted value in INM treatments which gives higher  $R^2$  value.

**Table 13:- Different parameters of Potential Mineralizable N ( $N_0$ ) estimated according to the first order equations using the NLLS technique to describe the net N mineralization and comparison of experimental with predicted values.**

Treatments	K ( $\text{mgkg}^{-1}\text{week}^{-1}$ )	$N_0$ ( $\text{mg kg}^{-1}$ )	$T_{1/2}$ (weeks)	$N_0/N$ (%)	N mineralized after 16 weeks		$R^2$
					Nm (experimental)	Nm (predicted)	
Absolute Control	0.063	23.18	11	9.86	19.98	14.72	0.91
STD+F	0.083	54.08	8	12.87	45.94	39.74	0.93
STD+VC	0.092	80.9	7	18.64	60.90	62.33	0.98
STD+F+BF	0.093	97.14	7	18.19	67.90	75.20	0.94
STD+VC+BF	0.095	112.83	7	17.62	90.94	88.15	0.99
STD+F+BF+L	0.101	119.7	6	18.13	94.20	95.91	0.99
STD+VC+BF+L	0.097	96.79	7	13.98	76.90	76.28	0.99
STD	0.063	36.38	11	9.62	27.70	23.10	0.92
BF	0.067	45.52	10	15.43	32.22	29.93	0.95
50%STD+BF	0.072	49.75	9	14.67	33.02	34.02	0.98

#### 4.12 Relationship of crop yield and nutrient N uptake with N fraction

Experimental findings (Table 14) demonstrate that different fractions of N had different influence on crop yield and N Uptake. Pearson correlation analysis helped to understand the relationship between N fraction, crop yield and N uptake. Grain yield of blackgram in surface soil (0-15cm) was positively and significantly correlated with soil Av. N ( $r=0.64^{**}$ ), Inorganic N ( $r=0.94^{**}$ ), Total Hydrolysable N ( $r=0.93^{**}$ ), HAN ( $r=0.92^{**}$ ), AAN ( $r=0.92^{**}$ ), ASN ( $r=0.93^{**}$ ) and UHN ( $r=0.93^{**}$ ). The ASN and UHN fraction of organic N were better correlated with yield than that of HAN and AAN whereas the contribution of NHN in yield was not significant. Yield is also highly positively correlated with SOC content. But in deeper layer (15-30 cm) there was no significant relation of av. N and SOC content with yield. All the fraction of organic N and inorganic showed strong

positive correlation with crop yield. N uptake by black gram was positively and significantly correlated with all organic and inorganic nitrogen fractions except av. N and NHN but only inorganic N ( $r=0.89^{**}$ ) among the total N and UHN ( $r=0.92^{**}$ ) among hydrolysable fraction gives with the highest correlation with N uptake in 0-15 cm. But in subsurface layers (15-30 cm) N uptake was positively and significantly correlated with all N fractions but no significant variation with Av. N and SOC content. Inorganic nitrogen was positively and significantly correlated with soil organic carbon content and all other N fractions in surface and sub-surface layers except no significant relation with SOC content in deeper layer. It showed highest correlation with total N in both the layers. PMN is significantly and positively correlated with yield, uptake and all N fractions.

The relative contribution of N fractions to blackgram grain yield and N uptake was worked out by stepwise multiple regression analysis (Table 15). Step down multiple regression analysis of N fractions of soil was carried out to explain the variations in grain yield and N uptake by blackgram as influenced by N fractions of soil, viz. HAN, AAN, ASN, UHN, NHN and inorganic N. The least important N fractions was discarded step-by-step on the basis of 't' value. The regression equation explained 92.2 % variations in grain yield due to combined effect of all soil N fractions. However, the individual effects of all the independent variables were observed to be non-significant. Elimination of least important factors one-by-one decreased the prediction value from 92.2 to 90.6% and the effect of ASN and inorganic N were found most significant.

Variations in N uptake by blackgram were tried to be explained through the variations in N fractions of postharvest soil with the help of regression equations. It was observed that as high as 93.5% variation in total N uptake by blackgram could be explained through all the factors, among which the variation through UHN and inorganic N was 89.8% in total N uptake up by difference of 3.7% variation over previous equation.

**Table 14:- Correlation coefficients (r) between seed yield, SOC content and N fractions at different soil depth**

	AV. N	TN	Inorg N	THN	NHN	HAN	AAN	ASN	UHN	SOC	PMN	k
<b>0-15cm</b>												
<b>Yield</b>	0.64*	0.92* *	0.94**	0.93**	0.65	0.92**	0.92**	0.93**	0.93**	0.82**	0.86**	0.86**
<b>Uptake</b>	0.59	0.89* *	0.93**	0.90**	0.60	0.91**	0.91**	0.91**	0.92**	0.77**	0.85**	0.84**
<b>Inorg N</b>	0.78**	0.98* *	1	0.98**	0.77**	0.96**	0.96**	0.96**	0.93**	0.92**	0.95**	0.90**
<b>PMN</b>	0.81**	0.93* *	0.95**	0.93**	0.73**	0.88**	0.87**	0.92**	0.95**	0.66*	1	0.95**
<b>15-30cm</b>												
<b>Yield</b>	0.57	0.83* *	0.83**	0.85**	0.80**	0.81**	0.82**	0.81**	0.76**	0.25		
<b>Uptake</b>	0.59	0.89* *	0.89**	0.90**	0.82**	0.87**	0.90**	0.89**	0.75**	0.13		
<b>Inorg N</b>	0.83**	0.96* *	1	0.96**	0.95**	0.92**	0.93**	0.86**	0.88**	0.30		

\*Significant at  $P=0.05$ , \*\*Significant at  $P=0.01$

**Table 15:- Step-wise multiple regression analysis of dependent variables (Seed yield and N uptake) and independent variables (forms of N)**

<b>Dependent Variables(Y)</b>	<b>Independent variables on which Y is regressed</b>	<b>Multiple Regression equation</b>	<b>R<sup>2</sup></b>
Seed Yield	HAN, AAN, ASN, UHN, NHN, Inorg N	$Y=104.63+0.031HAN-0.37AAN+0.30ASN-0.37UHN-0.68NHN+1.12InorgN$	0.922**
	HAN, AAN, ASN, UHN, Inorg N	$Y=56.128+0.197HAN-0.301AAN+0.377ASN-0.397UHN+1.054InorgN$	0.921**
	AAN, ASN, UHN, Inorg N	$Y=48.859-0.124AAN+0.428ASN-0.341UHN+0.974InorgN$	0.921**
	ASN, UHN, Inorg N	$Y=21.684+0.424ASN-0.300UHN+0.820InorgN$	0.920**
	ASN, Inorg N	$Y=-64.539+0.406ASN+0.562InorgN$	0.906**
N uptake	HAN, AAN, ASN, UHN, NHN, Inorg N	$Y=2.66+0.49HAN-0.67AAN+0.288ASN-0.66UHN-0.104NHN+1.517InorgN$	0.935**
	HAN, AAN, ASN, UHN, Inorg N	$Y=0.018+0.334HAN-0.563AAN+0.406ASN-0.705UHN+1.417InorgN$	0.933**
	AAN, ASN, UHN, Inorg N	$Y=-0.422-0.262AAN+0.493ASN-0.610UHN+1.280InorgN$	0.931**
	ASN, UHN, Inorg N	$Y=-2.468+0.483ASN-0.523UHN+0.956InorgN$	0.928**
	UHN, Inorg N	$Y=-0.900-0.499UHN+1.385InorgN$	0.898**

\*\*Significant at  $P=0.01$

## **CHAPTER-5**

---

### **DISCUSSION**

# DISCUSSION

---

Integration of different sources of nutrients like fertilizer (inorganic source), FYM/VC (organic source), microbial inoculants (BFs) and lime (acid soil) ameliorant were used to study the long term effect of INM practices on nitrogen transformation in acid *Inceptisols*.

## **5.1 Influence of organics, inorganics, biofertilizers and INM practices on Crop Productivity, Harvest Index and Relative Agronomic Efficiency and Nutrient Uptake**

Significant differences were noticed on total dry matter production of blackgram with the long term practice of INM .Seed yield is the net result of various organic inputs influencing growth and yield attributing characters during the life cycle of crop. INM practices have found to decrease dependence on chemical fertilizers and increase crop yield as compared to chemical fertilizers alone (Medhi *et al.*, 2002; Jeyabal *et al.*, 1999). A vast (386%) increment in potential yield (Table 3) was seen due to addition of organic manures with recommended dose of fertilizers. Application of organic manure acts as source of carbon and energy for growth and multiplication of microorganism which would have helped to mineralize the nutrients from organic to available inorganic form, ultimately increasing the seed yield. Organic manures not only slowly release nutrients but also prevent the loss of leaching (Dakshinamoorthy *et al.*, 2005). Enhancement of seed yield and total biological yield with biofertilizers over sole organic fertilization were mainly ascribed to the production of amino acids, vitamins and growth promoting substances. These are secreted by the introduced beneficial microbial inoculants like *Rhizobium* and PSB which provided N, P to plant growth and resulted economically profitable yield (Tomar *et al.*, 1998; Patel and Thakur, 2003).

The treatment having recommended dose of mineral fertilizers+organic manure+biofertilizers+Lime recorded highest seed, stover and siliqua yield compared to others. This might be due to more availability of nutrients from organic manure through a longer period and beneficial effect of microorganisms in the form of biofertilizers. Lime addition create better chemical and biological environment in the soil. The data depicted in Table 3 gives the clear picture on justification for continuing INM package of practices over the years. The control treatment having absolutely no intervention from external

nutrient source recorded significant increase in seed yield as compared to inorganic fertilization alone which manifested lowest seed yield and minimum dry matter production.

Among various treatments, combined application of inorganics, organic manures and biofertilizers with or without lime gave higher Harvest Index (HI). Patel and Thakur (2003) observed an increasing trend in HI with application of PSB and FYM. Agronomic efficiency was greatly increased in lime applied INM treatments and also by rational use of organic manure and biofertilizers with balanced inorganic fertilization. It might be owing to beneficial effect of combined application of organic manures and inorganic fertilizers on crop growth and increased availability of nutrients through inoculation of *Rhizobium* and PSB (Khatkar *et al.*, 2007) which influenced the growth and yield attributing characters positively. Moreover, proper decomposition of FYM, vermicompost supplied available plant nutrients directly to plants and created favourable soil environment which ultimately increased seed and stover yield of Black gram. These results are in agreement with the findings of Singh and Singh (2006) who reported higher grain yield of urd bean (13.4% during 2003) with FYM over no application.

Higher nitrogen uptake was recorded when nutrients were applied through integrated application of 100% NPK along with organic manure, microbial inoculants with soil amendments (Table 4). The increase in uptake under INM might be ascribed to more availability of these nutrients from the added fertilizers and also to the solubilizing action of organic acids produced during decomposition of organic manure, thus rendering more release of nutrients from the soil (Arulmozhiselvan *et al.*, 2013). Among the microbial inoculants dual inoculation of *Rhizobium* and PSB were shown to exert beneficial effect on plant growth and crop yield (Kant *et al.*, 2016). Interestingly, PSB dissolving interlocked phosphates efficiently appear to have primary implication on root growth, dry matter production, nodulation and nitrogen fixation. It also increases the number of lateral roots and enhances root hair formation to provide more root surface area to absorb efficient nutrients. Seed inoculation with biofertilizers significantly increased nitrogen uptake by black gram (Patil *et al.*, 2010). Nagarajan and Balachandra (2001) also observed that application of FYM significantly improved nodulation of urdbean and mungbean, increase the available nutrients to plants resulting in higher nutrient uptake rate. Lime addition significantly increases N mineralization of organic manures developed healthier roots and

increased uptake of nitrogen by reducing acid saturation and making congenial environment for microorganisms to grow and multiply. Uptake of nitrogen was lowest in the plot receiving sole inorganic fertilization. Plants grown in sole chemical fertilized plot do not develop good plant characters such as good root system and nutritional characters and also might be due to lowering nitrogen use efficiency. Inorganic fertilizers also a direct and immediate source of nutrients develop no further organic matter in soil which reduces its ability to store nutrients. Thus integration of inorganic fertilizers and biofertilizers resulted in better growth and nutrient uptake in black gram (Kumpawat, 2010) as compared to inorganic fertilization only.

## **5.2 Effect of Integrated Nutrient Management practices on pH, EC content of soil**

The data presented in Table 5, revealed that at the end of 25<sup>th</sup> crop in sequence, the pH of soil decreased in comparison to its initial status except sole biofertilization and lime application. The stronger acidification of legumes is valid as they tend to absorb less anions (nitrates) and the cations surplus uptake strongly acidifies the soil. Gawai (2003) reported reduction in soil pH due to release of organic acids through microbial decomposition of organic manures. The use of urea fertilizer might have resulted in soil pH decrease. Long term effect of chemical fertilizers can include leaching of nitrates and sulfates due to high solubility which will leach some basic cations causing acidification. Extra plant growth (for example of legumes) caused by fertilizer may also result in some acidification over time. The issue of excessive application and further leaching loss does not arise in the use of biofertilizers alone. They have long lasting effects due to slow but steady nutrients release, maintaining stable soil reaction. There is an increasing trend in pH with increasing depth except STD+FYM+BFs which might be attributed to leaching of  $\text{Ca}^{2+}$  and other basic cations from surface horizon and accumulation in deeper layer which was supported by Zhang *et al.* (2019). Liming provides basic cations to the soil and also suppress hydrolysis of  $\text{H}^+$  ions thus increasing soil pH.

The post-harvest soil analysis has shown that EC in all treatments were less than  $0.18 \text{ dS m}^{-1}$ ; which is considered safe for growth of all crops. Application of biofertilizers alone lowered EC significantly. It indicates that chemical fertilizers are responsible for the enhanced salinity of the soil. These findings are in close agreement with Arbad *et al.*

(2008). In deeper soil, integration of inorganics, organic manures and biofertilizers exhibited synergistic effect on mobility of soil ions and recorded highest EC.

### **5.3 Influence of organics, inorganics, biofertilizers and INM practices on depth wise distribution Soil Organic Carbon (SOC) content and Available Nutrients in soil**

In the present study, cultivation caused an enrichment of SOC content of the soil over initial status (Table 6). This was obviously associated with large amount of crop residues and root biomass carbon left over in the soil owing to significantly higher SOC content in the soil. Besides carbon supplementation through FYM/VC, inclusion of legumes in crop rotation increased the total organic carbon content due to legume effect such as higher below-ground biomass, leaf fall and higher rhizodeposition of carbon (Ghosh *et al.*, 2017). A considerable portion of legume roots (43-47%) are non-decomposable that finally contributes to SOC build-up (Parihar *et al.*, 2018). Significant increase in organic carbon content due to integrated nutrient management (INM) treatments was also observed. This was probably due to the rapid decomposition of organic material added to the soil and intensive humification process of organic matter as influenced by biofertilizers. Control treatments recorded the least organic carbon probably due to low dry matter production and hence low return of crop residues to the soil when compared with balance fertilization with or without microbial inoculants. In deeper soil, lower population of soil microorganisms reduces decomposition of organic matter, ultimately decreasing SOC status (by 49%). FYM applied lime treated plot with inorganics and biofertilizers exhibited highest significant (64.4%) depth-wise variation of SOC, greater effect of lime to accelerate carbon mineralization was noticed in surface layer only.

Continuous application of either combination of organic and inorganic or in combination with biofertilizers increased the available nitrogen content in soil (Table 6). This increment with the incorporation of organic source might be attributed to N mineralization (Sharma *et al.*, 2008). Lowest value was noticed in control. Continuous removal by crops without external addition of fertilizers and FYM/VC over a period of time resulted decrease soil available N. The result of the present study is in line with those reported by Katkar *et al.* (2011). In INM treatments, inclusion of microbial inoculants like *Rhizobium* and PSB along with lime significantly increased the available N in soil because fertilizer keep the soil environment rich in all macro, micro nutrients via nitrogen fixation,

phosphate and potassium solubilization on mineralization, with release of plant growth regulating substances like IAA, NAA, GA, cytokinins, production of antibiotics and biodegradation of organic matter (Sinha *et al.*, 2014). Lime addition improves the physio-chemical environment of soil and thereby efficiency of microorganisms is improved. It has been reported that in addition to fixing the atmospheric N through nodulation, *Rhizobium* shares many characteristics with other PGPRs including hormones production and solubilization of organic and inorganic phosphates (Russell *et al.*, 1982). Through plant growth promoting substances, it helps in root expansion, improves uptake of plant nutrients and most importantly biomass production.

Available phosphorus content of soil increased (Table 7) with addition of INM package as compared to control. Higher amount of available P was observed in combination mineral fertilizers and organic manure treatment. Higher availability may be due to solubilization of P by organic acids released from the organic manure, reduction of P fixation in soil due to chelation of P fixing cations like  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ , Fe, Al, Zn, Mn and Cu and also due to enhanced microbial activity (Sathya, 2010). Among the biofertilized treatments, PSB plays a very important role in P nutrition by increasing its availability to plants through release from locked inorganic and complex organic soil P pools by solubilization and mineralization. The main mechanism behind mineral phosphates solubilization is lowering the soil pH by microbial production of organic acids and mineralization of organic phosphorus by acid phosphate (Kumar Anand *et al.*, 2016).

The available potassium varied from 151 to 216 kg ha<sup>-1</sup>. Integrated application of organic manure along with fertilizers, biofertilizers and lime recorded highest available potassium in soil. Addition of biofertilizers held significant increase in available K by producing greater organic matter which could retain K in soil and enhanced release of roots exudates and plant growth regulators to solubilize K complexed with soil ions. The beneficial effects of organic manuring on K availability includes minimizing the losses from leaching by retaining K on exchange sites. Solubilization of insoluble components through action of organic acids released during decomposition besides minimizing losses due to fixation (Dakshinamoorthy *et al.*, 2000).

#### **5.4. Influence of organics, inorganics, biofertilizers and INM practices on depth wise distribution of Total Nitrogen content in soil**

The data pertaining to experimental findings (Table 8) showed that nine years of Integrated Nutrient Management with organic manures like FYM/VC with inorganic fertilizers under cereals-vegetables-pulses cropping system, increased total N content by 15 % in relation to soil that receive only balanced fertilization in surface soil. It was evident that a close relationship exist between total N and soil organic carbon. Integration of organics and inorganics increases both organic matter and organic carbon, thereby reducing bulk density and increase in total N. Addition of lime and vermicompost promoted appreciable amount of total N which may be ascribed to vast and diversified microbial population developed in the congenial soil environment. Moreover, inclusion of lower C:N ratio material from pulse crop in the cropping system every year and easily decomposable constituents like proteins present in these organic sources might be ascribed to improve in total N content in soil. The highest total N concentration was noticed upto 15 cm depth and gradually decreased with soil depth. This result is in line with Jagadamma *et al.* (2007). The crop residues are incorporated and fibrous root extension only in surface layer accumulated total N in upper layer compared to deeper layer.

#### **5.5 Influence of organics, inorganics, biofertilizers and INM practices on depth wise distribution of Inorganic Nitrogen content in soil**

Significant increase of inorganic N fraction accounted for 7% of the total N (Fig 3), was noticed in long term integrated nutrient package of practices in the post-harvest soil of black gram. Higher quantity of residue inputs associated with non-pulse rotations did not translate into higher mineralization rates than the lower biomass in pulse crops (Bedard-Haughn *et al.*, 2013). Sriramachandrasekharan (2009) also reported increase in inorganic N with integration of manures and fertilizers. The integration of organic manure along with mineral fertilizer increased the inorganic nitrogen due to addition of larger quantity of biomass along with external source of organic matter through manure leading to the accumulation of organic matter and its subsequent decomposition and mineralization (Duhan *et al.*, 2005; Manivannan and Sriramachandrasekharan, 2009). Low build-up of inorganic N over sole biofertilized plot was recorded in soils might be due to immobilization of available nutrient because residue incorporation was made just 10 days

before. The decline in inorganic N content from surface to sub-surface soil might be due to its uptake by crop, lower rate of mineralization in subsurface layer, less movement to the depth and loss of NO<sub>3</sub>-N through leaching. Significant increment in inorganic N was noticed in vermicompost applied biofertilized treatment. This might be ascribed to the enrichment of soil environment with micro and macro nutrients via nitrogen fixation and phosphorus solubilization by biofertilizers which enhance plant growth regulating/ growth promoting substances and biodegradation of SOM (Sinha *et al.*, 2014), besides high N supplementation through vermicompost.

### **5.6 Influence of organics, inorganics, biofertilizers and INM practices on depth wise distribution of Soil Organic N fractions**

The results pertaining to changes in different fractions of organic nitrogen in soil as influenced by the nine years of integrated nutrient management practices in acid *Inceptisols* in surface (0-15 cm) and sub-surface (15-30 cm) presented in Table (9-11) showed appreciable build-up of SON with conjunctive use of inorganic fertilizer, organic manure, biofertilizers and soil amendment. The concentration of SON varied from 199.3 mg kg<sup>-1</sup>, the lowest in unfertilized control to the maximum 543 mg kg<sup>-1</sup> in STD+VC+BF+Lime. A drastic low organic N was noticed in other INM treatments receiving only organic manure with inorganics or in combination with biofertilizers or reduced recommended fertilizer dose. These treatments owing to lower microbial population lead to very slow rate of crop residue decomposition due to high lignin. It may be possible that part of the mineralized N is very slowly available to soil because of greater lignin/N ratio in pulse crop residue (Carvalho *et al.*, 2012). The behavior of known fractions of THN eg: Hydrolysable Ammonium Nitrogen (HAN), Amino Acid Nitrogen (AAN), Amino Sugar Nitrogen (ASN) and Unidentified Hydrolysable Nitrogen (UHN) in relation to Total Hydrolysable Nitrogen (THN) are presented in Fig. 3.

The present study revealed that THN ranged from 143.73 to 429 mg kg<sup>-1</sup>. There was considerable build-up of THN over a period of time due to continuous manuring and fertilization in an integrated manner. This appreciable amount of THN attributed to successive addition of organic manures and also increase in organic carbon content of the experimental soil over 9 cycles of cropping systems. Most of the nitrogen applied through

inorganic sources get immobilized because of microorganisms and in turn it become a part of organically bound nitrogen exerting the priming effect (Mairan *et al.*, 2002). Many researchers reported increase in total hydrolysable nitrogen content of soil due to cropping, fertilization and organic manure application (Srivastava and Srivastava, 1993). The distribution of this fraction in the soils is related to the organic matter content of soils (Aggarwal *et al.*, 1990). Higher amount of this fraction was also due to the possible cleavage of amino acids and nitrogen containing mineral. Rao and Ghosh (1981) observed an increase in the levels of hydrolysable N due to the addition of organic manures and also reported the existence of an equilibrium between immobilization and mineralization processes going on individual fraction with a clear and perceptible shift towards greater immobilization and consequent accumulation of N in some forms.

Hydrolysable ammonium nitrogen (HAN) increased significantly in all integrated nutrient managed plots (Table 10). However much higher content was observed under treatments receiving all sorts of N input along with soil amendment. Continuous integrated treatments resulted in higher accumulation of organic matter and mineralization might have contributed in accumulating higher ammonium N over others. Hence, at the end of nine years of cropping sequence, a build-up of maximum 140 mg kg<sup>-1</sup> in surface and 91.5 mg kg<sup>-1</sup> of organic ammonium-N were observed. There was a decreasing pattern of HAN distribution with depth due to adsorption of ammonical N which may get fixed to the clay particles in deeper layer (Singh *et al.*, 1992).

The occurrence of amino acid nitrogen in the soil has been known since the turn of the century and is a major fraction of SON. This fraction is closely associated with microbial metabolism, simultaneously serving as an important storage pool for the immobilized N (Amelung, 2001) and a main source of available N for soil microorganisms and plants (Werdin-Pfisterer *et al.*, 2009). Amino acid nitrogen content in various treatments under study (Table 10) revealed marked increase in this fraction especially in integrated treatments. An increase in amino acid and protein contents were reported in blackgram crop grown under recommended doses of biofertilizer applications (Rajasekharan *et al.*, 2017). The inorganic fertilizers and organic manures applied treatments showed a higher content when compared to control. Similar findings of

increasing trend in amino acid due to fertilizer application were reported in maize (Tejeda *et al.*, 2008).

Prasad and Rokima (1991) observed that amino acid nitrogen fraction closely followed the trend similar to total nitrogen and organic carbon and its contents increased with increase in organic carbon and total nitrogen. AAN increased with the increase in organic matter and total nitrogen was subjected to rapid mineralization. A favourable soil pH could be one of the reason for increased immobilization of the added nitrogenous fertilizers which in term increased the amino acid and hexosamine N as reported by Subba Rao and Ghosh (1981). Their polymers decompose rapidly in the sub surface horizons owing to less effective stabilization of these components against microbial attack as reported by Keeney and Bremner (1990).

Amino sugar nitrogen content is basically microbiological products and variation in their composition with respect to depth depends on activities of fungi, bacteria. Predominant sources of mineralization are polymers of amino sugars present in soil microbial biomass. Influx into this pool occurs with application of organic matter, organic carbon released by plant roots, N<sub>2</sub> assimilation by leguminous crops and inorganic nitrogen (Mengel, 1996). Mohapatra and Khan (1989) reported that the changes in amino sugar were the opposite site of amino acid-N which Aggarwal *et al.* (1990) concluded ASN as relatively less stable and lower in amount than AAN. The amino sugar (ASN) contributed least to total hydrolysable N and it comprised of only 5% to 7% of THN (Fig 3).

The fractionation allows separating the labile N forms from the soil, such as Amino sugar-N and amino-N (acid hydrolyzable), which can be rapidly synthesized in the mineralization process, releasing inorganic N (NH<sub>4</sub><sup>+</sup> and NO<sub>3</sub><sup>-</sup>) to the soil solution. However, most of the organic N can compose more stable fractions in the soil, such as non-hydrolyzable-N and unidentified-N. Variation in the non-hydrolyzable-N may be related to soil management, because the higher the hydrolysis intensity of organic N fractions in the soil, the higher the presence of finer particles that form clay-metal-humus complexes that constitute the non-hydrolyzed N (Stevenson, 1982).

Experimental results showed that total N was constituted by 70% to 75% of THN, out of which 32% to 42% AAN and 5% to 7% ASN, 24% to 27% HAN, 25% to 36.3% UHN and NHN ranged from 19.2% to 25.6% of total N. Different fractions of soil organic

N like AAN, ASN, HAN and UHN in relation to THN were to the tune of 38%, 6%, 25.4% and 30% respectively (Fig 3). The dominant fraction of organic N is AAN under long term cereal-vegetable-pulse cropping system. The distribution of all these hydrolysable N fractions after nine long years of integrated manuring and fertilization increased in all balanced fertilized plots in comparison to unbalanced fertilization and unfertilized control. The same trend was recorded by Sarawad *et al.* (2001). This kind of relationship might be due to the fact that most of the added fertilizer-N was transformed into hydrolysable organic N fractions. Significant increment in all the hydrolysable N fractions with combined application of lime, mineral fertilizers, biofertilizers like *Rhizobium*, PSB and further by the substitution of N and P with FYM or vermicompost was highest over unfertilized control as compared to sole inorganic fertilization or biofertilization. These results indicated the supreme importance of INM PoPs to enhance SON status because mineralization and subsequent release of N from decomposed manure are attained in a favourable micro-environment developed with lime and organic matter in addition to biofertilizers. Similar results were reported by Bharti (2013) in an acid *Alfisols*. Durani *et al.* (2016) also concluded that organic manure had a more significant effect on soil organic nitrogen fractions and mineralization. The influence of organic manures, inorganic fertilizers and biofertilizers on the change in SON fractions provided an assessment that additional N provided by organic manure was primarily concentrated in hydrolysable organic nitrogen fractions (HAN, AAN, ASN, UHN) which are considered as major source of plant available N because THN is more susceptible to mineralization than NHN (Subba Rao and Ghosh, 1981). Decline in the magnitude of NHN was observed as compared to THN (Table 9). It might be ascribed to the fact that residual fertilizer-N was preferentially converted into the acid-soluble fraction of higher availability (Durani *et al.*, 2016).

### **5.7 Influence of organics, inorganics, biofertilizers and INM practices on Potential Nitrogen Mineralization (PMN)**

The time course of rate of change of nitrogen mineralization in different treatments showed that mineralization was faster during initial days of incubation followed by a relatively slower rate subsequently (Table 12). Very little N mineralization was reported in last two weeks. From the above result, it was found that large amount of mineralized N were observed during 2 to 8 weeks of incubation period. Higher

mineralization rates during early period of incubation and decreasing rate with time have also been reported earlier (Lindemann and Cardenas, 1984). Mohanty *et al.* (2013) reported that the amount of N released per unit C mineralization was higher in aerobic system that may result in greater loss of N from the system. The flush of mineral N and corresponding high mineralization rates during the initial period of incubation were attributed due to the decomposition of very labile organic N. As the first pool (more labile organic N) disappears the second pool of organic N predominates which is somewhat resistant to further decomposition and contributes a small proportion of nitrogen mineralization during a short-term incubation (Stanford, 1968). First order decay rates assumed in yearly time scale decomposition of organic matter for release of C and N in soils (Manzoni and Porporato, 2009). Although, N predicted overestimated or underestimated  $N_{\min}$ , at 0 to 15 cm, the overestimation was lower with manure and biofertiliser and lime treated plots. These data suggest that treatments with high substrate quality resulted in better agreement between  $N_{\text{predicted}}$  and  $N_{\min}$  ( $R^2=0.98$  to  $0.99$ ).

### **5.8 Relationship between N fraction, crop yield and N uptake**

Grain yield and N uptake of crop were significantly correlated with total N, inorganic N and all forms of organic N except NHN (Table 14). Yield and uptake are more strongly correlated with THN imply that hydrolysable N fractions are the most important source of mineral N, the supply of which increases N uptake and the yield. The parameters of N mineralization kinetics positively correlated with crop yield, and N uptake (Table 14). So, N mineralization kinetics can be used to estimate N nutrient uptake by plants. The higher value of  $N_0$  and  $k$  favor the N mineralized from organic matter. Among all N fractions, UHN were highly correlated ( $r=0.95^{**}$ ) with PMN. The positive and significant correlated with NHN implied that after easily decomposable material, the most stabilized fraction of organic N were attacked by microorganisms, supplying nutrients to the plants.

The multiple regression analysis indicated (Table 15) that UHN and inorganic N fractions were the main contributor towards crop yield and uptake which was strongly supported by highest correlation of inorganic N and UHN with PMN.

## **CHAPTER-6**

---

### **SUMMARY AND CONCLUSION**

## SUMMARY AND CONCLUSION

---

Soil is the key natural resource and integrated nutrient supply system plays a vital role in sustaining fertility on long term basis. Continuous application of mineral fertilizers, organic manures singly or in combination with microbial inoculants and soil ameliorant keeps a great signature on various fractions entrapping particularly nitrogen in soil. Transformation of these N fractions influences N availability in soil which in turn governs the crop growth and development and quality of the produce in the long run. The contribution of different N pools may also vary from soil to soil depending on fertilizer inputs and nutrient balance particularly mining and nutrient reserve in relation to a crop. Thus the present investigation was conducted to study the “**Soil nitrogen transformation under long term INM practices in an acid *Inceptisols*”**. The long term experiment with cereals-vegetables-pulses cropping sequence with variable doses of organic and inorganic nutrient sources in progress at the College of Agriculture, O.U.A.T., Bhubaneswar since 2010, was used for this study. The test crop for present study blackgram (cv. PDM-139) was the 25<sup>th</sup> crop in sequence. The experiment was laid out in a randomized block design with three replications and ten treatments in a loamy sand soil. Post-harvest soil samples of *summer* seasoned blackgram crop were collected from two different depths (0-15 cm and 15-30 cm). The treatments were such as 1. Absolute control, 2. STD+FYM, 3. STD+VC(vermicompost), 4. STD+F+BFs(Biofertilizers), 5. STD+VC+BFs, 6. STD+F+BFs+L(Lime), 7. STD+VC+BFs+L, 8. STD (100% NPK), 9. BFs, 10. 50% STD+BFs. The recommended Soil Test Dose (STD) for the present crop was 30-13-30-30 kg ha<sup>-1</sup> of N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O-SO<sub>4</sub> supplied through Navaratna (20-20-0-13), urea and MOP. The doses of farm yard manure and vermicompost were 5 and 2.5 t ha<sup>-1</sup> respectively. Biofertilizers like *Rhizobium* was seed inoculated @ 50 g kg<sup>-1</sup> seed and PSB for soil application was applied @ 4 kg ha<sup>-1</sup> as per treatment inoculated to 5% limed vermicompost incubated for a week and applied as basal. In the present investigation, simple correlation and regression were analysed between various soil attributes, crop yield and nutrient uptake and potentially mineralizable N (N<sub>0</sub>) as well as mineralization rate constant (k) were estimated using non-linear least-square regression in the first-order kinetic model.

From the experiment, it was observed that total dry matter production of blackgram was significantly affected by long term INM practices and varied between 191 kg ha<sup>-1</sup>, lowest with STD and maximum 1080 kg ha<sup>-1</sup> in STD+FYM+BF+Lime. Unfertilized control and application of even half dosed inorganic fertilizers recorded significant 72% and 109% yield increment over sole inorganic fertilization (full dose) respectively. Conjunctive application of biofertilizers, inorganics and various organic inputs increased total yield maximum upto 133% over unfertilized treatment whereas, lime inclusion in acidic soil improved the total crop productivity by adding extra 42%. Lime applied INM treatments recorded marked increase in seed yield over unfertilized control and contributed 55% more in yield economics of other biofertilized INM plots receiving full STD. The harvest index (HI) was observed highest in STD+FYM+BF+Lime (63%) and minimum HI in STD (27%). Addition of lime as a soil amendment in acidic *Inceptisols* indicated highest agronomic performance.

Sole biofertilized plot resulted maximum seed N concentration (5.12%) in blackgram although maximum N uptake in seed was recorded in lime applied INM treatment. Integration of biofertilizers with STD+FYM/VC increased total uptake by 36% to 59% and further addition of lime (PMS) manifested extra 49% to 84% increment. Nitrogen recovery was much higher in lime treated INM packages.

Marginal reduction in soil reaction was obtained after nine years of integrated nutrient supply system. In comparison to initial status, soil reaction decreased among all the treatments except that receiving sole biofertilization and inclusion of lime as soil ameliorant and significant variation was noticed among them only. Lowest pH was observed in STD in 0-15 cm. The treatments receiving lime as soil ameliorant showed significantly higher soil pH over all other integrated treatments. Soil reaction values followed an increasing trend in deeper soil layer (15-30 cm) in all treatments except that receiving STD, FYM and biofertilizers combinedly. Significant reduction in soil EC was noticed after long term INM packages as compared to initial value. The highest EC value (0.103 dS m<sup>-1</sup>) was shown in STD in sub-surface soil.

Significant build up in organic carbon was obtained where integrated nutrient sources were applied over the years by 62% to 104% as compared to initial SOC (2.7 g kg<sup>-1</sup>). Application of lime, vermicompost and biofertilizers have no significant effect on SOC

content. All treatments showed significant depth-wise variation in SOC content, the highest (64.4%) being recorded in lime treated plot combined with inorganics, FYM and biofertilizers.

Conjunctive application of organics, inorganics, biofertilizers and acid soil ameliorant caused significant increase in available nutrients status of soil. Vermicompost as an organic input along with STD, biofertilizers and lime resulted maximum N and K availability. However, integration of FYM improved soil P to the highest level. Application of biofertilizers alone increased the appreciable amount of available K. When compared with initial values considerable depletion in P availability was observed. However, soil available N and K recorded marked accumulation over a period of time.

The effect of different sources of nutrients on total N of soil proved better with lime applied INM packages, good with organics, inorganics and biofertilizers integration and lowest with unfertilized control. Surface soil exhibited maximum total N build up with 57% significant depth-wise variation.

Significant increase of inorganic N fractions accounted for 7% of the total N, was noticed in long term integrated nutrient package of practices in the post-harvest soil of black gram. Use of biofertilizers either alone or in combination increased inorganic soil N content ranging from 5.4% to 176% over STD in 0-15 cm depth and it varied from 18% to 157% with a significant increase in 15-30 cm soil. Inclusion of lime exhibited significantly higher accumulation of inorganic-N over all other lime excluded treatments in both layers except STD+VC+BF in surface soil. There was 58.44% significant depth wise variation of inorganic nitrogen content and it decreased with increasing depth.

Considerable build-up of all organic nitrogen fractions viz. hydrolysable ammonium nitrogen (HAN), amino acid nitrogen (AAN), amino sugar nitrogen (ASN), unidentified nitrogen (UHN) all together comprising acid soluble total hydrolysable N (THN) and acid insoluble non hydrolysable N (NHN) could be observed with conjunctive use of inorganic fertilizer, organic manure, biofertilizers and soil amendment. The concentration of SON varied from 199.3 mg kg<sup>-1</sup>, the lowest in unfertilized control to the maximum 543 mg kg<sup>-1</sup> in STD+VC+BF+Lime comprising 90.9% to 94.9% of total N. Variable response in relation to acid hydrolysis divided total N into two main fractions: Total Hydrolyzable Nitrogen (THN) and Non Hydrolysable Nitrogen, comprising 70% to 75% and 19.2% to

25.6% respectively. Present study concluded that THN ranged from 143.73 to 429 mg kg<sup>-1</sup> revealing significant relation of THN with organic carbon content of experimental soil. Much higher content of HAN was observed under treatments receiving all sorts of N input along with soil amendment. Among the hydrolysable N fractions, lowest was recorded in ASN and dominant organic N fraction was AAN under long term cereal-vegetable-pulse cropping system. Experimental results showed that THN was constituted by 38% of AAN, 6% of ASN, 25.4% of HAN and 30% of UHN.

The distribution of all these hydrolysable N fractions after nine long years of integrated manuring and fertilization increased in all balanced fertilized plots in comparison to unbalanced fertilization and unfertilized control. Significant increment in all these fractions with combined application of lime, mineral fertilizers, biofertilizers like *Rhizobium*, PSB and further by the substitution of N and P with FYM or vermicompost was noticed. The fractionation allows separating the labile N forms from the soil, such as Amino sugar-N and amino-N (acid hydrolyzable), which can be rapidly synthesized in the mineralization process, releasing inorganic N (NH<sub>4</sub><sup>+</sup> and NO<sub>3</sub><sup>-</sup>) to the soil solution. However, most of the organic N can compose more stable fractions in the soil, such as non-hydrolyzable-N and unidentified-N. All known and unknown organic nitrogen fractions showed appreciable decline in deeper soil layer except NHN fraction which recorded no significant depth wise variation.

Potential mineralization study of nitrogen in the long term INM practices revealed significant amount of mineralized N variation at each incubation period among the treatments. Integrated treatments released more N compared to only mineral fertilizer, or only biofertilizer or unfertilized control. Within first 8 weeks of incubation, total amount of mineralized N exhibited drastic increment most prominently in integrated treatments from 41 to 90 mg kg<sup>-1</sup>. A nonlinear least square (NLLS) regression analysis used to calculate N-Mineralization rate constant (K), Potential Mineralizable N (N<sub>0</sub>), half-life (T<sub>1/2</sub>), active fraction of N (N<sub>0</sub>/N) and coefficient of determination (R<sup>2</sup>) from the 16 weeks data resulted highest PMN (N<sub>0</sub>) and k values in lime applied INM treatment receiving FYM as organic input as well as lowest opportunity time to decompose half of the amount. The most readily decomposable active fraction (N<sub>0</sub>/N) of PMN dominates in INM treated plots ranging from 9% to 18%.

Blackgram yield and N uptake recorded variable correlation with different organic and mineral N fractions. Grain yield was positively and significantly correlated with soil Av. N, Inorganic N, Total Hydrolysable N and fractions of THN like HAN, AAN, ASN, UHN and Total N in both layers except with Av. N in deeper layer. In surface soil (0-15 cm) nitrogen uptake and crop yield showed significant positive correlation with SOC while no significant correlation was noticed in 15-30 cm depth. Inorganic N in 0-15 cm and THN in 15-30 cm exhibited strongest positive correlation with blackgram productivity. About N uptake, strong correlation was observed with inorganic pool and AAN in surface and sub-surface soil respectively. Also, yield and uptake are more strongly correlated with THN imply that hydrolysable N fractions are the most important source of mineral N. The parameters of N mineralization kinetics ( $N_0$ ,  $k$ ) significantly and positively correlated with yield, uptake and all N fractions.

Step wise multiple regression analysis of N fractions of post-harvest soil was carried out to explain the variations in grain yield and N uptake by blackgram as influenced by various N pools of soil, viz. HAN, AAN, ASN, UHN, NHN and inorganic N. Elimination of least important factors decreased the prediction value from 92.2% with all factors to 90.6% with two most relevant and thus the effect of ASN and inorganic N were found most significant with blackgram productivity. Similarly, N uptake by crop was explained by 89.8% significant variation due to UHN and inorganic N.

From the entire study the following conclusion can be drawn

- Due to development of acidity, the sole application of mineral fertilizer failed to achieve the satisfactory yield over absolute control where no external source of fertilizer were applied. There was a vast improvement in crop productivity in adopting INM package of practices. Further yield advantage were observed with the inclusion of soil amendment in the INM practices.
- Following INM practices including organics, inorganics, microbial inoculants and lime increased appreciable amounts of organic carbon and maintained the fertility status of the soil by increasing the availability of nutrients.
- As the soil is acidic, it is mandatory to include lime as one of the key components of INM for better growth and crop yield.

- Long-term integrated application of organic manures, mineral fertilizers, biofertilizers along with lime improved mineral and organic fractions of soil N under the cereal-vegetable-pulse cropping system. Organic N constituted about 93% of total soil N as compared with the 7% share of mineral N.
- The significantly highest correlation of hydrolysable unknown N and amino sugar nitrogen and non-significant correlation of non-hydrolysable N with grain yield and N uptake of black gram signify that hydrolysable N fractions are the potential contributors towards plant available N.
- From the experimental findings, it was found that the first-order exponential model could fit well with the observed nitrogen mineralization data of all treatments. In case of potential N-mineralization, it was observed that biofertilizer addition and co-application of organic manure with soil amendments has increased N-mineralization rate and decreased the half-life of decomposable substrate.
- Strong and positive correlation between PMN with inorganic N, Amino sugar nitrogen, and unidentified hydrolysable N and stepwise multiple regression showing that these three fractions were the most active N pools and the major source of N potentially available to plants and ultimately improving crop productivity which is substantiated by strong correlation between crop yield, N uptake and PMN.
- Overall, integration of organic manure, biofertilizers and lime as soil ameliorant with inorganic fertilizers is a sustainable approach for efficient nutrient management by enhancing N reserve in soil in relation to crop productivity.

---

## **REFERENCES**

# REFERENCES

---

- Abbasi MK and Khaliq A. 2016. Nitrogen Mineralization of a Loam Soil Supplemented with Organic–Inorganic Amendments under Laboratory Incubation, *Frontiers in Plant Science*, **7**:1038.
- Aggarwal RK, Kumar P and Sharma BK. 1990. Distribution of nitrogen in some *Aridisols*, *Journal of Indian Society of Soil Science*, **38**(3): 430-433.
- Agrawal RK and Sharma BK. 1990. Distribution of nitrogen in some *Aridisols*, *Journal of the Indian Society of Soil Science*, **28**(3): 430-433.
- Allen AL, Stevenson FJ and Kurtz LT. 1973. Chemical Distribution of Residual Fertilizer Nitrogen in Soil as Revealed by Nitrogen-15 Studies 1, *Journal of Environmental Quality*, **2**(1): 120-124.
- Amelung W. 2001. Methods using amino sugars as markers for microbial residues in soil, In: Assessment methods for soil carbon. **100**: 233-270, Lewis Publishers Boca Raton.
- Amruta N, Devaraju PJ, Mangalagowri SP, Ranjitha HP and Teli K. 2016. Effect of integrated nutrient management and spacing on seed quality parameters of black gram cv. Lbg-625 (rashmi), *Journal of Applied and Natural Science*, **8**(1): 340-345.
- A.O.A.C. 1984. Official Methods of Analysis of the Association of Official Analytical Chemists, (14th edition) Arlington, VA, Sec.33.056.
- Arbad BK, Syed Ismail, Shinde DN and Pardeshi RG.2008. Effect of integrated nutrient management practices on soil properties and yield in sweet Sorghum in *Vertisol*, *An Asian Journal of Soil Science*, **3**(2): 329-332.

- Arulmozhiselvan K, Elayarajan M and Sathya S. 2013. Effect of long term fertilization and manuring on soil fertility, yield and uptake by finger millet on *Inceptisol*, *Madras Agricultural Journal*, **100**(4-6): 490-494.
- Athokpam HS, Chongtham N, Singh RKK, Singh NG and Singh NB. 2009. Effect of nitrogen, phosphorus and potassium on growth, yield and nutrient uptake by blackgram (*Vigna mungo* L.), *Environment and Ecology*, **27**(2): 682-684.
- Aulakh MS and Adhya TK. 2005. Impact of agricultural activities on emission of greenhouse gases – Indian perspective. In: Proceedings of the International Conference on Soil, Water and Environmental Quality – Issues and Strategies, Indian Society of Soil Science, New Delhi, pp: 319-335.
- Aulakh MS, Khera TS, Doran JW, Singh K and Singh B. 2000. Yields and Nitrogen Dynamics in a Rice–Wheat System Using Green Manure and Inorganic Fertilizer, *Soil Science Society of America Journal*, **64**: 1876–1882.
- Bacon JE and Freney JR. 1989. Nitrogen loss from different tillage system and the effect on cereal grain yield, *Fertilizer Research*, **20**: 59-66.
- Bedard-Haughn A, Comeau L and Sangster A. 2013. Gross nitrogen mineralization in pulse-crop rotations on the Northern Great Plains, *Nutrient Cycling in Agroecosystems*, **95**: 159-174. DOI: 10.1007/s10705-013-9555-z
- Begum M, Narayanasamy G, Rai RK and Biswas DR. 2007. Influence of integrated nutrient management on nitrogen and phosphorus in soil under wheat- mung bean- maize cropping system, *Journal of the Indian Society of Soil Science*, **55**(1): 175-183.
- Benedetti A and Sebastiani G. 1996. Determination of potentially mineralizable nitrogen in agricultural soil, *Biology and Fertility of Soils*, **21**: 114-120.
- Bhandari AL, Ladha JK, Pathak H, Padre AT, Dawe D and Gupta RK. 2002. Yield and soil nutrient changes in a long-term rice-wheat rotation in India, *Soil Science Society of America Journal*, **66**: 162– 170.

- Bharti B. 2013. Dynamics of organic and inorganic fractions of nitrogen in an Acid *Alfisol* after long-term addition of chemical fertilizers and amendments in maize-wheat cropping system, *International Journal of Agricultural Science Research*, **3**(3): 179-84.
- Bhattacharyya P, Nayak AK, Mohanty S, Tripathi R, Shahid M, Kumar A, Raja R, Panda BB, Roy KS, Neogi S, Dash PK, Shukla AK and Rao KS. 2013. Greenhouse gas emission in relation to labile soil C, N pools and functional microbial diversity as influenced by 39 years long-term fertilizer management in tropical rice, *Soil and Tillage Research*, **129**: 93-105.
- Bol R, Ostle NJ, Petzke KJ, Chenu C, Balesdent J. 2008. Aminoacid  $^{15}\text{N}$  in long-term bare fallow soils: Influence of annual N fertilizer and manure applications, *European Journal of Soil Science*, **59**:617–629.
- Bol RJ, Eriksen P, Smith MH, Garnett K, Coleman and Christensen BT. 2005. The natural abundance of  $^{13}\text{C}$ ,  $^{15}\text{N}$ ,  $^{34}\text{S}$  and  $^{14}\text{C}$  in archived (1923–2000) plant and soil samples from the Askov long-term experiments on animal manure and mineral fertilizer, *Rapid Communications in Mass Spectrometry*, **19**(22): 3216–26.
- Brar MS and Brar BS. 2002. Assessment of soil nutrients depletion in Punjab, *Fertilizer News*, **47**(2): 33- 35.
- Bremner JM and Keeney DR. 1996. Determination and Isotope-Ratio Analysis for Different Forms of Nitrogen in Soils: 3. Exchangeable Ammonium, Nitrate, and Nitrite by Extraction-Distillation Methods, *Proceedings of the Soil Science Society of America*, **30**(5): 577-582.
- Bremner JM. 1965. Nitrogen-availability indexes, In: Methods of Soil Analysis, Part 2. Agronomy. C.A. Black et al. (ed.), **9**:1324-1345. American Society of Agronomy, Madison, Wisconsin.

- Campbell CA, Ellert BH and Jame YW. 1993. Nitrogen mineralization potentials in soils, In: Soil Sampling and Methods of Analysis. Carter MR (ed.), 341-349, Lewis Publishers, Boca Raton, FL.
- Carvalho AM, Coelho CM, Dantas RADE, Fonseca OP, Guimarães Júnior R, Figueiredo CC. 2012. Chemical composition of cover plants and its effect on maize yield in no-tillage systems in the Brazilian savanna, *Crop Pasture Science*, **63**: 1075-81. DOI: 10.1071/CP12272
- Chauhan S, Sheoran P, Singh M and Kumar M. 2006. Optimization of nitrogen and phosphorus fertilization in soybean, *Glycine max* (L.) under semiarid conditions of Haryana, *Journal of Oilseed Research*, **23**(2): 325-326.
- Chen H, Li D, Zhao J, Xiao K and Wang K. 2018. Effects of nitrogen addition on activities of soil nitrogen acquisition enzymes: A meta-analysis, *Agriculture, Ecosystems and Environment*, **252**: 126–13.
- Collins HP, Rasmussen PE and Doughlas CL. 1992. Crop rotation and residue management effect on soil and microbial dynamics, *Soil Science Society of America Journal*, **56**: 783-788.
- Curtin D and Campbell CA. 2007. Mineralizable nitrogen, In: Soil sampling and methods of analysis, Carter MR and Gregorich EG (eds) 2nd ed. pp: 599-606. CRC Press, Boca Raton, FL.
- Dakshinamoorthy M, Santhy P, Selvi D and Mathan KK. 2000. Sustenance of crop productivity and soil fertility on an Incepticol in a long term fertilizer experiment. *Proceeding of International Conference on Managing Natural Resources for Sustainable Agricultural Production in the 21st Century, New Delhi, India*, **3**: 1336-1337.
- Dakshinamoorthy M, Singh MV, Malarvizhi P, Selvi D and Baskaran A. 2005. Research bulletin on “Soil quality, crop productivity and sustainability as influenced by long term fertilizer application and continuous cropping of finger milletmaize- cowpea sequence

in swell-shrink soil”, AICRP on Long term fertilizer experiment, Department Soil Science and Agrilculture Chemistry, Tamil Nadu Agriculture University Coimbatore and Indian Institute of Soil Science (IISS), Nabibagh, Bhopal, p. 124.

Das A, Sudhishri S and Lenka NK. 2013. Integrated nutrient management to improve finger millet productivity and soil conditions in hilly region of Eastern India, *Journal of Crop Improvement*, **27**: 528–546.

Das AK, Boral L, Tripath RS and Pandey HN. 1997. Nitrogen mineralization and microbial biomass-N in a subtropical humid forest of Meghalaya, India, *Soil Biology and Biochemistry*, **29**(9-10): 1609-1612.

Dekhane SS, Khafi HR, Raj AD and Parmar RM. 2011. Effect of biofertilizer and fertility levels on yield, protein content and nutrient uptake of cowpea [*Vigna unguiculata* (L.) Walp], *Legume Research*, **34**(1): 51-54.

Duhan BS, Katarai D, Singh JP, Kuhad M S and Dahiya SS. 2005. Effect of nitrogen, FYM and metribuzin on nitrogen transformation, *Journal of the Indian Society of Soil Science*, **53**(2): 184-187.

Duraisami VP and Mani AK. 2001. Efficacy of rock phosphate and superphosphate with phosphate solubilizer (*Bacillus megatherium* var. *Phosphaticum*) on cowpea in a rainfed *Entisol*, *Annals of Arid Zone*, **40**: 433-438.

Duraisami VP, Rani Perumal and Mani AK. 2001. Changes in organic carbon, available nitrogen and inorganic nitrogen fractions under integrated nitrogen management of sorghum in a mixed black soil, *Journal of the Indian Society of Soil Science*, **49**: 435-439.

Duraisami VP, Rani Perumal and Mani AK. 2002. Grain quality as influenced by fertilizer nitrogen, coirpith and biofertilizer in sole and intercropped sorghum maize-soybean sequence, *Mysore Journal of Agricultural Sciences*, **36**: 46-48.

- Durani A, Brar BS and Dheri GS. 2016. Soil nitrogen fractions in relation to rice-wheat productivity: Effects of long-term application of mineral fertilizers and organic manures, *Journal of Crop Improvement*, **30**(4): 399-420.
- Gajbhiye BR and Bhoje RC. 2014. Evaluation of nitrogen fractions in soils of Lohara tahsil of Osmanabad district, *An Asian Journal of Soil Science*, **9**(1): 87-93.
- Gautam P, Agnihotri AK and Pant LM. 2003. Effect of phosphorus rate and *Pseudomonas* species in combination with *Bradyrhizobium japonicum* and farmyard manure on seed yield and yield attributes of soybean, *Indian Journal of Agricultural Sciences*, **73**(8): 426-428.
- Gawai PP. 2003. Effect of integrated nutrient management system in sorghum-chickpea cropping sequence. Ph.D. Thesis. Mahatma Phule Krishi Vidyapeeth, Rahuri (M.S.): 80-167.
- Ghosh PK, Hazra KK, Venkatesh MS, Nath CP, Singh J and Nadarajan N. 2017. Increasing Soil Organic Carbon through Crop Diversification in Cereal-Cereal Rotations of Indo-Gangetic Plain. *Proceedings of National Academy of Sciences, India-Section B: Biological Sciences*, **89**(156). DOI: 10.1007/s40011-017-0953-x
- Goel V and Duhan BS. 2011. Kinetics of nitrogen mineralization of some organic manures in a typic haplustept, *Annals of Biology*, **27**(2): 129-134.
- Gonzalez-Prieto SJ, Jocteur-Monrozier L, Hetier JM and Carballad T. 1997. Changes in the soil organic N fractions of tropical alfisol fertilized with <sup>15</sup>N-urea and cropped to maize or pasture, *Plant and Soil*, **1959**(1):151–160.
- Gupta RK, Arora BR and Sharma KN. 2000. Effect of urea and manure addition on changes in mineral N content in soil profile at various growth stages of rice, *Journal of the Indian Society of Soil Science*, **48**:787-92.

- Gupta RK, Sharma KN, Singh B, Singh Y and Arora BR. 2005. Effect of urea and manure addition on changes in mineral N content in soil profile at various growth stages of wheat, *Journal of the Indian Society of Soil Science*, **53** (1): 74-80.
- He HB, Li XB, Zhang W and Zhang XD. 2011. Differentiating the dynamics of native and newly immobilized amino sugars in soil frequently amended with inorganic nitrogen and glucose, *European Journal of Soil Science*, **62**: 144–151.
- He J-Z, Hu H-W and Zhang L-M. 2012. Current insight into the autotrophic thaumarchaeal ammonia oxidation in acidic soils, *Soil Biology and Biochemistry*, **55**: 146-154.
- Hedge DM, Dwivedi BS and Sudhakara SN. 1999. Biofertilizers for cereal production in India-a review, *Indian Journal of Agricultural Science*, **69**: 73-83.
- Holst J, Liu CY, Bruggemann N, Butterbach-Bahl K, Zheng XH, Wang YS, Han SH, Yao ZS, Jin Y and Han XG. 2007. Microbial N turnover and N-oxide (N<sub>2</sub>O/NO/NO<sub>2</sub>) fluxes in semi-arid grassland of Inner Mongolia, *Ecosystems*, **10**: 623–634.
- Hussain N, Mehdi M and Kant RH. 2011. Response of Nitrogen and Phosphorus on Growth and Yield Attributes of Blackgram (*Vigna mungo*), *Research Journal of Agricultural Sciences*, **2**(2): 334-336.
- Jackson ML. 1973. Soil chemical Analysis. Prentice Hall of India, Pvt. Ltd., New Delhi.
- Jagadamma S, Lal R, Hoefl RG, Nafziger ED and Adee EA. 2007. Nitrogen fertilization and cropping systems effects on soil organic carbon and total nitrogen pools under chisel-plow tillage in Illinois, *Soil and Tillage Research*, **95**: 348–356.
- Jagtap PB, Patil JD, Nimbalkar CA and Kadlag AD. 2007. Influence of integrated nutrient management on soil properties and release of nutrients in a saline sodic soil, *Journal of the Indian Society of Soil Science*, **55**: 147-156.
- Jain PC and Trivedi SK. 2005. Response of soybean [*Glycine max* (L.) Merrill] to phosphorus and biofertilizers, *Legume Research*, **28**(1): 30-33.

- Janzen HH. 2004. Carbon cycling in earth systems- a soil science perspective, *Agriculture, Ecosystems and Environment*, **104**(3): 399–417. DOI: 10.1016/j.agee.2004.01.040
- Jeyabal A, Palaniappan S P and Chelliah S. 1999. Evaluation of integrated nutrient management techniques in rice, *Oryza*, **36**(3): 263-265.
- Jones DL, Healey JR, Willett VB, Farrar JF, and Hodge A. 2005. Dissolved organic nitrogen uptake by plants—An important N uptake pathway, *Soil Biology and Biochemistry*, **37**(3): 413–423.
- Kant S, Kumar A, Kumar S, Kumar V, Pal Y and Shukla AK. 2016. Effect of Rhizobium, PSB and P-levels on Growth, Yield Attributes and Yield of Urdbean (*Vigna mungo* L.), *Journal of Pure and Applied Microbiology*, **10**(4): 3093-3098. DOI: 10.22207/JPAM.10.4.83
- Katkar RN, Sonun BA and Kadu PR. 2011. Long-term effect of fertilization on soil chemical and biological characteristics and productivity under sorghum (*Sorghum bicolor*)-wheat (*Triticum aestivum*) system in *Vertisol*, *Indian Journal of Agricultural Sciences*, **81**(8): 734–739.
- Kaur J and Singh J. 2014. Long-term effects of continuous cropping and different nutrient management practices on the distribution of organic nitrogen in soil under rice-wheat system, *Plant, Soil and Environment*, **60**: 63–68.
- Keeney DR and Bremner JM. 1964. Effect of cultivation on the nitrogen distribution in soils, *Soil Science Society of America Journal*, **28**(5): 653-656.
- Khankhane PJ and Yadav BR. 2000. Relative mineralization of nitrogen and phosphorus from farmyard manure, biogas slurry and sewage sludge, *Journal of the Indian Society of Soil Science*, **48**: 793-797.

- Khatkar R, Thomas A and Joseph SA. 2007. Effect of biofertilizers and sulphur levels on growth and yield of blackgram (*Vigna mungo* L.), *Legume Research*, **30**: 233-234.
- Kher D and Minhas RS. 1992. Long term effects of liming, manuring and cropping on different hydrolysable N forms in an arid Alfisol, *Journal of the Indian Society of Soil Science*, **40**: 840-842.
- Kokani JM, Shah KA, Tandel BM and Nayaka P. 2014. Growth, yield attributes and yield of summer BlackGram (*Vigna mungo* L.) as influenced by FYM, phosphorus and sulphur, *The Ecoscan*, Special Issue. **VI**: 429-433.
- Kumar A, Baby K and Mallick MA. 2016. Phosphate solubilising microbes: An effective and alternative approach as biofertilizers, *International Journal of Pharmacy and Pharmaceutical sources*, **8**(2): 37-40.
- Kumar A, Meena RN, Yadav L and Gilotia YK. 2014. Effect of organic and inorganic sources of nutrient on yield, yield attributes and nutrient uptake of rice Cv. PRH-10, *The Bioscan*, **9**(2): 595-597.
- Kumar D. 2015. Long term effect of organic manures and biofertilizers on dynamics of carbon and nitrogen under rice-wheat cropping system. Ph. D Thesis submitted to I.A.R.I., Delhi.
- Kumpawat BS. 2010. Integrated nutrient management in blackgram (*Vigna mungo*) and its residual effect on succeeding mustard (*Brassica juncea*) crop, *Indian Journal of Agricultural Sciences*, **80**(1): 76-79.
- Kumudha P and Gomathinayagam M. 2007. Studies on the effect of biofertilizers on germination of *Albizia lebbek* (L.) Benth. seeds, *Advanced Plant Sciences.*, **20**: 417-421.
- Kunrath TR, Berranger DC, Charrier X, Gastal F, de Faccio Carvalho PC, Lemaire G, Emile JC and Durand JL. 2015. How much do sod-based rotations reduce nitrate

leaching in a cereal cropping system?, *Agricultural Water Management*, **1**(150): 46-56.

Kurrey CD. 2014. Nitrogen release pattern in *Vertisol* as influenced by green manure and farmyard manure application in rice. A thesis submitted to Indira Gandhi Krishi Vishwavidyalay.

Ladha JK, Pathak H, Krupnik TJ, Six J and Kessel CV. 2005. Efficiency of fertilizer nitrogen in cereal production: retrospects and prospects, *Advances in Agronomy*, **87**: 85–156.

Leinweber P and Schulten HR. 2000. Non hydrolyzable forms of soil organic nitrogen: Extractability and composition, *Journal of Plant Nutrition and Soil Science*, **163**(4): 433-439.

Lindemann WC and Cardenas M. 1984. Nitrogen mineralization potential and nitrogen transformations of sludge-amended soil, *Soil Science Society of America Journal*, **48**: 1072-1077.

Mairan and Rameshwar N. 2002. Nitrogen fractionation studies in sorghum-sunflower cropping system under fixed plot fertilizer experiments. MSc. Thesis. Department of Soil Science and Agriculture Chemistry, Vasant Rao Naik Marathwada Agricultural University, Parbhani, India.

Mandal B, Majumder B, Bandyopadhyay PK, Hazra GC, Gangopadhyay A, Samantaray RN, Mishra AK, Chaudhury J, Saha MN and Kundu S. 2007. The potential of cropping systems and soil amendments for carbon sequestration in soils under long-term experiments in subtropical India, *Global Change Biology*, **13**: 357–369.

Manivannan R and Sriramachandrasekharan M. 2009. Response of lowland rice to addition of organics and mineral N grown on Typic Haplusterts soil, *Journal of Applied Sciences Research*, **5**(11): 1988–1991.

- Manzoni S and Porporato A. 2009. Soil carbon and nitrogen mineralization: Theory and models across scales. *Soil Biology and Biochemistry*, **41**: 1355–1379.
- Mariano E, Trivelin PCO, Leite JM, Megda MXV, Otto R and Franco HCJ. 2013. Incubation methods for assessing mineralizable nitrogen in soils under sugarcane, *Revista Brasileira de Ciencia do Solo*, **37**(2).
- Martin NR and Kachhave KG. 2009. Nitrogen fractions and their relationship under sorghum sunflower cropping sequence in a *Typic Haplustert*, *An Asian Journal of Soil Science*, **49**(1): 11-14.
- Medhi DN, Sarma AC and Medhi BD. 2002. Effect of integrated nutrient management on rice-linseed cropping sequence in high rainfall areas of Assam, *Annals of Agricultural Research*, **23** (1): 17-21.
- Mengal K. 1996. Turnover of organic nitrogen in soils and its availability to crops, *Plant and Soil*, **181**: 83-93.
- Mohanty S, Nayak AK, Kumar A, Tripathi R, Shahid M, Bhattacharyya P, Raja R and Panda BB. 2013. Carbon and nitrogen mineralization kinetics in soil of rice-rice system under long term application of chemical fertilizers and farmyard manure, *European Journal of Soil Biology*, **58**: 113-121.
- Mohapatra SP and Khan SK. 1989. Dynamics of soil nitrogen fractions under different soil moisture regimes, *Oryza*, **24**: 191-198.
- Muller C, Ruttig T, Kattge J, Laughlin RJ and Stevens RJ. 2007. Estimation of parameters in complex <sup>15</sup>N tracing models by Monte Carlo sampling, *Soil Biology and Biochemistry*, **39**(3): 715–726. DOI: 10.1016/j.soilbio.2006.09.021.
- Nagarajan P and Balachandar D. 2001. Influence of Rhizobium and organic amendments on nodulation and grain yield of blackgram and greengram in acid soil, *Madras Agricultural Journal*, **88**: 703-705.

- Nayak VN, Gatav GK and Bhagat RK. 2013. Different N fractions and their relationship with available Nitrogen, yield and nutrient uptake in safflower (*Carthamus tinctorius*) in *Vertisol*, *Current Advances in Agriculture Science*, **5**(1): 135-137.
- Page AL, Miller RH and Keeny DR.(eds), 1982, Methods of Soil Analysis, Part-2, Chemical and Micro-biological Properties, 2ndEdn. No (9) Part-2 in the series, Agronomy, American Society of Agronomy, Madison, Wisconsin, U.S.A.
- Parihar CM, Parihar M, Sapkota TB and Nanwal RK.2018. Long-term impact of conservation agriculture and diversified maize rotations on carbon pools and stocks, mineral nitrogen fractions and nitrous oxide fluxes in *Inceptisol* of India, *Science of the Total Environment*, pp: 640-641. DOI: 10.1016/j.scitotenv.2018.05.405
- Patel SR and Thakur DS. 2003. Response of blackgram (*Phaseolus mungo*) to levels of phosphorus and phosphate solubilizing bacteria, *Annals of Agriculture Research*, **24**: 819-823.
- Patil DS, Khistaria MK and Padmani DR. 2010. Effect of nutrient management and biofertilizer on quality, NPK content and uptake of blackgram in medium black soil, *International Journal of Agricultural Sciences*, **6**(1): 167-168.
- Prabhugouda MP. 2001. Distribution of major plant nutrients in an *Alfisol* subjected to long term manuring and cropping schedule in dryland. MSc (Agri) Thesis. University of Agriculture Sciences Bangalore, Karnataka India.
- Prasad B and Rokima J. 1991, Integrated nutrient management-1. Nitrogen fractionation and their availability in calcareous soils. *Journal of Indian Society of Soil Science*, **39**: 693-698.
- Rajasekharan S, Muthuraman B, Mathivanan J and Jayaraman P. 2017. Influence of biofertilizer, inorganic fertilizers and organic fertilizers on growth of Black gram (*Vigna mungo* L.), *International Journal of Current Research and Development*, **5**(2): 56-72.

- Rathi BK, Jain AK, Kumar S and Panwar JDS. 2009. Response of *Rhizobium* inoculation with sulphur and micronutrients on yield and yield attributes of blackgram [*Vigna mungo* (L.) Hepper.], *Legume Research*, **32**(1): 62-64.
- Ravankar HN, Manikrao S and Baldekar VD. 2005. Effect of long term integrated nutrient on N fraction in *Vertisols*, *Panjabrao Deshmukh Krishi Vidyapeeth Research Journal*, **29**(2): 225-237.
- Ren T, Wang J, Chen Q, Zhang F and Lu S. 2014. The Effects of Manure and Nitrogen Fertilizer Applications on Soil Organic Carbon and Nitrogen in a High Input Cropping System, *PLoS ONE*, **9**(5): e97732.
- Rilling MC, Caldwell BA, Wosten HAB and Sollins P. 2007. Role of proteins in soil carbon and nitrogen storage: Controls on persistence, *Biogeochemistry*, **85**: 25–44.
- Russell AD, Hugo WB and Ayliffo GAJ. 1982. Principles and Practices of Disinfection, Preservation and Sterilization, Blackwell Scientific, London.
- Saini R and Jaiwal PK. 2002. Age, position in mother seedling, orientation, and polarity of the epicotyl segments of blackgram (*Vigna mungo* L. Hepper) determines its morphogenic response, *Plant Science*, **163**(1): 101-109.
- Salvogiotti F, Cassman KG, Specht JE, Walters DT, Weiss A, Dobermann A. 2008. Nitrogen uptake, fixation and response to fertilizer N in soybeans, *Field Crop Research*, **108**:1-13.
- Sarawad IM and Singh D. 2005. Soil Nitrogen fractions under maize-wheat-cowpea cropping sequence under long-term fertilizer use, *Karnataka Journal of Agricultural Sciences*, **18**(2): 357-363.
- Sarawad LM, Singh D, Rana DS and Kumar K. 2001. Nitrogen fractions and their relationships with mineralizable N and its uptake by crops in a long-term fertilizer experiment, *Journal of the Indian Society of Soil Science*, **49** (4): 691-694.

- Sathya S. 2010. Evaluation of enriched FYM and flyash on soil fertility and yield of rice under system of rice intensification (SRI) in Periyar Vaigai Command (PVC) area -Tamil Nadu. Ph.D. Thesis, Agricultural College and Research Institute, Madurai, Tamil Nadu (India).
- Schnitzer M and Hindle DA. 1980. Effect of peracetic-acid oxidation on N-containing components of humic materials, *Canadian Journal of Soil Science*, **60**(3): 541–548.
- Schomberg HH, Wietholter S, Griffin TS, Reeves DW, Cabrera ML, Fisher DS, Endale DM, Novak JM, Balkcom KS, Raper RL, Kitchen NR, Locke MA, Potter KN, Schwartz RC, Truman CC and Tyler DD. 2009. Assessing Indices for Predicting Potential Nitrogen Mineralization in Soils under Different Management Systems. *Soil Science Society of America Journal*, **73**(5): 1575-1586. DOI: 10.2136/sssaj2008.0303.
- Sekhon KS, Singh JP and Mehla DS. 2011. Long-term effect of manure and mineral fertilizer application on the distributions of organic nitrogen fractions in soil under a rice-wheat cropping system, *Archives of Agronomy and Soil Science*, **57**(7): 705-714.
- Selvakumar G, Reetha S and Thamizhiniyan P. 2012. Response of biofertilizers on growth, yield attributes and associated protein profiling changes of blackgram (*Vigna mungo* L. Hepper), *World Applied Sciences Journal*, **16**(10): 1368-1374.
- Shahid M, Nayak AK, Puree C, Tripathi R, Lal B, Gautam P, Bhattacharyya P, Mohanty S, Kumar A, Panda BB, Kumar U and Shukla AK. 2017. Carbon and nitrogen fractions and stocks under 41 years of chemical and organic fertilization in a sub-humid tropical rice soil, *Soil and Tillage Research*, **170**:136–146.
- Sharifi M, Zebarth B, Burton DL, Grant CA and Cooper JM. 2007. Evaluation of some indices of potentially mineralizable nitrogen in soil. *Soil Science Society of America Journal*, **71**:1233–1239.

- Sharma MP, Bali VS and Gupta DK. 2008. Crop yield and properties of *Inceptisols* as influenced by residue management under rice-wheat cropping sequence, *Journal of the Indian Society of Soil Science*, **48**: 506-509.
- Sharma S, Chander G and Verma TS. 2014. Nitrogen dynamics under long term *Lantana Camara* (L.) residue and fertilizer application in a rice-wheat cropping system, *Journal of Plant Nutrition*, **37**(11): 1804-1816.
- Sharma SK and Sharma SN. 2002. Integrated nutrient management for sustainability of rice (*Oryza sativa*)-wheat (*Triticum aestivum*) cropping system, *Indian Journal of Agriculture Science*, **72**: 573-576.
- Shinde GG, Aglave BN and Deshmukh AS. 2006. Effect of urea transformation on nutrient release in saline-sodic soil, *Journal of Maharashtra Agricultural Universities*, **31**: 373-375.
- Sihag DJ, Singh D, Mehta DS and Bhardwaj K. 2005. Effect of integrated use of inorganic fertilizers and organic materials on the distribution of different forms of nitrogen and phosphorus in soil, *Journal of the Indian Society of Soil Science*, **53**(1): 80–84.
- Singaram P and Kamalakumari K. 2000. Effect of continuous application of different levels of fertilizers with farm yard manure on enzyme dynamics of soil, *Madras Agricultural Journal*, **87**(4/6): 364-365.
- Singh A and Singh NP. 2006. Management in urdbean-wheat crop sequence, *Indian Journal of Pulses Research*, **19**: 70-72.
- Singh AK, Tripathi PN and Singh R. 2007. Effect of Rhizobium inoculation, nitrogen and phosphorus levels on growth, yield and quality of kharif cowpea (*Vigna unguiculata* L.), *Crop Research*, **33**(1, 2 & 3): 71-73.

- Singh JP, Dahiya DJ, Kumar V and Sing M. 1992. Distribution and status of different forms of nitrogen in soil of Hariyana. *Journal of the Indian Society of Soil Science*, **40**: 698-704.
- Singh KK and Singh R. 2007. Distribution of nitrogen and sulphur forms in soil profiles of mid-western Uttar Pradesh, *Journal of the Indian Society of Soil Science*, **55**(4): 476-480.
- Singh M and Wanjari RH. 2013. Annual Report 2012-13. All India Coordinated Research Project on Long Term Fertilizer Experiments to Study changes in Soil Quality, Crop Productivity and Sustainability. AICRP-LTFE. Indian Institute of Soil Science (ICAR), Nabibagh, Bhopal pp: 1-142.
- Sinha RK, Valani D, Chauhan K, Agarwal S. 2014. Embarking on a second green revolution for sustainable agriculture by vermiculture biotechnology using earthworms: reviving the dreams of Sir Charles Darwin, *International Journal of Agriculture Health Safety*, **1**: 50-64.
- Snyder CS. 2009. Nitrogen use efficiency: Global challenges, trends and the future, Nutrient use efficiency. In: Proceedings of the XVIII Latin American Congress of Soil Science, Costa Rica, 10–17.
- Srivastava AK and Srivastava OP. 1993. Forms of soil nitrogen in relation to pH, *Journal of the Indian Society of Soil Science*, **41**(3): 551-553.
- Stanford G. 1968. Extractable organic nitrogen and nitrogen mineralization in soils, *United States Department of Agriculture*, **106**(5): 345-351.
- Stevenson FJ, 1996, Nitrogen organic forms, In: Methods of soil analysis, part 3-Chemical Methods, Sparks DL, Page AL, Helmke PA, Loeppert RH, Soltanpour PN, Tabatabai MA, Johnston CT and Summer ME (eds) SAP3CM.1185–1200. Madison (WI): ASA, SSSA.

- Stevenson FJ. 1982. Nitrogen-organic forms, In: Methods of Soil Analysis: Chemical and Microbiological Properties. Page AL, editor. Part 2. Madison, USA: Soil Science Society of America. pp. 625-641.
- Stevenson FJ. 1994. Humus chemistry: genesis, composition and reactions, Wiley, New York, NY.
- Subba Rao A and Ghosh AB. 1981. Effect of continuous cropping and fertilizer use on the organic nitrogen fractions in a *Typic Ustochrept* soil, *Plant Soil*, **62**: 377-383. DOI: 10.1007/BF02374135
- Subbiah BV and Asija GL. 1956. A rapid procedure for assessment of available nitrogen in soils, *Current Science*, **31**: 159- 160.
- Subehia SK and Dhanika. 2013. Soil nitrogen fractions and its effect on rice (*Oryza sativa*) yield under integrated nutrient management in a north-western Himalayan soil, *Indian Journal of Soil Conservation*, **41**(1):47-51.
- Sutaria GS, Akbari VD, Vora DS, Hirpara and Padmani DP. 2010. Response of legume crops to enriched compost and vermicompost on *Verticustochret* under rainfed agriculture, *Legume Research*, **33**(2): 128-130.
- Suzuki K, Matsunaga R, Hayashi K, Matsumoto N, Tobita S, Bationo A and Okada K. 2017. Effects of long-term application of mineral and organic fertilizers on dynamics of nitrogen pools in the sandy soil of the Sahel region, Niger, *Agriculture, Ecosystems and Environment*, **242**:76–88.
- Swarnam TP and Vel Murugan A. 2013. Nitrogen Release Pattern from Organic Manures Applied to an Acid Soil, *Journal of Agricultural Science*, **5**(6). DOI: 10.5539/jas.v5n6p174.
- Tabassum S, Reddy K, Samml, Vaishya UK, Singh M and Biswsa AK. 2010. Changes in organic and inorganic forms of nitrogen in a *Typic Haplustert* under soybean-

- wheat system due to conjoint use of inorganic fertilizers and organic manures. *Journal of the Indian Society of Soil Science*, **58**: 76-85.
- Tejeda M, Gonzalez JL, Garcia-Martinez AM and Parrodo J. 2008. Effects of different green manures on soil biological properties and maize yield, *Bioresource Technology*, **99**: 1758-1767.
- Thavaprakash N, Velayudham K and Muthukumar VB. 2005. Effect of crop geometry, intercropping systems and integrated nutrient management practices on productivity of baby corn (*Zea mays* L.) based intercropping systems, *Journal of Agricultural and Biological Science*, **1**: 295-302.
- Tomar RKS. 1998. Effect of phosphate solubilizing bacteria and farmyard manure on the yield of blackgram (*Phaseolus mungo*), *Indian Journal of Agricultural Sciences*, **68**: 81-83.
- Wander MM, Yun W, Goldstein WA, Aref S and Khan SA. 2007. Organic N and particulate organic matter fractions in organic and conventional farming systems with a history of manure application, *Plant Soil*, **291**: 311–321.
- Wander MM. 2004. Soil organic matter fractions and their relevance to soil function, In: Soil organic matter in sustainable agriculture. Magdoff FR and Weil RR (ed.), 67–102, CRC Press, Boca Raton, FL.
- Werdin-Pfisterer NR, Kielland K, and Boone RD. 2009. Soil amino acid composition across a boreal forest successional sequence, *Soil Biology and Biochemistry*, **41**(6): 1210–1220.
- Whalen JK, Benslim H, Jiao Y and Sey BK. 2008. Soil organic carbon and nitrogen pools as affected by compost applications to a sandy-loam soil in Quebec, *Canadian Journal Soil Science*, **88**: 443-450.
- Wheller T and Braun J. 2013. Climate change impacts on global food security, *Science*, **341**: 508-513.

- Yadav MD and Singh KDN. 1991. Transformation of applied nitrogen in relation to its availability to sugarcane in calcareous soil, *Journal of the Indian Society of Soil Science*, **39**(2): 292-297.
- Yang J, Gao W and Ren S. 2015. Long term effects of combined application of chemical nitrogen with organic materials on crop yields, soil organic carbon and total nitrogen in fluvo-aquic soil, *Soil and Tillage Research*, **151**: 67-74.
- Yang LL, Zhang FS, Mao RZ, Ju XT, Cai XB and Lu YH. 2008. Conversion of natural ecosystems to cropland increases the soil net nitrogen mineralization and nitrification in Tibet, *Pedosphere*, **18**(6): 699-706.
- Zhang X, Wang Q, Gilliam FS, Bai W, Han X and Li L. 2012. Effect of nitrogen fertilization on net nitrogen mineralization in a grassland soil, northern China, *Grass and Forage Science*, **67**:219–230. DOI:10.1111/j.1365-2494.2011.00836.
- Zhang YY, Wu W and Liu H. 2019. Factors affecting variations of soil pH in different horizons in hilly regions, *PLOS ONE*, **14**(6): e0218563. DOI:10.1371/journal.pone.0218563.