

DECOMPOSITION OF WIDE C: N RATIO CROP RESIDUES ON THE RELEASE OF ACTIVE CARBON POOL AND AVAILABLE NUTRIENTS IN INCEPTISOLS OF VARANASI

काशी हिन्दू
विश्वविद्यालय



BANARAS HINDU
UNIVERSITY

THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE
REQUIREMENTS FOR THE AWARD OF DEGREE OF

Master of Science (Agriculture)

in

Soil Science and Agricultural Chemistry

Supervisor

Prof. Surendra Singh

Submitted by

Pragnya Paramita Patel

**Department of Soil Science & Agricultural Chemistry
Institute of Agricultural Sciences
Banaras Hindu University
Varanasi 221005
India**

ID. No. 20412SAC024

2022

Enrolment No. 429477

Dr. Surendra Singh
Professor

Department of Soil Science & Agricultural Chemistry
Institute of Agricultural Sciences
Banaras Hindu University
Varanasi – 221005

Ref. No.

Date

CERTIFICATE

To,
The Registrar (Academic)
Banaras Hindu University,
Varanasi-221005 (India)

Through: The Head,
Department of Soil Science and Agricultural Chemistry,
Institute of Agricultural Sciences, Banaras Hindu University,
Varanasi-221005 (India)

Dear Sir,

I have great pleasure in forwarding the thesis “**Decomposition of wide C: N ratio crop residues on the release of active carbon pool and available nutrients in Inceptisols of Varanasi**” submitted by *Ms. Pragnya Paramita Patel* (I.D. No. 20412SAC024), in partial fulfilment of the requirements for the degree of **Master of Science (Agriculture) in Soil Science and Agricultural Chemistry**, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi.

I certify that the entire scheme of investigation presented herein was planned and carried out solely by the candidate under my guidance and supervision. The data presented in the thesis, to the best of my knowledge and belief, are genuine and original. No part of the work has been submitted for any other degree or distinction.

Thanking you,

Forwarded by

(Surendra Singh)
Supervisor

(Head)

DECOMPOSITION OF WIDE C: N RATIO CROP RESIDUES ON THE
RELEASE OF ACTIVE CARBON POOL AND AVAILABLE NUTRIENTS IN
INCEPTISOLS OF VARANASI



by

Pragnya Paramita Patel

Thesis submitted in partial fulfilment of the requirements for the degree of

Master of Science (Agriculture)

in

Soil Science and Agricultural Chemistry

Department of Soil Science and Agricultural Chemistry

Institute of Agricultural Sciences

Banaras Hindu University

Varanasi – 221 005 (INDIA)

ID. No. 20412SAC024

2022

Enrolment No. 429477

APPROVED BY ADVISORY COMMITTEE

Chairman/
Supervisor

Dr. Surendra Singh

Professor

Department of Soil Science and Agricultural Chemistry

Institute of Agricultural Sciences, B.H.U., Varanasi.

Members

Dr. P.K. Sharma

Professor

Department of Soil Science and Agricultural Chemistry

Institute of Agricultural Sciences, B.H.U., Varanasi.

Dr. J. K. Singh

Professor

Department of Agronomy,

Institute of Agricultural Sciences, B.H.U., Varanasi.

Dr. Md. Afjal Ahmad

Assistant Professor

Department of Plant Physiology,

Institute of Agricultural Sciences, B.H.U., Varanasi.

External Examiner

ACKNOWLEDGEMENT

Before I start inking let me truly admit that, it is practically impossible to mention all the worthy support, kind cooperation and directional guidance stretched out by my honourable teachers, supportive friends and loving relatives and all of my well-wishers in just two pages. However, I am trying to document all worth-mentioning hereunder.

*With a deep sense of devotion, I bow and pray to the feet of **Lord Viswanath, Lord Jagannath** and **Maa Samaleswari** who provided me choicest, everlasting blessing to get an opportunity to satisfy in Banaras Hindu University, Varanasi.*

*At the outset, being the student of this great institution, I bow my head with great reverence to lotus feet of **Bharat Ratna Mahamana Pandit Madan Mohan Malviyaji**, the founder of this great temple of **Goddess SARASWATI** for students like us to worship and nurture our lives.*

*With immense pleasure and profound sense of gratitude, I take this opportunity to express my heartfelt and sincere thanks to my esteemed supervisor **Prof. Surendra Singh**, Professor, Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University, for his meticulous guidance, indelible inspiration, persistent encouragement, ingenious suggestions, mellifluous nature and indefatigable attitude. I will ever cherish the elderly affection that he bestowed upon me throughout my tenure as a student under him which helped me to cope with many a trying situation.*

*I sincerely express my gratitude and warmest regard to **Prof. Nirmal De**, Head, Department of Soil Science and Agricultural Chemistry for providing the necessary research facilities, critical suggestions and help during the course of investigation.*

*I owe my sincere thanks to the members of my advisory committee, **Prof. P.K. Sharma**, Professor, Department of Soil Science and Agricultural Chemistry, **Prof. J.K. Singh**, Professor, Department of Agronomy, and **Dr. Md. Afjal Ahmad**, Asst. Professor, Department of Plant Physiology, Institute of Agricultural Sciences, Banaras Hindu University, for their critical suggestions, impeccable and directional guidance.*

*I extend my indebtedness to **Prof. Priyanka Raha**, **Prof. A. K. Ghosh**, **Prof. S. K. Singh**, **Prof. Janardan Yadav**, **Dr. A. Rakshit**, **Dr. Y. V. Singh** and **Dr. R. Meena**, and I am thankful to all staff members of Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University for all kinds of help and cooperation to me during my study period.*

*With profound regards in a more personal sense, I owe deepest debts to my revered parents **Sri Jayaprakash Patel** and **Smt. Arati Patel** who taught me the value of wisdom based on erudition but without being enslaved by it and their persistent inspiration, selfless sacrifice, continuous encouragement and blessing gave untiring help and have enabled me to be what I am, today. I will also like to acknowledge my affection towards my cousin **Sourav Ku. Patel** who was always with me during my ups and downs. I thank them once again for their kind cooperation.*

*I would like to express my warm deep appreciation to my friends **Lilan Behera**, and **Sumit Tripathi** for their immense selfless help and moral support which always animated me to rise against all odds and face them with smiles.*

*Without the help of seniors none can learn the lesson of life and cannot teach the same to loving juniors so, my heartfelt and special thanks to my seniors **Ms. Bharti Yadav**, **Ms. Astha Pandey**, **Ms. Chandini Pradhan**, **Mr. Ayush Bahuguna**, **Mr. Sachin Sharma** and **Mr. Aravind** for their kind co-operation during the study and investigation.*

It is a pleasure for me to offer thanks to my batchmates, Yuvraj, Soumya, Baburam, Kishan, Nisha, Sweta, Priyanka, Smita, Ashu, Vanita, Ashish, Awdesh, Abhishek, Vishal, Mounica and BHU friends.

*I wish to place on record my appreciation and sincere thanks to **Mr. Shishir Singh**, **Mr. Agraj Pathak**, **H.N. ji.**, **Anil Sharma ji**, **K.K. ji**, **Amarendra ji** and **Abhishek bhaiya** non-teaching Staff members of Department of Soil Science and Agricultural Chemistry for extending their kind cooperation and motivation during the entire course of this study.*

Before I conclude, I confess that I do not know how to acknowledge the help and co-operation of my Supervisor, members of advisory committee, family members and relatives, seniors, juniors, colleagues but above feelings come from the core of my heart in the shape of words and as gospel truth.

Date:

Place: Varanasi

(Pragnya Paramita Patel)

Contents



List of Symbols and Abbreviations

List of Tables

List of Figures

1. Introduction	1-6
2. Review of Literature	7-25
3. Materials and Methods	26-37
4. Results and Discussion	38-58
5. Summary and Conclusion	59-62
8. Bibliography	i-x

LIST OF SYMBOLS AND ABBREVIATIONS

%	: Per cent
/	: Per
°F	: Degree Fahrenheit
µg L ⁻¹	: Micro gram per litre
µg/g	: Micro-gram per gram
°C	: Degree centigrade
BC	: Before Christ
CaCO ₃	: Calcium carbonate
CEC	: Cation exchange capacity
cmol(p+) kg ⁻¹	: Centimole (proton) per kilogram
CRD	: Completely Randomized Design
dSm ⁻¹	: Desi Siemen per meter
e.g.	: For example,
EC	: Electrical conductivity
<i>et al.</i>	: And others
Fig.	: Figure
g	: Gram
gcm ⁻³	: Gram per cubic centimetre
gmol ⁻¹	: Gram per mole
hrs	: Hours
i.e.	: Which is to say, in other words
kg	: Kilogram(s)
Kg ha ⁻¹	: Kilogram per hectare

m	: Metre
M	: Molarity
meq l ⁻¹	: Milli equivalent per litre
mg	: Milligram
mm	: millimetre
MT year ⁻¹	: Million tonne per year
NaOH	: Sodium hydroxide
ng L ⁻¹	: Nano gram per litre
No.	: Number
OC	: Organic carbon
PC	: Principal components
pH	: Puissance de hydrogen
ppm	: Parts per million
r	: Correlation coefficient
rpm	: Revolution per minute
v/v	: Volume by volume
viz.	: That is to say

LIST OF TABLES

Table No.	Particular	Page No.
3.1	Soil characteristics and available nutrients of experimental soil	27
3.2	Characteristics of crop residues for total C, N, P, K and S content and their ratio	28
3.3	Treatments combination	30
3.4	Treatment details	30
3.5	Soil sampling time	31
3.6	Soil and plant test parameters	36
4.1	Characterization of crop residues for total C, N, P, K and S contents and their ratios	38
4.2	Decomposition of wheat and rice residues in soil on evolution of CO ₂ -C	41
4.3	Decomposition of wheat and rice residues in soil on evolution of CO ₂	42
4.4	Decomposition of wheat and rice residues on water soluble carbon content in soil	47
4.5	Decomposition of wheat and rice residues on the release of available nitrogen in soil	48
4.6	Decomposition of wheat and rice residues on the release of available phosphorus in soil	53
4.7	Decomposition of wheat and rice residues on the release of available potassium in soil	54
4.8	Decomposition of wheat and rice residues on the release of available sulphur in soil	57

LIST OF FIGURES

Figure No.	Particular	Page No.
3.1	Six sets of incubation bottles	29
4.1	Release of net CO ₂ -C (mg/100g/day) amended with wheat and rice residues	43
4.2	Release of net CO ₂ (mg) amended with wheat and rice residues	43
4.3.	Release of net water soluble carbon (µg/g) amended with wheat and rice residues	49
4.4	Release of net available nitrogen (kg ha ⁻¹) amended with wheat and rice residues	49
4.5	Net release of available phosphorus (kg ha ⁻¹) amended with wheat and rice residues	55
4.6	Net release of available potassium (kg ha ⁻¹) amended with wheat and rice residues	55
4.7	Net release of available sulphur (kg ha ⁻¹) amended with wheat and rice residues	58

INTRODUCTION

Crop residues are plant parts that have been left in the field after harvesting and threshing. These materials were once thought to be waste that needed to be disposed of, but it is now widely recognized that they represent valuable natural resources rather than waste. Those natural resources provides nutrients to living organisms. These nutrient elements are essential for life; hence it is essential to recycle and continuously replenish nutrients into the soil for the life to exist. This recycling of crop residues helps in converting the excess farm wastes into useful product, in order to meet the nutrient needs of the crops. At the same time it also maintains the soil physical and chemical properties and improves the total ecological balance of the crop production system. If the residues are not returned, it may result in soil mining for important nutrients, resulting in a net negative balance and crop multi-nutrient deficits.

According to the data given by Directorate of economics and statistics, MOA, DAC, New Delhi (2012-2013), reported (**Jain *et al.* 1914**), the production of wheat and rice in India is 93.51 million tons (Mt) and 105 Mt, respectively. Those two crops are preferred the most by the farmers because they provide higher economic return, as compared to other crops and at the same time those crop residues are more prone to burning. As per the data given by Ministry of New and Renewable Energy, the generation of crop residues is highest in Uttar Pradesh (60Mt) followed by Punjab (51Mt). It was found that cereals generates maximum residues (352 Mt), followed by oilseeds (29 Mt) and pulses (13 Mt). Among the cereals rice crop contributes the highest residue.

10 t ha⁻¹ crops removes 730 kg NPK from the soil that is not returned to the soil (**Gupta *et al.* 2002**), which may cause nutrient mining that leads to negative balance and multi-nutrients deficiencies in soil and this causes declining yield of rice-wheat system. Incorporation of residues in the soil increases soil organic carbon and N, P and K contents in soil.

Carbon is one of the structural elements in plants, and is the foundation of all life on earth. Carbon is required to form complexes like DNA, proteins, carbohydrates etc. In the atmosphere we get carbon in the form of carbon dioxide, and this element regulate the Earth's temperature, make life possible in the earth, is a key ingredient in the food and provide a major source of energy to sustain our global economy.

Most carbon on earth is stored in rocks and sediments, while the rest is located in the ocean, atmosphere and the biosphere. These are the sinks through which carbon cycles. The process in which carbon atoms continually travel from the atmosphere to the earth and then back to the atmosphere is called carbon cycle (**Gottschalk *et al.* 2012**). Since earth and its atmosphere form a closed environment, hence the carbon in this system does not change. Carbon released back to its sink i.e. atmosphere via burning of fossil fuels, volcanoes eruption, death and decomposition of organisms, and through a variety of other mechanisms. Crop residues are extremely carbonaceous having a variable C: N ratio, which serves as a parameter for determination of the rate of decomposition and nutrient release pattern in soil.

Lower C/N ratios (**Swift *et al.* 1979**) and high N and P concentration (**Bosatta *et al.* 1982, Wang *et al.* 2008**) of residues have been associated with faster decomposition rates. Residues containing high N concentration is often decomposed rapidly as growth of soil microbes is limited by the low N availability in soils (**Berg *et al.* 2006**). During decomposition the relative availability of carbon (C) and Nitrogen (N) in the plant residues, to the microbial population decides the C and nutrient dynamics. When the C: N ratio is more than 20, there will be immobilization until decomposition lowers the C: N ratio (**Heal *et al.* 1997, Hill *et al.* 2006**), and when the C: N ratio is less than 20, N will be released by enhancing the decomposition of the materials. Other indices that includes Carbon chemistry and nutrient content, like lignin: N or C: P ratios are negatively correlated with early decay rates in various studies (**Thomas *et al.* 2014 and Moore *et al.* 2006**).

Decomposition and decay are the yin to the yang of growth. Together they make the two halves of the whole that is the closed-loop cycle of the natural ecosystem (**Wieder *et al.* 2013**). The lay definition of decomposition is- "it is the

process by which complex dead tissues break down and are converted into simpler organic forms”. Without decomposition and decay the earth would overflow with dead residues. It would also experience a decline in growth, due to unavailability of nutrients that would be locked up in the dead forms. Plants nutrients like carbon, nitrogen, phosphorus, potassium, sulphur and other micronutrients need to be replenished by the decomposition process.

During the early decomposition phase, rapid mass loss was strongly correlated with the soluble labile C content (**Harmon *et al.* 1994 and Berg *et al.* 2008**). This is because of the fact that the amount of C, and the chemical composition of molecules containing carbon (i.e. cellulose, lignin) determines the decomposition rates (**Berg *et al.* 2008**). For instance, starch can be easily break down and provides a greater energy yield than lignin. There is no single parameter that can explain the carbon mineralization during the process of decomposition, but a combination of environmental and biological factors has been involved (**Laskowski *et al.* 2006 and Berg *et al.* 2008**).

Soil organic matter (SOM) a major component of the global carbon cycle; retain soil nutrients and water and reserves more global carbon than do atmosphere and plants combined (**Schlesinger 1990, Field & Raupach 2004**). The microbes i.e. the decomposers decompose this SOM returning CO₂, to the atmosphere. Addition of nitrogen through atmospheric deposition or fertilization might accelerate initial residue decomposition but nevertheless it also promotes soil carbon stabilization. Most carbon models, assume static linear relationships between carbon inputs and conversion of carbon pools to more stable forms (**Jackson *et al.* 2000, Liski *et al.* 2002, Gottschalk *et al.* 2012, Wieder *et al.* 2013**). For creating a balanced carbon cycle, we need to understand the ecological and physical controls over SOM, increasing food and fiber production, safeguarding ecosystem services. Through land use changes and unsustainable forest and agricultural management practices, soil carbon stocks have been widely lost or degraded. Hence to slow down the rise of atmospheric CO₂, management practices are important tools.

A great deal of research has been done in studies of soil CO₂ emission in recent years because of the potential impacts of this process on the greenhouse effect **(Schlesinger and Andrews 2000)**. Worldwide, about 1600 gigatons (Gt) of organic carbon is being stored in the soils as compared to 750 Gt in the atmosphere mostly in the form of CO₂ **(Rustad et al. 2000)**. Thus, if soil respiration increased such that only 10% of the soil carbon pool was converted to CO₂, atmospheric CO₂ concentrations could increase by one-fifth! Respiration rates depend upon the diffusivity of CO₂ molecule on the soil surface. Diffusion will be affected by soil moisture and soil texture. Thus, the soil respiration rates are mostly influenced by soil temperature, moisture, pH, density and texture.

Nutrient release pattern from decomposition of plants residues involves three phases **(Swift et al. 1979 and Berg et al. 2008)**: (1) initial phase- where nutrient release and leaching dominates; (2) a net mobilization phase; and (3) a net release phase where the mass of nutrients decreases. However, it is not easy to demonstrate all those phases in practical experiments. For instance, the immobilization phase could be absent, particularly in residues with high nitrogen concentration **(Berg et al. 2006)** i.e. legumes. In some cases, N and P dynamics can also be characterized by an initial immobilization followed by net release **(Vitousek et al. 1986)**. Phosphorous (P) concentration of plant residue represents important factor controlling residue decomposability in soil **(Vitousek et al. 1986)**. Potassium (K) serves as an essential macronutrient for energy metabolism, photosynthesis and membrane transport of plants **(Solvic 1997)**. K is not a structural constituent of the plants and it exists mainly in plant sap thus mobile K is leached out quickly from decomposing litters. The later phase of the K dynamic, is characterized by seasonal changes regardless of the initial residue quality **(Osono and Takeda 2004)**.

Today's residue burning causes a major challenging issue for the scientist's and the policy makers as it affects directly, to our environment, soil health and crop productivity. Crop residue management leads to increased organic carbon in soil which enhances water and nutrient retention capacity. Organic materials as soil supplements are an essential management technique that can increase and improve

soil quality features while also altering nutrient cycle through mineralization-immobilization turnover (MIT) of added materials (**Hueso-Gonzalez *et al.*, 2014**).

Local organic materials originating from animals or plants have gained widespread support for enhancing the fertility and productive potential of degraded and nutrient-impooverished soil. Plant residues can help to maintain organic carbon content, improve soil physical qualities, boost biological activity, and increase nutrient availability in agricultural soils (**Cayuela *et al.*, 2009**). Local organic materials originating from animals or plants have gained widespread support for enhancing the fertility and productive potential of degraded and nutrient-poor soil. Plant residues offer energy and nutrients for microbial growth and activity in the near term, operate as a driving force for mineralization-immobilization processes in the soil, and are a source of nitrogen for plants in the long run (**Jansson and Persson, 1982**). Crop residues must be incorporated into the nutrient pool of arable soils throughout time in order to maintain organic carbon (C) and nitrogen (N) stocks (**Rasmussen and Parton, 1994**).

Crop residue integration in the field is advantageous in terms of recycling nutrients, but also causes temporary nitrogen immobilization, necessitating the addition of additional nitrogenous fertilizer to rectify the C: N ratio at the time of residue inclusion (**Singh *et al.*, 2015**). Returning plant debris to the soil is an efficient way to maintain soil organic matter levels, boost biological activity, improve physical characteristics, and increase nutrient availability (**Smith *et al.*, 1992**). Plant residue management has a significant impact on organic matter, which is an important soil component. When plant leftovers or other organic sources are not returned to a soil, it loses biological fertility and resilience as the soil's physical, chemical, and biological qualities deteriorates (**Lal, 1994**). This process leads to low soil productivity.

Furthermore, considerable amounts of N, P, K, and other nutrients can be found in crop residues, which can boost long-term plant productivity. High N mineralization rates are common in higher quality plant residues with high N concentrations, low lignin and cellulose concentrations, and low C:N and lignin:N ratios. Low-quality residues, on the other hand, have a reduced N mineralization rate,

which might have a detrimental impact on plant accessible nitrogen due to nitrogen immobilization (**Manzoni *et al.* 2008**).

The nature of crop leftovers and how they are managed has a significant impact on the soil's nutrient-supply capacity in the short and long term. In agricultural production rotation systems all over the world, the impact of past crop residue on nutrient availability to following crops has gotten a lot of attention. Nitrogen (N), phosphorus (P), potassium (K), sulphur (S), and micronutrients are found in almost all crop residues. The nutritional composition of crop residues varies as well. Crop residual nutrients will eventually be recycled through soil organic matter and made accessible for plant uptake in the future. Due to the complicated nature of how nutrients in residues are recycled and transformed to plant accessible form, it is more difficult to anticipate how much nutrient will become available at a certain moment.

Keeping all these above in view, the research work entitled “**Decomposition of wide C: N ratio crop residues on the release of active carbon pool and available nutrients in Inceptisols of Varanasi**” was carried out with the objectives given below

1. To determine active carbon pool as influenced by addition of crop residue.
2. To study the release pattern of N, P, K and S with addition of crop residue in soil.



REVIEW OF LITERATURE

In this section, an attempt is made to review the research work already done and reported by different workers pertaining to nutrient release pattern and active carbon pool during decomposition of crop residues under the following topics in order to properly design the research effort and effectively convey the findings in order to meet the goals of the current investigation.

- 2.1 Decomposition of crop residues involving microbes in soil.
- 2.2 Factors affecting decomposition of crop residues in soil.
- 2.3 Effect of decomposition of crop residues on evolution of carbon dioxide in soil.
- 2.4 Decomposition of crop residue on release of nutrients in soil.

2.1 Decomposition of crop residues involving microbes in soil

Decomposition of soil organic matter (SOM) is widely regarded as a significant contributor to nutrient availability in the soil. Incorporating animal dung and other organic elements into the soil has been shown to improve the physical, chemical, and biological qualities of the soil. Plant remains are the main source of organic matter in the soil. SOM is made up of various pools, humus, fresh plant residues (active fraction or particle organic matter), and root exudates, according to the NRCS (n.d.). The breakdown rates of these pools differ, with rates falling in the following order: root exudates>fresh residues>humus. The food source for the community of heterotrophic organisms is these components. The importance of SOM in improving soil quality necessitates a thorough understanding of how it decomposes, how plant residual nutrients are released, and the factors that influence decomposition. Decomposition processes are influenced by a variety of known and

unknown factors, including nutrient availability, soil microorganisms, physical environment, crop residue quality, root exudation, and rhizosphere priming effects (Singh *et al.* 2004).

Stegarescu *et al.* (2020) had conducted an experiment to study the decomposition effects of residue from two different cover crops (*Brassica napus* var. oleifera and *Secale cereale*) and one main crop (wheat straw) on soil aggregate stability. Determining the soil functional groups, carbon dioxide (CO₂), nitrous oxide (N₂O), and methane (CH₄) emissions, soil microbial biomass carbon (MBC), and water-stable aggregates were used to assess the breakdown impacts of organic matter on soil conditions during incubation (WSA). And it was concluded that fresh organic material breakdown rates were linked to soil functional groups and the C/N ratio.

Manna *et al.* (2021) had conducted an experiment to explore lingo-cellulolytic microorganisms' potential to speed up in situ breakdown of crop residues. In the states of Haryana and Maharashtra, field trials on farmers' fields were done to target the burning of rice and wheat residue and sugarcane garbage, respectively. In a comparison of crop residue removal (CRR), crop residue burning (CRB), and in situ decomposition of crop residues (IND), it was found that rice and wheat residues took 30 days to decompose, whereas sugarcane trash took 45 days.

Environmental elements such as soil texture, moisture, and temperature are critical because their influence on microbial activity can alter decomposition rates. The pace of decomposition and nutrient dynamics are both determined by the quality of plant residues applied to soils. The chemical composition of residues, namely the carbon/nitrogen (C/N) and carbon/phosphorus (C/P) ratios, as well as the concentration of simple and complex molecules, have all been proven to be essential. Cellulose (45 percent), hemicellulose (20 percent), lignin (20 percent), proteins (8 percent), sugars and starches (5 percent), and fats and waxes (2 percent) are the most common green plant residues (NRCS 2000).

When plant remains are returned to the soil, their organic substances are decomposed by microbes. Plant residue decomposition is a biologically driven

process, meaning that it is carried out by soil organisms' metabolic processes. Soil organisms, the physical environment (temperature, moisture, soil textures, and oxygen levels), and the quality of the plant leftovers (C/N ratios and other chemical qualities) all play a role in its rate. As it is known, chemical, physical, and biological agents convert complicated organic chemicals into accessible organic and inorganic components that plants may absorb, enhancing soil biological, chemical, and physical status. By increasing soil structure and nutrient cycling, these activities have a significant impact on soil productivity and crop yields. The content of plant residues changes as it decomposes. Carbon dioxide, water, energy, microbial biomass, inorganic nutrients, and re-synthesized organic carbon compounds such as humus, phenolics, celluloses, hemicelluloses, and lignin are all ultimate products of plant residue decomposition (**Baldock, 2007**). Humus has a significant impact on soil qualities; as the soil darkens, aggregation and aggregate stability rise, and it acts as a slow-release storage pool for N, P, and other nutrients.

Organic compounds in residues are classified according to their molecular sizes, solubility, and primary ingredients. Some plant wastes decompose quickly in the soil, whereas others decompose slowly. Simple molecules like sugars, amino acids, and low molecular weight phenolics disintegrate quickly, whereas polymeric materials like celluloses, hemicelluloses, and lignin decompose slowly (**Berg and McClaugherty 2003**). Because a large number of microorganisms consume simple/soluble chemicals, the rate of degradation of plant residue is usually high at first.

Plant residue breakdown occurs quickly, resulting in a loss of mass. This is due to the emission of CO₂ and the leaching of degraded organic molecules. Water flow during the decay processes causes leaching, which is the loss of nutrients and incompletely degraded chemicals. Under aerobic conditions, microbial activity produces CO₂; however, under anaerobic conditions, organic acids or methane may be produced instead of CO₂ (**Wood, 1989**).

Measurements of carbon dioxide (CO₂) evolution or respiration, nutrient release, and residue carbon have all been used to investigate the decomposition of

plant wastes. Microbial populations rapidly expand as plant wastes disintegrate, as demonstrated by increasing CO₂ emission from the soil via respiration. The rate of carbon mineralization in residues can be estimated by measuring CO₂ evolution. Another way for determining decomposition rate is to measure the carbon content of the residue during the decomposition process. In terms of nutrient availability to soil microbes and plants, nutrient release during decomposition is particularly interesting (Trinsoutrot *et al.* 2000; Corbels *et al.* 2003; Baggie *et al.* 2005).

2.2 Factors affecting the decomposition of crop residues in soil

2.2.1 Plant residue properties

In the following sections, the important chemical and physical features of the residues that determine the rate of decomposition and nutrient release are discussed.

2.2.1.1 Chemical properties

A variety of chemical residual features can be used to forecast the rate and course of residue breakdown. Residues are usually divided into three fractions, each with a different rate of decomposition: 1) carbohydrates and amino acids that decompose quickly; 2) cellulose and hemicellulose that decompose slowly; and 3) refractory components like lignin that decompose slowly (Van Veen *et al.* 1984).

Singh *et al.* (2019) had conducted a study under the rice-wheat cropping system in Inceptisols of Bihar and had found that crop residue management practices involving residue incorporation improved favorably and significantly soil properties such as bulk density, infiltration rate, mean weight diameter, aggregate stability, electrical conductivity, organic carbon, available nitrogen, phosphorus, and potassium, bacterial and fungal.

Many studies have found that the initial concentrations of nitrogen (Jensen 1997), phosphorus (Soon and Arshad 2002), lignin (Müller *et al.* 1988), polyphenols (Constantinides and Fownes 1994) and soluble carbon (Kachaka *et al.* 1993) are good indicators for plant residue quality and decomposition rates. Because it controls

the turnover of the microbial mass mineralizing the residues, the initial N concentration of plant residues is one of the most important variables speeding or inhibiting residue decay (**Heal *et al.* 1997**).

Baldock (2007) had studied about C/N ratio affecting decomposition and has found that the proportion of N mineralization is positively associated with the nitrogen content of plant residues. Microorganisms have a C/N ratio of 12 while soil has a C/N ratio of 8. While the ideal C/N ratio for microbial growth is roughly 25, the C/N ratio in agricultural residues varies between 20 and 500, depending on plant maturity and species. Plant residues with a high C/N ratio (>40) mineralize far more slowly than residues with a C/N ratio less than 40.

Soon and Arshad (2002) discovered that the decomposition rate of straw of three crops was, in order: pea>canola>wheat, with residue N concentrations of 7.09, 7.04, and 5.06 mg g⁻¹ straw, respectively, and C/N ratios of 66, 71, and 97. And had stated that low C/N plant materials will meet the N needs of the soil microbial population, with any excess N being mineralized and made available for plant uptake. Plant residues from the Poaceae family, such as wheat, oat, and barley, typically have a high C/N ratio, whereas plant residues from the Fabaceae or leguminous family, such as vetches, lupin, soybean, and green gram, typically have a low C/N ratio.

Heal *et al.* (1997) had studied the effect of lignin/carbohydrate ratio on the rate of plant residue decomposition and has found that lignin contributes to the structure of plant cell walls and renders them resistant to microbial attack. Plant cell wall disintegration is critical for the breakdown of plant leftovers because it permits microbial access.

Herman *et al.* (1997) had conducted an experiment regarding the relationship between C/N ratio and N mineralization rate and had concluded that as the concentration of lignin and the C/N ratio increase or the N content drops, organic matter breakdown and N mineralization decrease. When easily decomposable chemicals are depleted in plant residue breakdown, lignin decomposers will take over and control the rate of degradation.

Berg and McClaugherty (2003) had stated that carbon mineralization kinetics varies amongst plant sections with varied biochemical compositions. Most plant materials have an organic carbon content of about 40%, and while most of this is returned to the environment as CO₂, about 20-32 percent persists in the soil as soil organic matter.

Reinertsen *et al.* (1984) had studied on the rate of decomposition of wheat straw and had found that the quantity of N immobilised in the microbial biomass in the early stages of decomposition substantially dependent on the soluble and accessible C pools dissolved during the first few days.

Palm and Sanchez (1991); Oglesby and Fownes (1992) has investigated the impact of initial polyphenol concentration and polyphenol/N ratio on mass loss and N release in plant residues and had come to the conclusion that plant residue breakdown rate is slowed by large concentrations of polyphenolics, celluloses, and waxes, due to enzyme inhibition and mineralized N binding to insoluble organic molecules. Nitrogen mineralization was also found to be adversely linked with polyphenol concentration ($r = -0.63$) and polyphenol/N ratio ($r = -0.75$) because stable polymers develop between polyphenolics and amino groups, they reasoned that plant residues abundant in polyphenols have little N mineralization. The findings of **Oglesby and Fownes (1992)**, who discovered that the initial polyphenol/N ratio was the best chemical index of N mineralization, backed up this conclusion.

2.2.1.2 Physical properties

Bending and Turner (2004) had stated that the physical features of plant residues and their interface with the soil, in addition to their biochemical makeup, have a significant impact on N immobilization/mineralization turnover. Reducing particle size enhances the surface area available to soil microorganisms for colonization and provides for a more uniform distribution of leftovers in the soil. As a result, tiny residues disintegrate more quickly than bigger residues.

Singh et al. (2004) found that the particle size of canola residue had a substantial impact on mineral N immobilization but had no effect on the rate of C mineralization. They also discovered that the size of the canola particles had no effect on the microbial C and N levels throughout incubation. However, little is known about how high and low C/N residues decompose in the soil when they are introduced frequently, individually and/or together, and/or at varied distances from the interface between high and low C/N residues.

2.2.2 Effects of environmental factors on decomposition

2.2.2.1 Soil properties

Sylvia et al. (2005), had concluded that clay content has been found to be negatively connected with potential N mineralization and to be favorably correlated with aggregate size and aggregate formation. Clay is a fundamental soil texture component that impacts residue breakdown rates and determines soil aeration and drainage. Soil particles less than 0.002 mm (2 μ m) are classified as clay. Clay binds plant residues and chemical interactions between clay minerals (negatively charged) and cations such as ammonium (NH_4^+), minimizing residue mass loss and improving soil C, water, and nutrient retention.

Epstein et al. (2002), had stated that the rate of SOM breakdown increased when soil clay content dropped due to lower oxygen levels in soils, and the accumulation of SOM was positively linked with soil clay concentration.

The study made by **Berg and McClaugherty (2003)** shows that aerobic metabolism yields more energy than anaerobic metabolism because microbial populations grow faster and decomposition is greater under aerobic conditions. The degradation of plant wastes and therefore the proliferation of microorganisms are accelerated by adequate soil aeration. Soil organisms are stimulated to remodel organic substances into inorganic compounds when there's enough oxygen. Bacteria and fungus are the main principal decomposers of plant waste. Bacteria include

aerobic and anaerobic organisms that may break down polymeric molecules like lignin, celluloses, and hemicelluloses.

Bolan and Hedley (2003) had studied on the impact of soil pH on plant residue decomposition processes because it affects microbial activity. It can even influence the composition of microbial communities and affect nutrient solubility. If microbial populations are harmed, nutrient cycling is hindered or stopped. At neutral soil pH, microbial activity is at its peak. In keeping with **Allison (1973)**, high pH and nitrogen concentrations favor bacteria multiplication, while low pH and nitrogen concentrations favor fungal growth.

Marschner et al. (2005) found that soil pH had a greater impact on microbial community composition than other soil variables during a pot experiment with ten soil types. As a result, soil pH affects microbial species' ability to survive and compete. In terms of the function of plant residues in soil pH changes, the degree of decomposition, the pattern of anions and cations released, and microbial immobilization will all influence soil pH.

Bolan and Hedley (2003) had stated that ammonification produces hydroxyl ions (OH⁻) and raises soil pH, whereas nitrification produces protons H⁺ and lowers soil pH. Furthermore, plant leftovers containing high levels of organic nitrogen, such as proteins and amino acids, will result in increased ammonium and/or nitrate mineralization in the soil.

Xu et al. (2006), had studied about pH change with relation to nature of plant residue and had concluded that the soil pH change after the addition of plant residues, depends on the type of plant residue and the baseline soil pH. They discovered that adding legume residues boosted soil pH at first, but gradually decreased it after a 42-day incubation, whereas adding low N wheat residues kept soil pH reasonably steady.

2.2.2.2 Temperature and Moisture

Berg and McClaugherty (2003), had stated that microbial respiration is dependent on organisms' ability to adapt to their soil habitat and is positively

connected with temperature. Temperature and moisture are crucial physical elements that influence the rate of residue decomposition because they influence soil microbial activity directly. Microbial activity rises as temperature rises, with a peak of 30 to 45 degrees Celsius, however the link between microbial activity and temperature varies by microbial species.

Eijsackers and Zehnder (1990) had argued that under aerobic conditions, higher residue decomposition with increasing temperature would result in increased N release and a slower rate of SOM buildup. In addition to soil temperature, soil moisture has a significant impact on residue breakdown. Water is essential for the breakdown of plant wastes, therefore adequate moisture will speed up decomposition and microbe proliferation.

Osono et al. (2003) had experimented with *Chamaecyparis obtuse* survival and had found that its activity were shown to be favorably linked with moisture content and soluble carbohydrate concentration in the residue. High moisture levels, on the other hand, can cause anaerobic conditions and stymie operations. It's crucial to keep most or all environmental parameters constant in studies exploring the effect of residual qualities on decomposition.

2.2.3 Properties of the rhizosphere

The rhizosphere is described in a variety of ways, the most prevalent being Hiltner's definition from 1904: the volume of soil next to and impacted by plant roots (**Bertin et al. 2003**). Plant roots have an impact on the soil's physiochemical qualities.

Wang and Zabowski (1998), had conducted an experiment regarding the factors affecting the pH of the rhizosphere and had concluded that the pH of the rhizosphere can differ by up to 2 pH units from the bulk soil. Because of various characteristics, the rhizosphere offers a favorable environment for the proliferation of soil microorganisms. The rhizosphere is a microbial habitat that differs significantly from that of the bulk soil due to the presence of easily decomposable root exudates. Plant growth can be stimulated or slowed by microorganisms in the rhizosphere.

2.2.3.1 Root Exudation

Exudation from the roots stimulates the breakdown of plant leftovers. Rhizo-deposition, which is a major source of soil organic C released by developing plant roots, includes root exudation. Exudates, secretions, lysates, and gases are all classed as rhizo-deposits depending on how they arrived.

Paterson *et al.* (2006), stated that organic substances produced from roots, influence the rate of residue breakdown and nutrient release through influencing the activity and abundance of decomposer populations in the soil. Because soluble root exudates can act as a glue between clay particles, this adds to increased aggregate stability.

Lynch and Whipps (1990); Marschner *et al.* (2001) had shown that plant-microbe interactions, which have strong effects on microbial activity and microbial community structure and hence nutrient release, need the release of organic compounds from plant roots. Because of the direct relationship between microbial growth and root exudation, rhizosphere respiration can be used as a predictor of root exudation rate. CO₂ production in the rhizosphere, on the other hand, is due to root and microbial respiration.

Lynch (1990) conducted an experiment and had stated that plant species, age, mineral nutrient availability (**Eldhuset 2005**), and external factors all influence the quality and quantity of chemicals released. Young plants secrete roughly twice as much fixed C as older plants in the form of root exudates.

Lynch and Whipps (1990), had stated that sugars, amino acids, organic acids, hormones, vitamins, and unexplained compounds such as microbial growth stimulants and inhibitors are commonly found in root exudates. According to **Baldock (2007)**, amino acids provide a quickly available supply of nitrogen for microorganisms, whereas sugars are easily available amounts of carbon for microbial development

Kuzyakov *et al.* (2007) simulated the rhizosphere by adding malate, glucose, and glutamate to soil with residues at two different temperatures (15oC and 25oC),

and discovered that adding these labile root exudates significantly increased plant residue decomposition, but the increase was temperature-dependent.

2.2.3.2 Rhizosphere priming effect

Kuzyakov *et al.* (2000), defined Priming effects (PEs), are short-term alterations in SOM turnover caused by the addition of various organic and mineral compounds to the soil. The addition of C sources promotes microbial growth and may result in the formation of PEs. The SOM turnover is determined by the activity and density of microorganisms. The rhizosphere priming effect (RPE) has a significant impact on the rate and course of plant residue breakdown. The RPE is a priming effect in the soil that surrounds plants' live roots.

Fu and Cheng (2004), had stated that soil treatments like tillage and fertilizer applications have a big impact on plant root exudation and rhizosphere deposition, which can lead to RPEs. RPEs differ according on the plant type and stage of development. Low C/N plant species have a greater RPE than high C/N plant species.

Kuzyakov (2002), had stated that RPEs are influenced by a variety of circumstances, these include root proliferation, plant and soil types, water and nutrient uptake, preferential substrate use of soil organisms, soil C and N levels, and photosynthetic rate.

Dijkstra *et al.* (2006) looked at how plant biomass affects RPE in two distinct plant species in two previously different managed soils, an organically farmed soil and an annual grassland soil. Their finding was that annual plants' rhizosphere priming effects on SOM decomposition are mostly governed by plant biomass, especially in high-fertility soils with high plant production.

Kandeler *et al.* (2002) investigated how the presence of maize roots altered the microbial community composition and functional diversity. They came to the conclusion that the microbial community composition within the first 2.2 mm of the root surface differed significantly from that at further distances, which could influence

SOM decomposition. However, it is unclear how RPE is affected by residue C/N and at what distance from the root surface RPE occurs.

2.3 Effect of decomposition of crop residues on evolution of carbon dioxide in soil

Hu *et al.* (2006) studied about the carbon cycle and soil respiration in relationship to climate change and has shown that soil respiration is a good indication for determining the rate of decomposition of plant wastes and plant root respiratory activities.

Environmental conditions have an effect on the metabolic activities of plants and microbes, which can speed up or slow down these processes. Temperature, water availability, and pH all play a role in the rate of soil respiration, according to several studies (**Hobbie 1996; Osono *et al.* 2003; Marschner *et al.* 2005**).

Studies done by **Nikliska and Klimer (2007)** shows that temperature has a significant impact on soil respiration and plant residue loss, both directly and indirectly through its effect on water loss. The qualities of the plant remains also influence the components produced during decomposition. Plant residues with a high C/N ratio have a lower respiration rate than those with a low C/N ratio because they do not contain enough nitrogen to meet the needs of soil organisms. Furthermore, they frequently include high amounts of C compounds that are difficult to decompose, such as celluloses or lignin. Mixed plant residues (a mixture of high and low C/N residues) have a faster respiration rate than high C/N residues, but N release is higher.

Aita and Giacomini (2003) investigated the decomposition and nitrogen release dynamics of cover crop residues in mixed and single applications, including (a) black oat; (b) common vetch; (c) oilseed radish; (d) black oat + common vetch; and (e) black oat + common vetch. Their findings showed that mixed residues of common vetch and oat decomposed at a slower rate than the vetch alone, but produced more nitrogen.

Jensen (1997) also discovered that mixing plant remains in soil stimulates soil microbial biomass on and around the residue particles, which is viewed as a source of nutrients and a breakdown catalyst. However, the rate of respiration, the methods of nutrient release when plant wastes are often introduced, and the effect of living plants are all factors to consider.

2.4 Decomposition of crop residue on release of nutrients in soil

Sylvia *et al.* (2005), described mineralization as the transformation of an element's organic form to its inorganic form as a result of microbial degradation in the soil. During the degradation of plant wastes, two primary processes occur: mineralization and immobilisation. Mineralization produces accessible forms of nutrients that are easily taken by plants and other living organisms. Immobilization, on the other hand, is the process of turning inorganic forms in soils into microbial biomass, which helps to prevent nutrient loss through leaching and erosion. Plants and soil microorganisms get their nitrogen via mineralization of plant leftovers in the soil. It is largely reliant on the chemical makeup of plant residues.

Jansson and Persson (1982), had stated that the crop residue nitrogen availability is determined by the balance between mineralization and immobilization, as well as the stabilization of residue N in SOM pools. Nitrogen losses from the soil-plant system can affect how much nitrogen is available for successive crops through leaching, denitrification, and ammonia volatilization. As a result, a better knowledge of the dynamics of plant residue N turnover is critical in order to reduce N losses.

Stevenson (1982), had stated that amino acids and amino sugars are the most easily recognized organic nitrogen molecules in soil; amino acids, in particular, are easily mineralized under aerobic circumstances. Under microbial action, organic N deaminates to amino acids, which are then transformed to NH_4^+ during mineralization. The mineralized NH_4^+ can be immobilized, nitrified to NO_3^- , liberated from the cells, and used as a nitrogen or energy source by other microbes.

Bolan and Hedley (2003), had found that mineralization-immobilization turnover is the ongoing process of converting mineralized N into organic products and mineralized N back into inorganic forms. "Net N mineralization" is the difference between total N mineralization and immobilization from plant residues. This area is a significant source of nitrogen for plants. NH_4^{4+} and NO_3^{3-} are both used by plants. Plants and soil microbes compete for mineralized nitrogen.

Singh et al. (2021) had studied the nitrogen and sulphur release pattern from added millets and oilseeds residues in Indo- Gangetic black and alluvial soils of Varanasi. The experiment was laid out in a factorial completely randomized design with four replications. From the present experiment it was concluded that soils amended with millets and oilseeds residues displayed wide variations in N and S release. Residues of sunflower and mustard showed fast release of N and S, so they should be utilized for short-term supply of N and S to growing crops in black and alluvial soils.

Chowdhury et al. (2017) had studied about the transformation of S and P in soil through the decomposition of plant and animal residues. Inorganic sulphate – S, available P and microbial respiration i.e. carbon dioxide evolution were monitored in a S deficient soil amended with cow dung, dhanicha and rice straw at the rate of 1 gram per 50 gram soil during 30 days incubation. Basal dose of N, P and K was applied to soil at the rate of 250 µg, 200 µg and 250 µg respectively. The decomposition rate was highest for dhanicha, intermediate for cow dung and lowest for rice straw. It was found that decomposition has close relation to its nutrient status (C:N:S ratio). During decomposition of rice straw S was immobilized markedly. Significant increase in P mineralization was caused due to application of plant and animal residues.

Talgre et al. (2014) had studied about P and K release during decomposition of shoots and roots of green manures crops. A trial was conducted at the Estonian University of Life Sciences regarding decomposition rates of under and above ground biomass and the dynamics of the remaining P and K were studied. The ultimate P and K release happened in six months. It was found that legume roots decomposed more

slowly than the above ground residues. And hence it was concluded that shoot residues decomposes rapidly and serves as a source of P and K for the subsequent crop.

Seta *et al.* (2016) had made a study regarding carbon and nutrient release patterns during decomposition of leaf litter in Boter-Becho Forest, Southwestern Ethiopia. The objective of this study was to assess the effect of disturbances and season in the C and nutrient release patterns from decomposing leaves. The differences in carbon and nutrients remaining between seasons and the sites were evaluated by one way ANOVA at $P < 0.05$. And as a result it was found that there was no significant differences between the initial litter chemistry and nutrient release except for K ($P=0.021$), a significant difference was noticed ($P<0.005$) in C and nutrient release pattern between wet and dry season in both sites being greater the release in wet season. So it was concluded that the rate of decomposition, C and nutrient release pattern in the Boter-Becho forest depend on the climatic conditions but not on the initial litter chemistry or disturbance of site.

Lupwayi *et al.* (2005) studied the potassium release during decomposition of crop residues under conventional and zero tillage. In this experiment litterbag method was used to determine K release patterns from various crop residues under conventional and zero tillage. Correlations between K release and residue quality were inconsistent, because K is not a structural component of plant tissue, and hence its release is more related to leaching than to residue decomposition.

Aliabro *et al.* (2011) had conducted an experiment regarding carbon dioxide emission from maize straw incubated with soil under various moisture and nitrogen levels. The result was that mixing of straw with soil accelerated decomposition rates and enhance cumulative carbon dioxide production as compared with controls. Hence, it was concluded that incorporation of straw into soil along with the addition of N and moisture levels significantly affected carbon dioxide evolution, cumulative carbon dioxide, C mineralization and soil organic carbon deposition.

Rezig et al. (2014) had studied about the decomposition and nutrient release pattern of wheat residues under different treatments in desert field conditions of Sudan. In a 12 week litter bag experiment under field conditions, decomposition and nutrient release pattern from wheat residue were investigated. And it was concluded that application of mineral fertilizer or sewage sludge enhances the decomposition of low-quality residue (wheat). Hence, it is essential to apply fertilizer in degraded soil before incorporation of crop residue with high C: N ratio.

Dung et al. (2022) conducted an experiment regarding decomposition of rice straw residues and the emission of Carbon dioxide, methane under paddy rice and crop rotation in the Vietnamese Mekong Delta region. The studied soil undergoing crop rotation systems were rice-rice-rice (SR) and baby corn-rice-mungbean (SB). There were two main microcosm set-ups: aerobic (SR-AE, SB-AE) and anaerobic (SR-AN, SB-AN) conditions. Litter bags which were containing rice stems were inserted into the soil and recollected at different point of time for chemical analysis and the gas sampling were collected to measure the carbon dioxide and methane emissions. It was found that the total carbon (TC) decreased around 30% and the removal of TC significantly higher than in aerobic conditions. This study assured that the decomposition of rice straw residues is faster in the anaerobic paddy soil condition compared to the aerobic crop rotation condition.

Pangga et al. (2000) conducted two laboratory perfusion experiments to study the decomposition and nutrient release pattern from straw of various paddy varieties which were collected from the field. Over a 6 week period, cumulative evolution of carbon dioxide and nutrient release from the straw of 20 rice varieties was measured. The result was such that, it indicated that under flooded conditions, depletion of oxygen decreases decomposition rate of straw but the initial rate of nutrient release is unaffected. The more labile components of the nutrients present in the plants and their physiological role appear to be related to the uncoupling of C and nutrient release.

Gharmakher et al. (2012) conducted an experiment to study the impacts of soil sulphate availability on residue breakdown, as well as the correlations between plant residue quality and S and C mineralization. In a loamy soil, rapeseed straw

mineralization was investigated after adding sulphate at rates of 20 and 50 mg S-SO₄ kg⁻¹ soil. Wheat straw, tall fescue, mustard, and beech leaf residues were added to the soil and incubated. During a 175-day incubation at 20 °C, net C and S mineralization were assessed continuously, and gross S mineralization and immobilisation were determined using ³⁵S soil labelling. And it was found that sulphate addition had little effect on C mineralization, showing that the soil S supply was sufficient to meet microbial demands during decomposition. The chemical nature of the residue had a substantial impact on the rate of decomposition and gross and net S mineralization, with mustard and fescue residues releasing a lot of sulphate but minimal net change in soil sulphate. Hence, it was concluded that chemical composition and C/S ratio of plant residues are essential variables for forecasting the kinetics of residue degradation as well as the amount of sulphate available.

Berg and McClaugherty (2003), had conducted an experiment regarding the C/N ratio of plant leftovers and soils, which is a major determinant of net N mineralization. And had concluded that net N mineralization from plant residues is based on the relationship between (1) gross N mineralization and respiration (C mineralization) and (2) gross immobilization and respiration. The C/N ratio of plant residues introduced has a big impact on net N mineralization.

Walley and Yates (2002), had conducted an experiment to show the relationship between the C/N ratio and the rate of mineralization and it was concluded that, the lower the C/N ratio in plant material (below than 21:1), the greater the chance of net mineralization. Microorganisms have a C/N ratio of 7:1, implying that they require 7 parts of C for every 1 part of N to maintain functionality, with one-third of the C integrated into their cells and the other two-thirds used as a source of energy. As a result, plant wastes with a C/N ratio of less than 21:1 will meet *all* of the N demands of microbial mass, with any excess N being released or mineralized, and N flowing from the organic to inorganic pool

Kachaka et al. (1993), had stated that a C/N ratio of residue 25:1 (N content > 1.4 percent) results in net mineralization, whereas a C/N ratio of residue > 25:1 results in net immobilisation. N immobilisation occurs when low N plant leftovers are first

mixed into the soil because these plant materials do not meet the N nutritional needs of soil bacteria. When microorganisms die, the nitrogen that they have immobilised will be released.

Singh *et al.* (2006) conducted a two-year field experiment in a tropical dryland location to assess the impact of single and mixed plant residues with varied C/N ratios. When compared to a single residue, adding Sesbania (C/N 16) + wheat straw (C/N 82) resulted in a higher level of microbial biomass N and N availability.

Carlyle (1986) has stated that the C/N ratio in soils also has an impact on the N mineralization process. Net N mineralization occurs when the amount of nitrogen in soils and the amount of nitrogen released by SOM decomposition exceeds the amount of nitrogen required by microbial decomposers. However, one of the key issues in this study is the kinetics of N mineralization in soils when high and low C/N plant residues are introduced in the soil singly or mixed frequently.

Webley and Jones (1971) estimate that about 60% of microbial P is in the form of nucleic acids, 20% in acid soluble P-esters, and 5% in phospholipids, with these proportions varying depending on cell growth stage, residual management, and cultivation procedures. The three main types of P found in soils are inorganic, organic, and microbial. Phosphorus is required by organisms for metabolic activity and as a structural component of many biological molecules. Only P in the soil solution is available for plant absorption, but due to precipitation and immobilization in the soil, its concentration is usually low. Phosphorus in agricultural residues or green manures put to the soil can significantly enhance total soil P. The quantity of P released from the soluble P fraction in plant residues during decomposition has a big impact on the amount of P in the soil solution. The P form taken up by plants is inorganic phosphate in soil solution, however this soluble P is easily absorbed by Al and Fe oxides and hydroxides, clay colloids, or immobilized by microbial biomass. The concentration of P in microorganisms, on the other hand, varies depending on their growth stage and residue quality.

Friesen and Blair (1988) and Kwabiah *et al.* (2003), had studied the link between plant residue quality, accessible (resin extractable) P, and microbial biomass P and C. Plant-available P in soil and changes during plant residue decomposition are influenced by mineralization and immobilization of P.

Tarafdar and Jungk (1987), had studied the phosphatase enzymes, which are produced by microbes, plants, and mycorrhizae, mineralize organic P in plant wastes during decomposition. The amount of phosphorus in soil solution is determined by the amount of phosphorus released by plant residues. The initial rise in accessible P was attributable to the release of soluble P from plant residues, they concluded.

McLaughlin *et al.* (1988) had studied P immobilization, by using ^{32}P -labeled fertilizer and ^{33}P -labeled medic residues to explore the effect of the microbial mass in P cycling. The amount of P in the fertilizers ^{32}P and ^{33}P recovered in the microbial biomass was found to be 5% and 22-28 percent, respectively, in the medic residues.



MATERIALS AND METHODS

The present investigation has been planned to study the “Decomposition of wide C: N ratio crop residues on the release of active carbon pool and available nutrients in Inceptisols of Varanasi”. The materials and method used for selecting the sources, location and method of collection, analysis and interpretation of data generated are described below.

3.1 Climate and Weather

Varanasi, also known as Banaras, is one of the world's oldest cities. It is located on the banks of the Ganga River and has an area of 1535 km² in Uttar Pradesh. It is situated between the confluences of the Ganga and the Varuna rivers, as well as the Ganga and the Assi rivulet. Between 82° 56'E and 83° 03'E, and 25° 14'N and 25° 23.5'N, the urban agglomeration is located. Varanasi is situated between 25°00' and 25°16' N latitude and 82°50' and 83°10' E longitude. The city's topography rises between 50 feet (15 meters) and 70 feet (21 meters) above the river. The Ganga River travels from south to north, and on its left bank are the world-famous Ghats averaging 50 to 70 feet (15 to 21 meters) above the river. Varanasi falls in semi-arid to sub-humid, which receives a mean annual rainfall of 1100 mm and the PET is about 1525 mm. The mean relative humidity in Varanasi is 88%, it rises to 91% during July to September and decreases to 39% during April to early June. Winter is cool whereas summer is hot and dry.

3.2 Collection of soils

The bulk surface soil samples were collected from the “University farm” of the Institute of Agricultural Sciences located inside the BHU campus, which is at a latitude of 25° 08'44"N and longitude of 82° 58' 26"E. Prior to the time of sampling groundnut was grown in the field. This type of soil fall under Inceptisols (Haplustepts).

3.3 Preparation of soil sample for analysis

Soil samples brought to the lab was spread out in a thick brown paper. Unwanted materials like pieces of roots, stone sand undecomposed organic residues were removed. Then the samples were air dried in the department soil processing lab and it was grounded to pass through 2 mm sieve. A total of 9-10 kg well processed soil was collected. Samples were stored in card board and was used for chemical analysis.

3.4 Physico-chemical properties of soils

The data related to the physico-chemical properties of the soil sample is presented in the table 3.1.

Table 3.1: Soil characteristics and available nutrients of experimental soil.

Soil Characteristics	Value
Sand (%)	50.2
Silt (%)	31.2
Clay (%)	18.4
Texture	Sandy loam
Water holding capacity (%)	42.1
pH	7.65
EC (dsm ⁻¹)	0.5
Organic Carbon (g kg ⁻¹)	3.8
Available Nitrogen (kg ha ⁻¹)	276.00
Available Phosphorous (kg ha ⁻¹)	16.6
Available Potassium (kg ha ⁻¹)	168.8
Available Sulphur (kg ha ⁻¹)	18.5

3.4.1 Physical properties of soil

It was found that the clay content of alluvial soil sample is 20.6 per cent. The water holding capacity of 42.1 per cent (Table 3.1).

3.4.2 Chemical properties of soil

The pH value was found to be 7.65, whereas EC was 0.5 dsm^{-1} . The organic carbon content was 3.8 g kg^{-1} . Available nitrogen content was $275.96 \text{ kg ha}^{-1}$. Available phosphorous content was 16.6 kg ha^{-1} and the available potassium was 168.8 kg ha^{-1} . Available sulphur was 18.5 kg ha^{-1} (Table 3.1).

3.5 Collection of crop residues

Two wide C: N ratio crops namely wheat (*Triticum aestivum L.*) straw and paddy (*Oryza sativa L.*) straw were considered for this study. Crops residue were bought from the “University farm” of the Institute of Agricultural Sciences located inside the BHU campus. The residues were collected after harvest of crops during *Kharif* and *Rabi* seasons in the year 2020-2021. These residues were washed with running tap water and then with distilled water, dried at 65°C for 48 hours, milled and then it was passed through 1 mm sieve. The crops sample were analyzed for total carbon (C), total nitrogen (N), total phosphorus (P), total potassium (K) and total sulphur (S).

Table 3.2: Characteristics of crop residues for total C, N, P, K and S content and their ratio.

Crop residue	Total C (%)	Total N (%)	Total P (%)	Total K (%)	Total S (%)	C:N ratio	C:P ratio	C:K ratio	C:S ratio
Rice	47.67	0.49	0.18	1.51	0.12	97.29	264.0	31.56	397.25
Wheat	53.67	0.58	0.21	1.21	0.14	92.93	255.6	44.35	283.35

3.6 Soil incubation

3.6.1 Laboratory incubation

In order to study the changes in active carbon pool, soil respiration and the release pattern of available nitrogen, available phosphorus, available potassium and available sulphur, an incubation study on crops residue incorporation were conducted with an alluvial soil was conducted in the Soil Health and Plant Nutrition laboratory, Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University.



Figure 3.1: Six sets of incubation bottles

One hundred and sixty two incubation bottles of 250 ml capacity were used for the incubation study and filled with 50 g of processed air dry soil. Inside each incubation bottles small test-tubes of 20 ml capacity was planted for carrying 1N NaOH inside it, as shown in the figure 3.1. After imposing the treatments (as given in table 3.4), the soils were incubated at room temperature (30°C). Moisture content in the soil was maintained at the field capacity by addition of distilled water as and when

required. The bottles were sealed tightly and incubated for 15, 30, 45, 60, 75 and 90 days at room temperature. After each incubation period, the soil samples were drawn, air-dried, ground and analyzed for available N, P, K and S contents using standard methods.

Table 3.3: Treatments combination

Soil	Alluvial Soil (Inceptisols)
Treatments	9
Crop residues	Rice and Wheat straw
Days of intervals	15, 30, 45, 60, 75 and 90 days
Moisture Content	Field capacity
Replication	Three
Design	Completely Randomized Design
No. of experimental unit	$9 \times 3 \times 6 = 162$

Table 3.4: Treatment details

Symbols	Treatments
T1	Control (Soil with no residue amendment)
T2	Wheat straw incorporated into the soil at the rate of 20 tons per hectare.
T3	Paddy straw incorporated into the soil at the rate of 20 tons per hectare.
T4	T2 + Urea incorporated into the soil at the rate of 20 kg N per hectare.
T5	T3 + Urea incorporated into the soil at the rate of 20 kg N per hectare.
T6	T2 + <i>Trichoderma</i> incorporated into the soil at the rate of 10 kg per hectare.
T7	T3 + <i>Trichoderma</i> incorporated into the soil at the rate of 10 kg per hectare.
T8	T4 + <i>Trichoderma</i> incorporated into the soil at the rate of 10 kg per hectare.
T9	T5 + <i>Trichoderma</i> incorporated into the soil at the rate of 10 kg per hectare.

Table 3.5 Soil sampling time

S.No.	Incubation Period (Days)	Date of samples drawn
1	15	11.12.2021
2	30	26.12.2021
3	45	10.01.2022
4	60	25.01.2022
5	75	09.02.2022
6	90	24.02.2022

3.7 Soil Chemical Analysis

3.7.1 Soil pH

A soil water suspension was prepared in the ratio of 1:2.5 (10g soil with 25ml of distilled water) and pH was measured with the help of pH meter (Jackson, 1967).

3.7.2 Electrical Conductivity

The soil water suspension prepared for determination of pH was used to determine the electrical conductivity of the soil. Soil suspension was allowed to settle till supernatant become clear. Electrical conductivity was measured with the help of EC meter and expressed as dsm^{-1} (Jackson, 1967).

3.7.3 Mechanical composition

Particle size was determined by Bouyoucos hydrometer method (Bouyoucos, 1927) and the textural class was determined by using U.S.D.A textural triangle.

3.7.4 Organic Carbon

Organic matter (OM) in the soil is oxidized with a mixture of potassium dichromate and concentrated sulphuric acid utilizing the heat of dilution of sulphuric

acid. Unused potassium dichromate is back-titrated with ferrous ammonium sulphate. Organic Carbon in the soil was determined using Walkley and Black method (Walkley and Black, 1934).

3.7.5 Water holding capacity

The water holding capacity of soils was measured in the laboratory using Keen's box (Black, 1965).

3.7.6 CO₂ evolution

The cumulative carbon evolved after every 15 days of incubation at 25 °C i.e. at room temperature was used to estimate soil respiration, which was treated as basal respiration. For analysis of CO₂, 50 g of soil sample were taken in incubated jar, a small bottle of 20 ml capacity was inserted in the jar having 1N NaOH and made the jar air tight. The evolved CO₂ carbon was trapped in NaOH containing tube and then titrated with 1N HCl (Page *et al.* 1982).

3.7.7 Water soluble carbon

The water soluble carbon content in soil was estimated by the procedure described by Kalbitz *et al.* (2000). In this method 50 ml distilled water was used to fully mix the 12 g of soil sample followed by 2 hour shaking and centrifuged it for ½ hour at 4000 ppm and then after filtered the solution through filter paper (Whatman No. 1). 5 ml of filtered extract was mixed into 5 ml of 0.1 N K₂Cr₂O₇ and 20 ml concentrated H₂SO₄ after few minute 5 ml of concentrated H₃PO₄ was added and kept for 1 hour cooling followed by titration process by using 0.02 N of FAS.

3.7.8 Available nitrogen in soil

Available Nitrogen content in soil was determined using Kjeltec Semi-Auto Nitrogen Analyzer by alkaline Potassium permanganate method as proposed by (Subbiah and Asija 1956). The method has been widely adopted to get a reliable index of Nitrogen availability in soil due to its rapidity and reproducibility. Five gram of

soil sample was weighed and transferred in a distillation tube. Twenty-five ml 0.32% KMnO_4 was added to it and the distillation tube was set to the instrument. In a 250 ml conical flask, 20 ml of 2% boric acid mixed indicator was taken and placed under the receiver tube. Twenty-five ml of 2.5% NaOH was sucked and added to the distillation tube. Then it was put on distillation for 6 min. During the process the N released in the form of ammonia is trapped in the boric acid, which develops green colour. The flask containing the distillate was removed. The distillate was then titrated against 0.02N H_2SO_4 until pink colour developed.

Calculation

$$\text{Mineralizable N (kg/ha)} = \frac{(S-V) \times 14 \times 106 \times 2.24}{1000 \times 5}$$

Where, S = Sample titration reading

V = Blank titration reading

3.7.9 Available phosphorous in soil

Soil phosphorous in the soil samples were estimated by Olsen method (Olsen, 1954) as soil samples were having pH more than 5.5. When pH is <5.5 Bray's method is followed and when pH > 5.5 Olsen's method is followed.

Olsen's method of estimation

Firstly, reagent A and reagent B was prepared. In a conical flask 2.5g of soil was taken and to this soil sample 50 ml of Olsen's reagent (0.5M NaHCO_3) was added and a pinch of activated charcoal was also added. The contents were shaken for 30 min in a shaker and filtered through Whatman no: 1 filter paper. From this filtrate 10 ml of aliquot was taken in a 25 ml volumetric flask and 2-3 drops of nitro phenol indicator was added drop by drop until the colour was changed to yellow colour. After the colour was changed to yellow 2.5 ml of 2.5 M H_2SO_4 was added drop by drop till the yellow colour was disappeared. Then 8 ml of reagent B (Murphey Riley colour reagent) was added and volume was made up to 25ml with distilled water. After 15

min readings were observed in spectrophotometer at 730 nm. Standards of 0, 1, 2, 3, 4, 5 ppm were also prepared. A blank was also carried out. Calibration curve was plotted using daily prepared standard solutions.

Calculation

$$\text{Available P (kg/ha)} = \frac{R \times \text{Volume of extractant} \times 2.24 \times 10^6}{\text{Volume of aliquot} \times 2.24 \times \text{wt. of soil}}$$

Where, R = $\mu\text{g P}$ in the aliquot (obtained from standard curve).

3.7.10 Available potassium in soil

Available potassium in soil samples was measured on Flame photometer (**Schollenberger and Simon, 1945**), and the soil samples were extracted using neutral normal ammonium acetate. A 100 ml conical flask 5 g soil sample and 25ml of 1N neutral normal ammonium acetate was shaken on a mechanical shaker for 5 minutes. The suspension was then filtered immediately by using Whatman No. 1 filter paper. The concentration of potassium in the filtrate was measured on a flame photometer. A standard of 0, 20 and 40 ppm were prepared from 1000ppm of KCl solution. First, the standard reading was taken, followed by a sample reading.

$$\text{Dilution factor} = 25/5 = 5 \text{ times}$$

$$\begin{aligned} \text{Reading of the flame photometer for the test sample} &= \text{C Available Potassium (kg/ha)} \\ &= C \times 5 \times 2.24 \end{aligned}$$

3.7.11 Available sulphur in soil

The 0.15 % extractable available S (**Williams and Steinbergs, 1959**) was determined by turbidity method of **Chesnin and Yein, (1951)**. The aliquot was prepared from the extract, and barium chloride and gum acacia solution were added. Turbidity produced by barium sulphate was measured on a spectrometer at 340 nm,

and the readings were noted. Standards of 0.25, 0.5, 1.0, 2.5, and 5.0 were also prepared from 100 ppm A.R grade K_2SO_4 .

3.8 Crop residues analysis

The collected crop residues were dried in an oven at 70°C for 48 hours for chemical estimation and was ground with the help of grinder and passed through 40 mesh sieve and preserved separately for determination of total C, N, P, K and S content.

3.8.1 Digestion of crop residues

For nutrients other than N, the crop residues were digested using a mixture of HNO_3 : H_2SO_4 : $HClO_4$ in the ratio of 9:4:1 in a di-acid or tri-acid. The tri-acid digestion was used for estimation of P and K whereas sulphur was estimated after di-acid digestion using the mixture of HNO_3 : $HClO_4$ in the ratio of 9:1.

3.8.2 Total carbon content

The crop residues were dried at 70°C and the carbon analysis was done by combustion analysis on the C N Elemental Analyzer in lab of ISSS, Bhopal.

3.8.3 Total nitrogen content

Total nitrogen in crop residues is determined by Kjeldahl method as described by Jackson (1973). The essentiality involves (1) digestion of sample to convert the N compounds in the sample to the NH_4^+ from (2) determination of NH_4^+ in the digest in lab of IISS, Bhopal.

3.8.4 Total phosphorus content

Total phosphorus of the crop residues was determined using the methods Vandomolybdo phosphoric acid yellow color method as suggested by Jackson (1973).

Table 3.6 Soil and Plant test parameters

S.No.	Test Parameter	Method Used	References
Soil Test Parameters			
1	pH	Potentiometric titration method	Jackson, 1967
2	EC	Conductometric titration method	Jackson, 1967
3	Mechanical Composition	Bouyoucos hydrometer method	Bouyoucos, 1927
4	Water holding capacity	Keen's box method	Black, 1965
5	CO ₂ evolution	NaOH absorption method	Page et al., 1982
6	Water soluble carbon	Potassium dichromate method	Kalbitz et al., 2000
7	Available N	Alkaline potassium permanganate method	Subbiah and Asija, 1956
8	Available P	Olsen's method	Olsen et al., 1954
9	Available K	Neutral normal ammonium acetate method	Hanway and Heidel, 1952
10	Available S	0.15% CaCl ₂ extractable S method	Williams and Steinbergs, 1959
Plant Test Parameters			
1	Total Carbon	C N Elemental Analyzer method	
2	Total Nitrogen	Kjeldahl method	Jackson, 1973
3	Total Phosphorous	Vandomolybdo method	Jackson, 1973
4	Total Potassium	Flamephotometer method	Jackson, 1973
5	Total Sulphur	Turbidometric method	Chesnin and Yein, 1951

3.8.5 Total potassium content

Potassium content in the acid digest of crop residue was determined using flamephotometer exactly as the same manner as described (Jackson 1973) for available K in soil.

3.8.6 Total sulphur content

A 10 ml aliquot from crop residues digest ($\text{HNO}_3\text{:HClO}_4$; 9:4) was transferred into 50 ml volumetric flask, add 10 ml of BaCl_2 gelaine reagent and swirl the flask for a few second to mix the content. After 40 minutes the resulting mixture was measured its turbidity with spectrophotometer at 420 nm wave length (Chesnin and Yein, 1951).

3.9 Statistical analysis

The data were analyzed as per the standard procedure for “Analysis of Variance” (ANOVA) as described by Gomez and Gomez (1984). The significance of treatments was tested by “F” test (Variance ratio). Standard error of mean was computed in all cases. The difference in the treatment mean was tested by using Critical Differences (CD) at 5% level of probability.



RESULTS AND DISCUSSION

The present investigation entitled “**Decomposition of wide C: N ratio crop residues on the release of active carbon pool and available nutrients in Inceptisols of Varanasi**” was conducted in the Soil Health and Plant Nutrition laboratory, Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University. The main motto of this study was to investigate the soil CO₂ release pattern, variations in active carbon pool as well as release pattern of major nutrients like available nitrogen, available phosphorus, available potassium and available sulphur of added crop residues in the soil under incubation study. The release of available N, P, K and S with addition of crop residues in different treatment conditions was recorded at various interval of time. The data which was generated during the course of investigation was statistically analyzed for drawing the valid conclusions. In this chapter, the results of present study are described and discussed.

4.1 Chemical composition of wheat and rice residues

The analyzed value of total carbon, total nitrogen, total phosphorous, total potassium and total sulphur contents of the wheat and rice residues used along with their ratios to carbon are given in the table 4.1.

Table 4.1 Characterization of crop residues for total C, N, P, K and S contents and their ratios.

Crop residue	Total C (%)	Total N (%)	Total P (%)	Total K (%)	Total S (%)	C:N ratio	C:P ratio	C:K ratio	C:S ratio
Rice	47.67	0.49	0.18	1.51	0.12	97.29	264.0	31.56	397.25
Wheat	53.67	0.58	0.21	1.21	0.14	92.93	255.6	44.35	283.35

4.2 Characterization of wheat and rice residues for total C, N, P, K and S contents

The carbon content was higher in wheat residue i.e. 53.67 percent as compared to rice residue which was 47.67 percent. The rice residue had a lower total N content i.e. 0.49 percent as compared to wheat residue which was 0.58 percent. Wheat residue showed a total P content of 0.21 percent while rice residue showed 0.18 percent. A minimum total K content was recorded in wheat residue (1.21 percent) as compared to rice (1.51 percent). Wheat residue showed a total sulphur content of 0.14 percent while rice residue showed 0.12 percent. After the analysis, it was found that rice residues has a higher C: N ratio as compared to wheat residues and their values are 97.29 and 92.93, respectively. The C: P and C: S value was higher for rice residue whereas C: K values were higher for wheat residue.

Microorganisms can first immobilize nutrients (N, P, S) when crop residues with a wide range of carbon to nutrient ratios are added to soil (Salas *et al.* 2003; Wu *et al.* 1993). Microbial immobilization of nutrients can reduce nutrient availability to plants temporarily by storing large amounts in slowly accessible organic forms, limiting nutrient losses caused by leaching of mobile nutrients (nitrate and sulphate), volatilization of nitrogen (Williamson and Johnson, 1994) or soil phosphate fixation

4.3 Release of CO₂-C during decomposition of wheat and rice residue in soil

Results showed that control soil (without any crop residue) released a maximum of 3.94 mg CO₂-C per 100 g per day compared to its initial value, indicating a substantial release of CO₂-C (Table 4.2 and Fig. 4.1). Among the crop residues added, rice residue had significantly higher CO₂ – C release than that of the wheat residue. The maximum release from this crop residue with various treatments varied from 6.07 to 7.44 mg per 100 g per day. It was seen that, the treatment T₉ i.e. rice residues, along with urea and *Trichoderma* at 90 days released the highest CO₂ – C which was 7.44 mg per 100 g per day. At 15 days incubation, the least release of CO₂ – C varied from 1.48 mg per 100 g per day in the control to 4.46 mg per 100 g per day.

After addition of crop residues in soil, the process of decomposition begins leading to the breakdown of organic matter and the final product is CO₂ and humus. Addition of wide C: N ratio crop residues to soil leads to release of more CO₂. Between the two residues i.e. wheat and rice residues, rice residue of having a wide C: N ratio releases more CO₂ compared to wheat residue. This may probably be due to low content of total organic carbon.

4.4 Release of CO₂ during decomposition of wheat and rice residue in soil

The value of data regarding release of CO₂ in alluvial soil (Inceptisols) as influenced by addition of wide C: N ratio crop residues along with various treatments are presented in table 4.3 and figure 4.2. It has been clearly seen from the data that CO₂ release pattern follows an increasing trend with an increasing incubation period. Maximum release was seen with rice residue, when it was treated with urea and *Trichoderma* i.e. 204.70 mg CO₂. A critical perusal of the data shows that there has been a significant release of CO₂ from each rice residue treatment compared to its respective wheat residue treatment. At an interval of 15 days the least release of 40.70 mg was recorded in the control. At each interval, the CO₂ release was lowest in control 40.70mg to a mean value of 106.41 mg.

Table 4.2 Decomposition of wheat and rice residues in soil on evolution of CO₂-C.

Treatments	CO ₂ -C (mg per 100 g per day) Incubation Period (Days)						Mean
	15	30	45	60	75	90	
T ₁ - Control	1.48	4.40	4.42	4.43	4.45	4.46	3.94
T ₂ – Wheat	2.88	5.50	6.00	7.12	7.21	7.76	6.07
T ₃ – Rice	3.44	6.03	6.42	7.36	7.42	7.88	6.42
T ₄ – Wheat + Urea	3.20	5.85	6.21	7.25	7.56	7.68	6.29
T ₅ - Rice + Urea	3.60	6.32	6.68	7.42	7.87	7.96	6.64
T ₆ - Wheat + <i>Trichoderma</i>	3.76	6.41	6.65	7.45	7.91	7.99	6.69
T ₇ - Rice + <i>Trichoderma</i>	4.00	6.56	7.00	8.31	8.78	8.82	7.20
T ₈ -Wheat + Urea + <i>Trichoderma</i>	4.12	6.84	7.04	7.97	8.44	8.57	7.16
T ₉ – Rice + Urea + <i>Trichoderma</i>	4.22	6.90	7.13	8.52	8.91	8.97	7.44
Mean	3.41	6.09	6.39	7.31	7.61	7.78	
SEM ±	0.04	0.05	0.13	0.03	0.04	0.05	
CD (P=0.05)	0.12	0.15	0.41	0.11	0.14	0.13	

Table 4.3 Decomposition of wheat and rice residues in soil on evolution of CO₂.

Treatments	CO ₂ (mg) Incubation Period (Days)						Mean
	15	30	45	60	75	90	
T ₁ - Control	40.70	104.50	115.05	121.00	127.00	130.25	106.41
T ₂ - Wheat	79.20	165.30	181.50	194.15	203.50	213.40	172.84
T ₃ - Rice	94.60	176.05	183.60	215.30	218.95	220.35	184.80
T ₄ – Wheat + Urea	88.00	171.80	185.65	202.56	210.87	219.75	179.78
T ₅ - Rice + Urea	99.00	184.25	189.98	220.25	225.45	234.45	192.23
T ₆ - Wheat + <i>Trichoderma</i>	103.45	181.25	187.55	210.15	217.75	224.50	187.44
T ₇ - Rice + <i>Trichoderma</i>	110.25	192.55	191.25	225.85	230.45	237.80	198.02
T ₈ -Wheat + Urea + <i>Trichoderma</i>	112.15	183.15	191.25	213.35	220.15	225.45	190.91
T ₉ – Rice + Urea + <i>Trichoderma</i>	118.65	195.75	199.65	235.65	237.35	241.15	204.70
Mean	94	172.74	180.60	204.25	210.16	216.34	
SEM ±	0.40	0.35	0.56	0.42	0.27	0.55	
CD (P=0.05)	1.32	1.15	1.66	1.38	0.98	1.58	

Fig. 4.1 Release of net CO₂-C (mg/100g/day) amended with wheat and rice residues

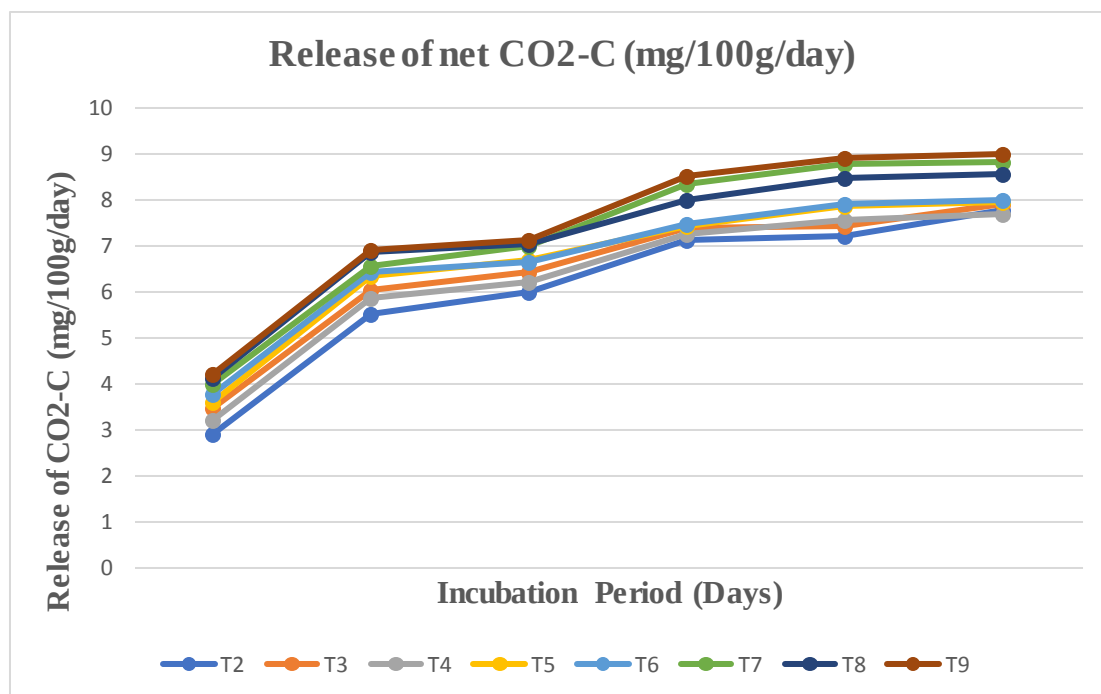
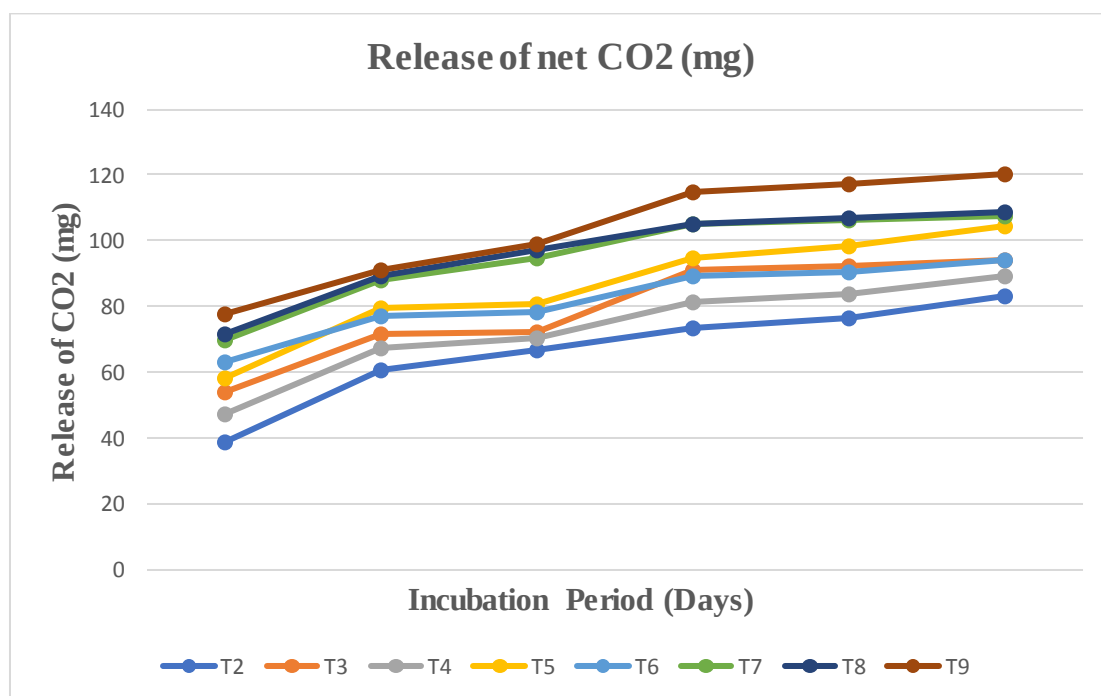


Fig. 4.2 Release of net CO₂ (mg) amended with wheat and rice residues



4.5 Release of Water soluble carbon in soil

The value of data regarding release of water soluble carbon from decomposition of crop residues along with various treatment measures at different period of incubation in the Inceptisols of Varanasi has been depicted in table 4.4 and fig. 4.3. From the data given in the table 4.4, release of water soluble carbon follows a decreasing trend, it was highest for the control at an incubation period of 15 days i.e. 459.75 ($\mu\text{g/g}$) and was lowest for treatment T8 i.e. wheat residue along with urea and *Trichoderma* at an incubation period of 90 days which was 234.90 ($\mu\text{g/g}$). The mean indicates that control has the highest mean value as compared to other treatments, showing the lowest mean value. The higher water soluble carbon value was associated with rice residue as compared to wheat residue among the treatments. Mean available water soluble carbon released with varying from 369.34 ($\mu\text{g/g}$) to 317.18 ($\mu\text{g/g}$).

Analysis of water soluble carbon in both the crop residues followed a decreasing trend with an increase of incubation period, the reason to this is the decrement of C: N ratio with an increment of time because of mineralization (Bending and Turner, 1999).

4.6 Release of available nitrogen in soil

The value of data regarding release of available nitrogen from decomposition of crop residues along with various treatment measures, at different period of incubation has been depicted in table 4.5 and fig. 4.4. It can be stated from the result that control soil which do not contain any residues, released available nitrogen at a mean value of 273.90 kg ha^{-1} . The available nitrogen release from wheat residue was more when compared to rice residue, with any of the treatment. At 15 days of incubation the highest available nitrogen was released was from wheat residue treated with urea, followed by treated with urea and *Trichoderma*. It was found that at 90 days of incubation, wheat residue along with urea and *Trichoderma* released the highest amount of available Nitrogen i.e. 425.45 kg ha^{-1} as compared to any other treatment, followed by the treatment of wheat and urea.

When crop residues are introduced to the soil, microbes begin to degrade them. Immobilization and mineralization are the two processes at work. Microbial populations increase quickly after fresh plant remains are added. If the C/N ratio of the plant material is more than 25, the microbial population will breakdown the residue using available soil nitrogen. Nitrogen immobilization is the term for this process. The microbial population will release additional accessible nitrogen if the C/N ratio of fresh plant materials is less than 25. When large C/N ratio residues are added, they frequently cause a net immobilization phase followed by a net re-mineralization phase. Mineralization of N from narrow C: N crop residue happens only after 50-60% of the residues have been degraded or the C/N ratio has dropped below 30 (Christensen, 1986). Incorporation of low-nitrogen residues, such as rice and wheat, may result in soil microbial immobilization.

The quantity of N mineralized or immobilized during decomposition determines the amount of N available from crop wastes. However, environmental factors such as temperature and soil moisture, as well as the biochemical composition of plant materials and their interaction, influence nutrient release rates of residues (Abiven *et al.* 2005; Khalil *et al.* 2005). Microbial degradation of wide C: N ratio crops releases nitrogen more slowly because it is mostly organically bound in the form of proteins.

The results showed that the release of accessible nitrogen was reduced from 15 to 45 days of incubation and thereafter increased. Our findings indicated that released mineral nitrogen could be locked up in the soil over time by microbial immobilization or adsorption on soil minerals. At 45 days of incubation period the decrease in available nitrogen was found to be more with crop residues when it was treated with *Trichoderma*, as additional microbes could have utilized more Nitrogen, whereas the least decrease in available nitrogen was with crop residues and urea, perhaps it may be due to the addition of nitrogen by urea hydrolysis. At 90 days of incubation period it was seen that wheat residues treated with urea and *Trichoderma* released the most available nitrogen followed by corresponding treatment with the rice crop residues, this may be due to the later has a wider C: N ratio than the former. Through the turn-

over of microbial biomass over time, nutrients trapped by the microbial biomass can boost the nutrient providing capability of soil (Singh *et al.* 1989). Due to the production of resistant organic N forms, crop residues with high lignin (and/or poly phenol) content at wide C: N ratios may interact with soil or plant residue N, reducing N availability (Wang *et al.* 2004a). Mineralization takes a long time for non-legume crop residues with a high C: N ratio and/or lignin concentration.

Table 4.4 Decomposition of wheat and rice residues on water soluble carbon content in soil

Treatments	Water soluble carbon (µg/g) Incubation Period (Days)						Mean
	15	30	45	60	75	90	
T ₁ - Control	459.75	439.50	398.20	345.40	297.30	275.90	369.34
T ₂ - Wheat	423.00	382.35	355.20	324.40	298.10	265.70	341.45
T ₃ - Rice	445.00	395.40	378.6	355.90	305.80	297.10	362.96
T ₄ – Wheat + Urea	418.00	364.40	348.70	318.20	287.40	257.90	332.43
T ₅ - Rice + Urea	439.00	382.20	365.90	347.90	296.20	288.30	353.25
T ₆ - Wheat + <i>Trichoderma</i>	402.00	351.60	328.10	304.70	269.40	247.30	317.18
T ₇ - Rice + <i>Trichoderma</i>	410.00	372.40	351.10	338.50	276.00	249.5	332.91
T ₈ -Wheat + Urea + <i>Trichoderma</i>	397.00	341.40	314.90	284.30	251.60	234.90	304.01
T ₉ – Rice + Urea + <i>Trichoderma</i>	399.00	365.10	336.40	297.60	266.30	241.50	317.65
Mean	421.41	377.15	353.01	324.10	283.12	262.01	
SEM ±	0.30	0.27	0.24	0.35	0.42	0.29	
CD (P=0.05)	0.81	0.77	0.72	0.85	0.94	0.79	

Table 4.5 Decomposition of wheat and rice residues on the release of available nitrogen in soil

Treatments	Available nitrogen (kg ha ⁻¹) Incubation Period (Days)						Mean
	15	30	45	60	75	90	
T ₁ - Control	275.97	250.88	251.00	263.42	288.51	313.60	273.90
T ₂ - Wheat	278.00	238.34	263.42	326.15	363.78	413.95	313.94
T ₃ - Rice	276.00	225.79	250.88	301.06	351.23	376.32	296.88
T ₄ – Wheat + Urea	301.06	243.25	270.34	331.25	371.24	415.00	322.02
T ₅ - Rice + Urea	288.51	231.56	257.79	315.4	368.58	398.78	310.10
T ₆ - Wheat + <i>Trichoderma</i>	270.51	234.65	256.15	314.85	345.65	402.45	304.04
T ₇ - Rice + <i>Trichoderma</i>	265.15	218.15	238.45	287.56	340.24	362.32	285.31
T ₈ -Wheat + Urea + <i>Trichoderma</i>	298.24	238.34	264.25	332.45	385.56	425.45	324.04
T ₉ – Rice + Urea + <i>Trichoderma</i>	278.26	225.56	248.36	325.56	372.45	411.86	310.35
Mean	281.30	234.05	255.62	310.86	354.13	391.08	
SEM ±	0.38	0.51	0.49	0.46	0.37	0.42	
CD (P=0.05)	1.26	1.53	1.48	1.41	1.24	1.34	

Fig. 4.3 Release of net water soluble carbon ($\mu\text{g/g}$) amended with wheat and rice residues.

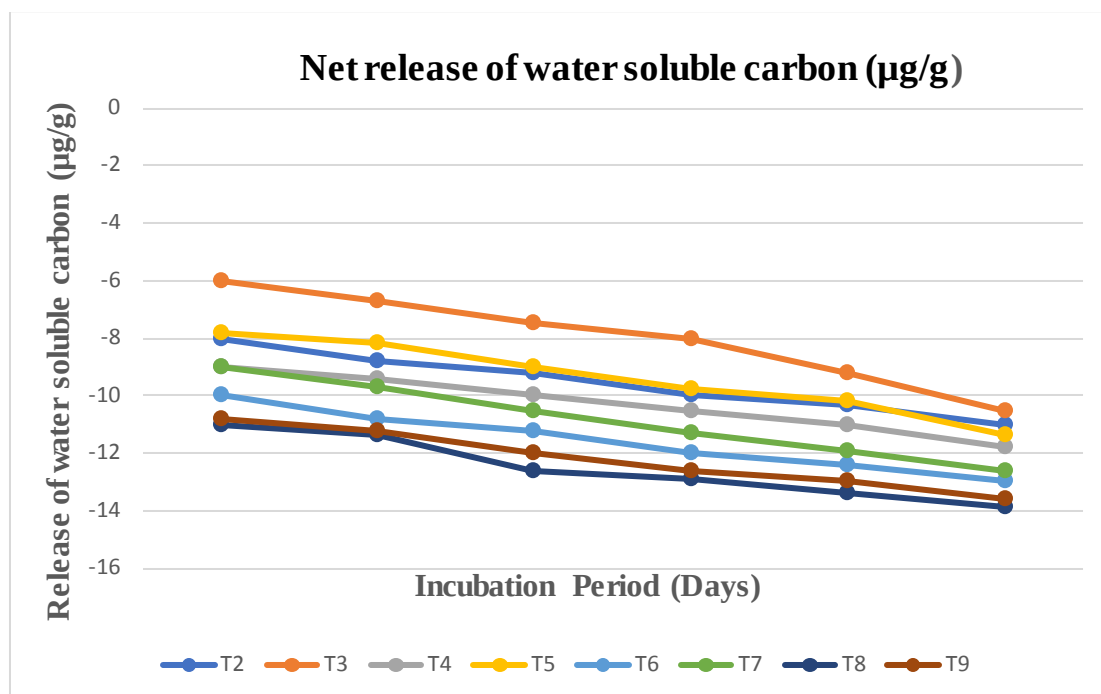
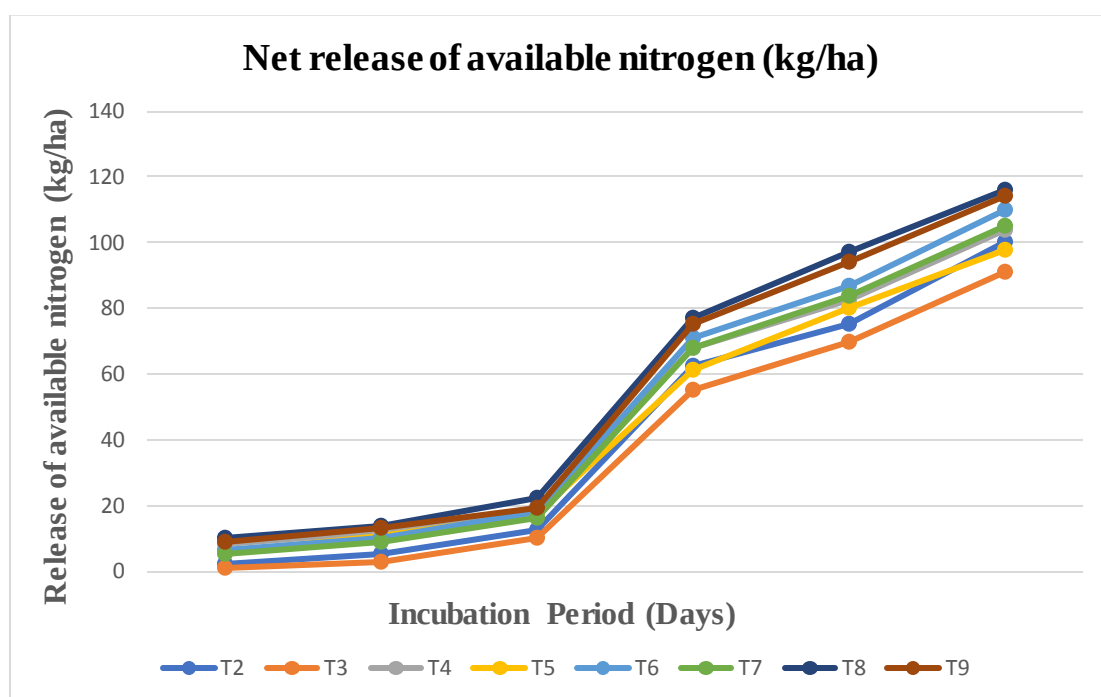


Fig. 4.4 Release of net available nitrogen (kg ha^{-1}) amended with wheat and rice residues.



4.7 Release of available phosphorus in soil

The value of data regarding release of available phosphorus from decomposition of crop residues along with various treatment measures, at different period of incubation in the Inceptisols of Varanasi has been depicted in table 4.6 and fig. 4.5. It can be clearly stated from the data that the release of available phosphorus was increased up to 45 days in a slow pace and there after it was released rapidly in the last days of incubation at up to 90 days. By comparing the mean, it is observed that highest available Phosphorus release was associated with wheat –urea-*Trichoderma* treatment i.e. 19.54 kg ha⁻¹ followed by rice residue –urea-*Trichoderma* treatment i.e. 19.27 kg ha⁻¹. At 15 days of incubation, control has the lowest rate of release of available phosphorus i.e. 16.76 kg ha⁻¹, followed by rice residue (17.10 kg ha⁻¹). And at the same time the highest release was obtained from wheat –urea-*Trichoderma* treatment i.e. 19.01 kg ha⁻¹ followed by rice residue –urea-*Trichoderma* treatment i.e. 18.55kg ha⁻¹. At 90 days of incubation, control has the lowest rate of available phosphorus release i.e. 19.62 kg ha⁻¹, followed by rice residues (19.64 kg ha⁻¹). And at the same time, the highest release was associated from wheat –urea-*Trichoderma* treatment i.e. 20.80 kg ha⁻¹ followed by rice residue –urea-*Trichoderma* treatment i.e. 20.23kg ha⁻¹.

Until the residue decomposes, the plant phosphate ions are protected from soil fixation. Microbial activity in the soil regulates decomposition (Cunningham and Martin, 1973), which is influenced by the release of energetic organic molecules. Furthermore, organic phosphorus can be mineralized via phosphate (Jugk and Tardar, 1987) or phytase (Matheson and Strother, 1969) enzyme activity. The release of phosphorus was high from the wheat crop residue as compared to rice residue with any of the corresponding treatments, the reason for this is due to the high C: P ratio of rice as compared to wheat. It's possible that the slow release of P from additional grain residues is due to P immobilization by microorganisms with a high C: P ratio.

During the decomposition of rice straw, P content increased from 0.10 to 0.195 % with time (Mishra *et al.* 2001b). In about 5 weeks of incubation 22.5% of total P present in the rice straw was released and at 23 weeks of incubation 59.4% of

total P present in the rice straw was released. The substantial variance in orthophosphate concentrations among residues appeared to be connected to total P concentrations; crop residues with higher total P concentrations had a higher proportion of orthophosphate present. If the P in the residue is mineralized, it is first released as orthophosphate or other organic forms (Noack *et al.* 2012) with phospholipids and RNA accounting for 10-40% and 5-30% of the total, respectively (Noack *et al.* 2012). As a result, when these agricultural leftovers decompose, the bulk of the P will be released in bioavailable forms in the soil, where it can be taken up by plants or immobilized by microorganisms.

It is well known that P from residues will be mineralized below 200:1, while P from residues will be immobilized over 300:1. Plant wastes with low biochemical quality tend to decompose slowly due to phosphate immobilization during the early stages of decomposition (Baggie *et al.* 2005; Fosu *et al.* 2007). Higher C:N ratio slow down the process of decomposition and nutrient release by crop residues leading to a higher amount of nutrients concentration over a long period (Bauder *et al.* 2007; Fosu *et al.* 2007). The residue decomposes more quickly at first due to its high biological quality, but it slows down with time as refractory compounds accumulate (Baker *et al.* 2001; Jacob *et al.* 2010). Crops with greater total P concentrations will not return more P to the soil, but will return more P in the form of orthophosphate, which is more plant accessible (White and Ayoub, 1983).

4.8 Release of available potassium in soil

The data value regarding release of available potassium in Inceptisols as influenced by addition of crop residues along with various treatments being depicted in table 4.7 and fig. 4.6. A critical perusal of data revealed that the release of available potassium follows an increasing trend of release along with increasing in the incubation period. Comparing the mean, highest amount of available potassium was released from rice residue-urea-*Trichoderma* treatment i.e. 195.31 kg ha⁻¹ and the least was from control i.e. 179.6 kg ha⁻¹. A critical analysis of the data shows that the treatment rice residue-urea-*Trichoderma* has significant effect than that of rice residue-urea treatment at 15 days of incubation. From the data given in the table 4.7, it

can be stated that rice residue along with any of the treatment released more available potassium than the corresponding treatments with wheat residue.

Whitbread *et al.* (2000) had reported that the crop residues are rich source of potassium. The rate of release varies based on the amount of nutritional elements in the residue. When it comes to nutrient elements like potassium, where the majority of the element is found in the free ionic form in plant tissue, release from the residue occurs quickly after the plant dies. The rate of release of available K increased as the incubation period was extended up to 90 days. The release of available potassium was higher from the rice residue as compared to wheat residue along with various treatments perhaps which may be due to the higher C: K ratio of wheat than rice. Rice residue caused a higher release of K, which could be related to the high K level in rice residue. Because potassium is not bonded in any organic component in the plant, microbes are not involved in its release. According to Mishra *et al.* (2001b), the K content of rice straw reduced from 1.30 to 0.28 percent after decomposition. Within 5 weeks of its integration into the soil, almost 79 percent of the total K present in rice straw was released, and 95.3 percent of the K from straw was mineralized by the end of 23 weeks. The quick transfer of potassium from plant waste to other nutrients is a well-known phenomenon (Njunie *et al.* 2004).

Table 4.6 Decomposition of wheat and rice residues on the release of available phosphorus in soil

Treatments	Available phosphorus (kg ha ⁻¹) Incubation Period (Days)						Mean
	15	30	45	60	75	90	
T ₁ - Control	16.76	17.04	18.20	18.49	18.95	19.62	18.17
T ₂ - Wheat	17.91	18.37	18.55	19.06	19.47	20.05	18.9
T ₃ - Rice	17.10	17.28	18.26	18.60	19.30	19.64	18.36
T ₄ – Wheat + Urea	18.32	18.49	18.78	19.07	19.53	20.16	19.05
T ₅ - Rice + Urea	17.33	18.20	18.32	18.89	19.47	20.05	18.71
T ₆ - Wheat + <i>Trichoderma</i>	18.49	18.95	19.01	19.18	19.59	20.16	19.23
T ₇ - Rice + <i>Trichoderma</i>	18.03	18.46	18.95	19.05	19.41	19.99	18.99
T ₈ -Wheat + Urea + <i>Trichoderma</i>	19.01	19.07	19.12	19.30	19.93	20.80	19.54
T ₉ – Rice + Urea + <i>Trichoderma</i>	18.55	19.01	19.03	19.17	19.61	20.23	19.27
Mean	17.94	18.31	18.69	18.97	19.47	20.07	
SEM ±	0.04	0.08	0.03	0.11	0.14	0.16	
CD (P=0.05)	0.16	0.21	0.11	0.34	0.42	0.49	

Table 4.7 Decomposition of wheat and rice residues on release of available potassium in soil.

Treatments	Available potassium (kg ha ⁻¹) Incubation Period (Days)						Mean
	15	30	45	60	75	90	
T ₁ - Control	170.10	173.20	179.00	183.50	185.60	186.20	179.6
T ₂ - Wheat	186.70	189.80	192.50	194.20	197.10	198.60	193.15
T ₃ - Rice	187.70	190.30	193.10	195.40	197.60	199.40	193.91
T ₄ – Wheat + Urea	189.50	190.6	192.40	193.50	195.20	196.10	192.89
T ₅ - Rice + Urea	190.70	191.20	193.40	194.90	196.00	196.50	193.78
T ₆ - Wheat + <i>Trichoderma</i>	191.30	192.40	193.50	193.80	194.80	195.70	193.59
T ₇ - Rice + <i>Trichoderma</i>	191.90	192.90	194.00	194.60	195.60	196.30	194.21
T ₈ -Wheat + Urea + <i>Trichoderma</i>	192.35	193.60	194.70	195.10	196.00	196.80	194.75
T ₉ – Rice + Urea + <i>Trichoderma</i>	193.00	193.90	195.00	195.90	196.40	197.70	195.31
Mean	188.13	189.76	191.95	193.43	194.92	195.92	
SEM ±	0.52	0.55	0.65	0.59	0.40	0.60	
CD (P=0.05)	1.55	1.61	1.86	1.72	1.42	1.79	

Fig. 4.5 Net release of available phosphorus (kg ha^{-1}) amended with wheat and rice residues

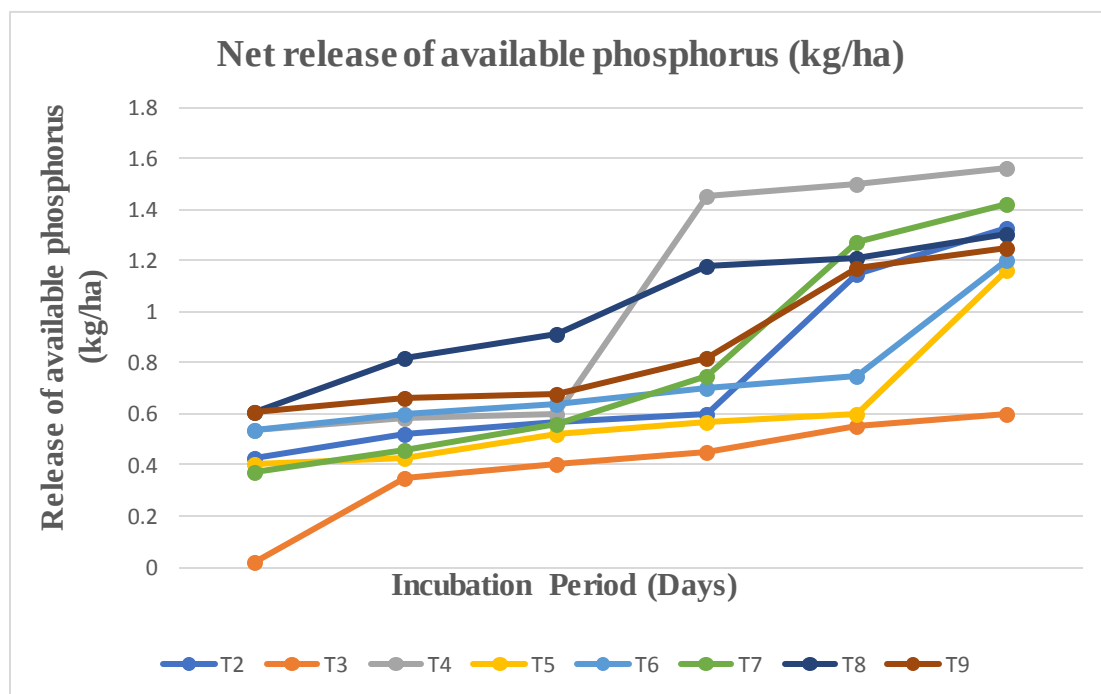
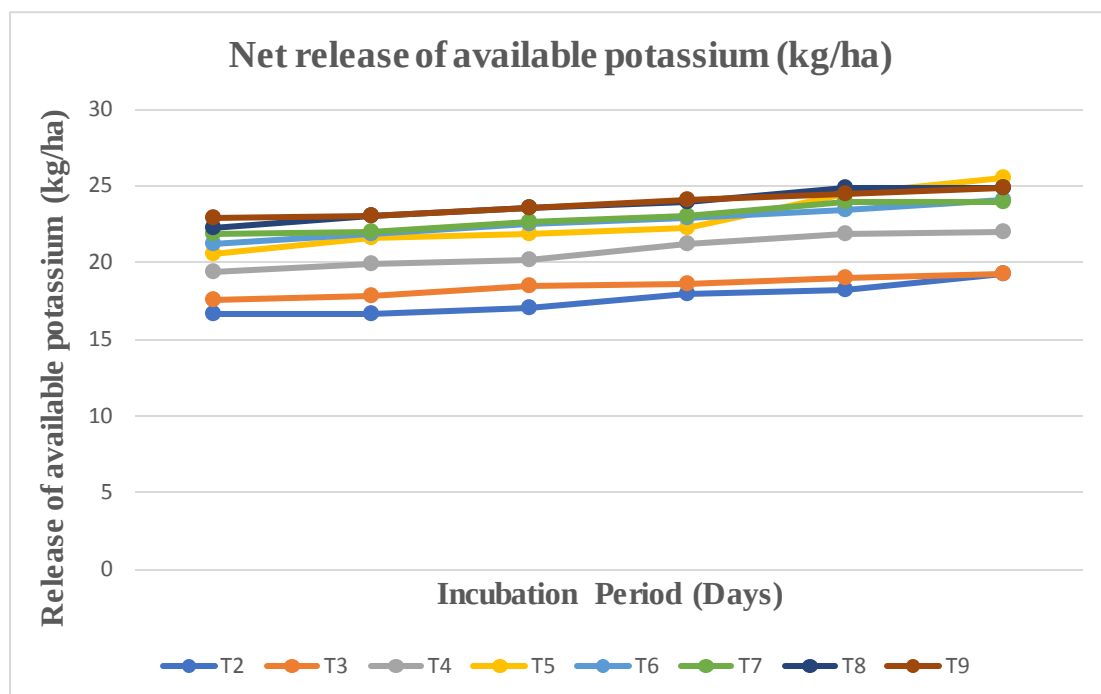


Fig. 4.6 Net release of available potassium (kg ha^{-1}) amended with wheat and rice residues.



4.9 Release of available Sulphur in soil

Addition of crop residues along with various treatments showed a significant effect on release of available sulphur in Inceptisols of Varanasi incubated at different days, are shown in table 4.8 and fig 4.7. At 15 days of incubation, lowest rate of available S was released as compared to any other incubation periods. The mean value of control was 20.61 kg ha⁻¹. The mean value for the treatments ranged from 20.61 to 23.67 kg ha⁻¹. Comparing the mean value, it was observed that wheat residue-urea-*Trichoderma* had the highest available S release i.e. 23.67 kg ha⁻¹. At 45 days of incubation wheat residue-urea-*Trichoderma* showed a significant effect from wheat residue treated alone.

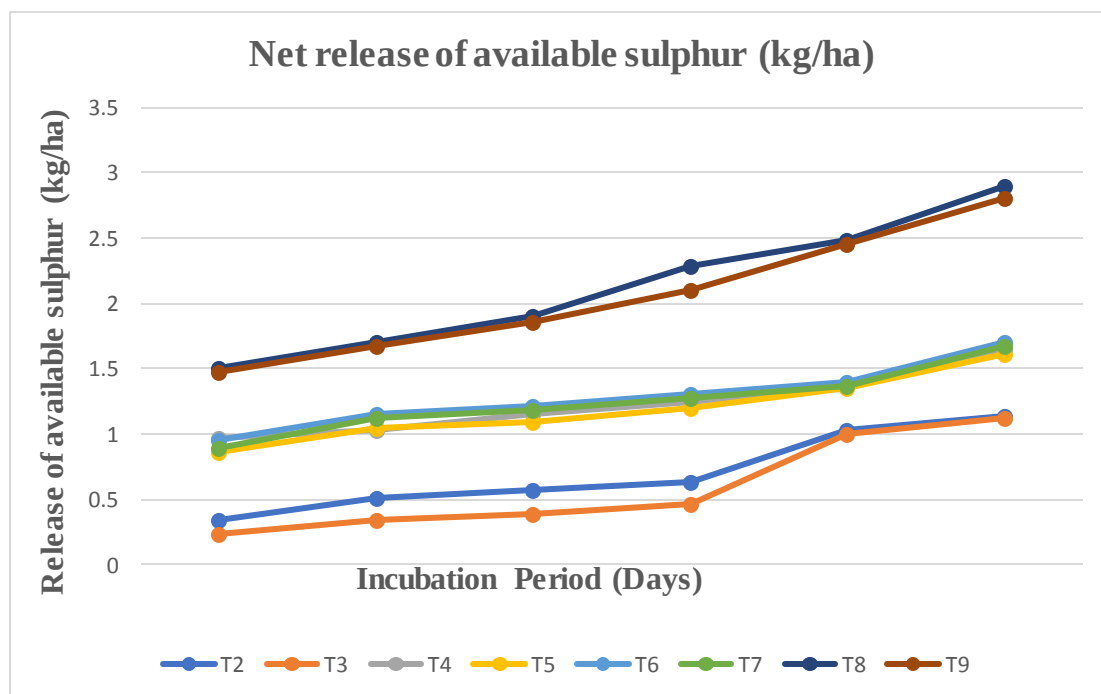
Some plant nutrients in soluble inorganic form (SO₄²⁻) or linked with readily mineralisable organic elements (viz. amino and protein-bound S) may be found in crop wastes (Salas *et al.* 2003; Wu *et al.* 1993). When crop residues are returned to the soil, sulphur is easily liberated, mineralized, and immobilised in microbial biomass. The release of available sulphur increased when the incubation period was extended up to 90 days. Available S concentration rises with incubation, possibly due to microbial conversion of organic S to inorganic S form, and falls in later stages, possibly due to soil immobilisation or fixation.

Nutrients released into the soil from agricultural wastes that are not easily immobilised by microbes or taken up by plants may become unavailable due to fixation on soil particles or loss through leaching, volatilization, and/or soil erosion. Wheat residue and rice residue, for example, had a high C: S ratio, which resulted in significant S immobilisation during the early phases of decomposition (Somani and Saxena, 1975). The addition of wheat straw with a low C: S ratio (100:1) resulted in much more sulphate-S buildup than the control (Islam and Dick, 1998b). The total amount of C mineralized was proportional to the total amount of S mineralized. With the addition of agricultural leftovers, Singh and Sharma (2000) noticed a considerable increase in the availability of S in soil.

Table 4.8 Decomposition of wheat and rice residues on release of available sulphur in soil.

Treatments	Available sulphur (kg ha ⁻¹) Incubation Period (Days)						Mean
	15	30	45	60	75	90	
T ₁ - Control	19.43	20.00	20.51	20.86	21.20	21.66	20.61
T ₂ - Wheat	20.57	21.03	21.14	21.43	21.71	22.00	21.31
T ₃ - Rice	19.89	20.12	20.9	21.20	21.66	21.89	20.94
T ₄ – Wheat + Urea	21.08	21.37	21.71	22.11	22.29	22.63	21.86
T ₅ - Rice + Urea	20.11	20.74	21.20	21.43	22.06	22.34	21.31
T ₆ - Wheat + <i>Trichoderma</i>	21.20	21.66	22.89	23.10	23.34	25.80	23.00
T ₇ - Rice + <i>Trichoderma</i>	20.86	21.14	22.29	22.86	23.27	24.20	22.43
T ₈ -Wheat + Urea + <i>Trichoderma</i>	21.91	22.29	22.93	24.00	25.14	25.71	23.67
T ₉ – Rice + Urea + <i>Trichoderma</i>	21.31	22.00	22.86	23.77	24.00	24.86	23.13
Mean	20.70	21.15	21.82	22.30	22.74	23.45	
SEM ±	0.41	0.44	0.52	0.46	0.50	0.49	
CD (P=0.05)	1.23	1.32	1.57	1.38	1.51	1.48	

Fig. 4.7 Net release of available sulphur (kg ha^{-1}) amended with wheat and rice residues.



SUMMARY AND CONCLUSION

This chapter attempts to summarize the experiment as well as offer conclusions based on the major findings of the current inquiry, which is entitled **“Decomposition of wide C: N ratio crop residues on the release of active carbon pool and available nutrients in Inceptisols of Varanasi”**. The investigation was carried out in the year 2020-2021 in Soil Health and Plant Nutrition laboratory, Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University. The main purpose of this study was to investigate release pattern of active carbon pool and available nutrients in soil incorporated with wide C: N ratio crop residues in combination with urea and *Trichoderma*.

The bulk surface soil samples were collected from the “University farm” of the Institute of Agricultural Sciences located inside the BHU campus. Two wide C: N ratio residues i.e. rice straw and wheat straw were collected from the “University farm” of the Institute of Agricultural Sciences located inside the BHU campus. The residues were collected after harvest of crops during *Kharif* and *Rabi* seasons in the year 2020-2021. These residues were washed with running tap water and then with distilled water, dried at 65 °C for 48 hours, milled and then it was passed through 1 mm sieve. The crops sample were analyzed for total carbon (C), total nitrogen (N), total phosphorus (P), total potassium (K) and total sulphur (S).

One hundred and sixty two plastic bottles of 250 ml capacity were used for the incubation study and each filled with 50 g of processed air dry soil. Inside each incubation bottles, small test-tubes of 20 ml capacity was planted for carrying 1N NaOH inside it. After imposing the treatments, the soils were incubated at room temperature (30°C). Moisture content in the soil was maintained at the field capacity by addition of distilled water as and when required. The bottles were sealed tightly and incubated for 15, 30, 45, 60, 75 and 90 days at room temperature. After each

incubation period, the soil samples were drawn, air-dried, ground and analyzed for available N, P, K and S contents using standard methods. Under the incubation study, the following data on the assessment of active carbon pool and the release of available N, P, K, and S with added crops residue are summarized.

1. Sand, silt and clay content of the experimental soil was 50.2, 31.2 and 18.4 percent, respectively.
2. The pH and EC value of the soil sample were 7.65 and 0.5 dsm^{-1} , respectively.
3. The organic carbon content for the experimental soil was 3.8 kg ha^{-1} .
4. The available nitrogen content of the soil sample was $276.00 \text{ kg ha}^{-1}$.
5. The available phosphorus content for the experimental soil was 16.6 kg ha^{-1} .
6. The available potassium content of the soil sample was $168.80 \text{ kg ha}^{-1}$.
7. The available sulphur content of the experimental soil was 18.5 kg ha^{-1} .
8. The total C content was higher (53.67%) in wheat whereas for rice residue contain 47.67 percent of organic carbon.
9. The total nitrogen content in the rice and wheat residues were 0.49 and 0.58 percent, respectively.
10. Among the two wide C: N ratio crop residues used in this experiment, rice residue had a wider C: N ratio (97.29%) than that of wheat residue (92.93%).
11. An increasing trend on the release of $\text{CO}_2\text{-C}$ and CO_2 was seen with increasing in the incubation period. The highest release was obtained from the rice residue-urea- *Trichoderma* treatment i.e. $7.44 \text{ mg CO}_2\text{-C per 100 g per day}$ and 204.70 mg CO_2 .
12. A decreasing trend on the release of water soluble carbon was seen with an increase in the incubation period. At 90 days of incubation period, the control without any crop residue has the highest water soluble carbon content i.e. $275.90 \text{ }\mu\text{g/g}$.

13. Available N was released slowly, up to 45 days, with the integration of crop residues and other treatments, and then N release was rapid with 90 days of incubation period.
14. With crops residues along with various treatments of urea and *Trichoderma*, the release of soil available phosphorus was slowly up to 45 days and then increased rapidly beyond 45 days of incubation up to 90 days. At 45 days of incubation period, the highest release of available P was obtained from wheat along with urea and *Trichoderma* treatment followed by wheat along with *Trichoderma* treatment.
15. The release of soil available K increased with increasing incubation period upto 90 days. The rice residue-urea-*Trichoderma* treatment resulted the highest amount of available k i.e. $195.31 \text{ kg ha}^{-1}$. A close examination of the data revealed that crop residue, in combination with various urea and *Trichoderma* treatments, had a significant impact on the release of available K. The maximum release was obtained from rice residue as compared to wheat residue at any corresponding treatments.
16. The mean value of soil available S ranged from 20.61 kg ha^{-1} to 23.67 kg ha^{-1} . At 90 days of incubation period, wheat residue-urea-*Trichoderma* had the highest release of available S (25.71 kg ha^{-1}).
17. Highest amount of soil available nitrogen and phosphorus was released from added wheat residue in combination of various treatments of urea and *Trichoderma*, on the other hand, highest amount of soil available potassium was released from the added rice residue along with various treatments of urea and *Trichoderma*.

Conclusion

As a thumb rule, the higher the C: N ratio, the longer the substance takes to decompose, and vice versa. This has a direct correlation with the amount of nitrogen, phosphorus, potassium, and sulphur available in soils. With the advancement of incubation period, the release of carbon dioxide increases rapidly up to 45 days, there

after carbon dioxide is released slowly up 90 days. The result further revealed that wide C: N ratio crops such as rice and wheat, release soil available N, P, and S slowly during the first 45 days and then started to release rapidly as the incubation period progresses up to 90 days. With the addition of crop residues and a longer incubation period of up to 90 days, the release of available K might continue.

Addition of supplemental decomposers aids in higher release of available nutrients at a longer period of incubation but at the same time it may cause immobilization at a shorter incubation period. Higher amount of available nitrogen and available phosphorus was released from addition of wheat residue in Inceptisols of Varanasi. This study was conducted in the laboratory under perfect soil moisture and temperature conditions. It is recommended that addition of wheat and rice residue along with urea and supplemental decomposers (viz. *Trichoderma*) has the potential to increase content of available N, P, K, and S in Inceptisols of Varanasi. It requires validation under field condition at farmer's field of Varanasi.



BIBLIOGRAPHY

- Abro A.K., Tian X. (2012). Carbon dioxide emission from maize straw incubated with soil under various moisture and nitrogen levels. *Journal- Chemical Society of Pakistan*, 34: 22-27.
- Aita C., Giacomini S. J. (2003) Crop residue decomposition and nitrogen release in single and mixed cover crops. *Revista Brasileira de Ciência do Solo* 27, 601-612.
- Allaway, W.H. and Thompson, J.F. (1966) Sulphur in nutrition of plants and animals. *Soil Science* 101, 240-247.
- Allison F. E. (1973) '*Soil organic matter and its role in crop production.*' (Elsevier Scientific Publishing Company, Amsterdam, the Netherlands).
- Badanur, V. P., Poleshi, C. M. and Balchandra, K. N. (1990) Effect of organic matter on crop yield and physical and chemical properties of Vertisol. *Journal of the Indian Society of Soil Science* 38, 426-429.
- Baggie I., Rowell D. L., Robinson J. S., Warren G. P. (2005) Decomposition and phosphorus release from organic residues as affected by residue quality and added inorganic phosphorus. *Agroforestry Systems* 63, 125-131.
- Baldock, J. A. (2007). Composition and cycling of organic carbon in soil. *Nutrient Cycling in Terrestrial Ecosystems*, pp 1-35.
- Bending G. D., Turner M. K. (2004) Interaction of biochemical quality and particle size of crop residues and its effect on the microbial biomass and nitrogen dynamics following incorporation into soil. *Biology and Fertility of Soils* 29, 319-327.
- Berg B., Laskowski R. (2006). Litter Decomposition: A Guide to Carbon and Nutrient Turnover. *Adv Ecol Res*, 38: 448-450.
- Berg B., McClaugherty C. (2003). Plant Litter: Decomposition, Humus Formation, Carbon Sequestration. *Berlin: Springer*, 2: 78-84.
- Bertin C., Yang X. H., Weston L. A. (2003). The role of root exudates and allelochemicals in the rhizosphere. *Plant and Soil* 256, 67-83.
- Bolan N. S., Hedley M. J. (2003) *Role of carbon, nitrogen and sulfur cycles in soil acidification*. In 'Handbook of Soil Acidity'. (Ed. Rengel Z) pp. 29-55. (Marcel Dekker AG: NewYork, USA).

- Bosatta E., Staaf H. (1982). The control of Nitrogen turn-over in Forest litter. *Oikos*, 39: 143-151.
- Bouyoucos, G. J. (1927). The hydrometer as a new method for the mechanical analysis of soils. *Soil Sci.* 23: 343-353.
- Cayuela, M. L., Sinicco, T., and Mondini, V. (2009). Mineralization dynamics and biochemical properties during initial decomposition of plants and animal residues in soil. *Appl. Soil Ecol.* 48: 118-127.
- Chesin, L. and Yien, C. H. (1951). Turbidimetric determination of available sulfates. *Soil Science Society of America Proceedings*, 15: 149-151.
- Constantinides M., Fownes J. H. (1994). Nitrogen mineralization from leaves and residue of tropical plants: Relationship to nitrogen, lignin and soluble polyphenol concentrations. *Soil Biology and Biochemistry* 26, 49-55.
- Corbels M., O'Connel A. M., Grove T. S., Mendham D. S., Rance S. J. (2003). Nitrogen release from eucalypt leaves and legume residues as influenced by their biochemical quality and degree of contact with soil. *Plant and Soil* 250, 15-28.
- Das, D. K. (2019) *Introductory Soil Science*, Kalyani Publishers, Ludhiana, pp. 432-433
- Dijkstra F. A., Cheng W., Johnson D. W. (2006) Plant biomass influences rhizosphere priming effects on soil organic matter decomposition in two differently managed soils. *Soil Biology and Biochemistry* 38, 2519-2526.
- Dung T. V., Thu T. A., Long V. V., Chau T. D. (2022). Decomposition of rice straw residues and the emission of CO₂, CH₄ under paddy rice and crop rotation in the Vietnamese Mekong Delta region – A microcosm study. *Plant, Soil and Environment*, 68: 29–35.
- Eijsackers H., Zehnder A. J. B. (1990) Litter decomposition: A Russian matryoshka doll. *Biochemistry* 11, 153-170.
- Eldhuset T. (2005) Minor effects of nitrogen availability on organic-acid exudation from roots of young *Picea abies* plants. *Journal of Plant Nutrition and Soil Science* 168, 341-342.
- Epstein H. E., Burke I. C., Lauenroth W. K. (2002) Regional patterns of decomposition and primary production rates in the U.S. Great Plains *Ecological society of American* 83, 320-327
- Fatoma A. M., Rezig E. A., (2014). Decomposition and nutrient release pattern of wheat (*Triticum aestivum*) residues under different treatments in desert field

- conditions of Sudan. *International Journal Recycling Organic Waste Agriculture*, 3: 60-69.
- Field C. B., Raupach M. R. (2004). The global carbon cycle: Integrating humans, climate and natural world. *Advancing Earth and Space Science*, 7: 605-612.
- Friesen D. K., Blair G. J. (1988) A dual radiotracer study of transformations of organic, inorganic and plant residue phosphorus in soil in the presence and absence of plants. *Australian Journal of Soil Research* 26, 355-366.
- Fu S., Cheng W. (2004) Defoliation affects rhizosphere respiration and rhizosphere priming effect on decomposition of soil organic matter under a sunflower species: *Helianthus annuus*. *Plant and Soil* 263, 345-352.
- Gharmakher H. N., Piutti S., Machet J. M., Benizri E., Recous S. (2012). Mineralization-immobilization of sulphur in a soil during decomposition of plant residues of varied chemical composition and S content. *Plant and Soil*, 360: 391-404.
- Gottschalk J., Hodell D., Skinner L. C. (2012). Past carbonate preservation events in the deep southeast Atlantic Ocean and their implications for Atlantic overturning dynamics and marine carbon cycling. *Advancing Earth and Space Science*, 10: 645-662.
- Gupta R. K., Shukla A. K., Asharf M., Ahmed Z. U., Sinha R. K. P., Hobbs P. R. (2002). Options for establishment for rice and issues constraining its productivity and sustainability in eastern Gangetic plains of Bihar, Nepal and Bangladesh Rice-wheat consortium. *Travelling seminar report series*, 4 New Delhi, India.
- Harmon M. E., Sexton J., Caldwell B. A., Carpenter S. E. (1994). Fungal sporocarp mediated losses of Ca, Fe, K, Mg, Mn, N, P, and Zn from conifer logs in the early stages of decomposition. *Can J Forest Res*, 24: 1883-1893 .
- Havlin, J. L. and Soltanpour, P. N. (1980) A nitric acid plant digest method for use with inductively coupled plasma spectrometry. *Communications in Soil Science and Plant Analysis* 11, 969-980.
- Heal O. W., Anderson J. M. (1997). Plant litter quality and decomposition: An historical overview. In: Cadisch G., Giller K. E. editors. *Driven by nature: plant litter quality and decomposition*. *CAB International*, 55: 79-92.
- Herman W. A., McGill W. B., Dormaar J. F. (1977) Effects of initial chemical composition on decomposition of roots of three grass species. *Canadian Journal of Soil Science* 57, 205-215.

- Hill P. W., Jones D. L., Marshal C., Farrar J. F. (2006). Temporal and spatial dynamics of soil solution C and N concentrations during *Lolium perrene* establishment and the effect of elevated CO₂ and N additions. *Soil Biol Biochem*, 38: 1290-1297.
- Hobbie S. E. (1996) Temperature and plant species control over litter decomposition in Alaskan tundra. *Ecological Society of America*, 66, 503-522.
- Hu S., Tu C., Chen X., Gruver J. B. (2006) Progressive N limitation of plant response to elevated CO₂: A microbiological perspective. *Plant and Soil* 289, 47-58.
- Hueso- Gonzalez, P., Martinez-Murillo, J. F., and Ruiz-Sinoga, J. D. (2014). The impact of organic amendments on forest soils properties under Mediterranean climatic condition, *Land Degrad. Dev.*, 25: 604-612.
- Islam, M. M. and Dick, R. P. (1998) Effect of wheat straw carbon:sulphur ratio on mineralization of sulphur in soils under simulated laboratory aerobic-flooding cycles. *Communications in Soil Science and Plant Analysis* 29, 983-995.
- Jackson, M. L. (1971) *Soil Chemical Analysis*. Prentice Hall International Inc., Englewood Cliffs.
- Jackson, M. L. (1971) *Soil Chemical Analysis*. Prentice Hall of India Pvt. Ltd., New Delhi.
- Jain, Niveta., Bhatia, Arti and Pathak, Himanshu (2014). Emission of air pollutants from crop residues burning in India. *Aerosol and Air Quality Research*, 14: 422-430.
- Jansson, S. L., and Persson, J., (1982). *Mineralization and immobilization of soil nitrogen*, in : *Nitrogen in agricultural soils*, edited by: Stevenson, F.J., ASA, SSSA Special Publication No. 22: 229-252.
- Jensen E. S. (1997) Nitrogen immobilization and mineralization during initial decomposition of XSN-labelled pea and barley residues. *Biology and Fertility of Soils* 24, 39-44.
- Kachaka S., Vanlauwe B., Merckx R. (1993) Decomposition and nutrient mineralization of prunings of different quality. In '*Soil organic matter dynamics and sustainability of tropical agriculture*'. (Eds Mulongoy K, Merckx R). (IITA/K.U: Leuven, Belgium).
- Kachroo, D., Dixit, A. K. and Bhat, A. K. (2006) Decomposition of various residues and their nitrogen release pattern under Alfisols of Jammu region. *Journal of the Indian Society of Soil Science* 54, 342-344.

- Kandeler E., Marschner P., Tscherko D., Gahoonia T. S., Nielsen N. E. (2002) Microbial community composition and functional diversity in the rhizosphere of maize. *Plant and Soil* 238, 301-312.
- Kuzyakov Y. (2002) Factors affecting rhizosphere priming effects. *Journal of Plant Nutrition and Soil Science* 165, 382-396.
- Kuzyakov Y., Friedel J. K., Stahr K. (2000) Review of mechanisms and quantification of priming effects. *Soil Biology and Biochemistry* 32, 1485-1498.
- Kuzyakov Y., Hill P. W., Jones D. L. (2007) Root exudate components change litter decomposition in a simulated rhizosphere depending on temperature. *Plant and Soil* 290, 293–305.
- Kwabiah A. B., Palm C. A., Stoskopf N. C., Voroney R. P. (2003) Response of soil microbial biomass dynamics to quality of plant materials with emphasis on P availability. *Soil Biology and Biochemistry* 35, 207-216.
- Lal R. (1994). Sustainable land use system and land resilience. In: Greenland DJ, Szaboles I (eds) *Soil resilience and sustainable land use*. CAB International, Wallingford, pp 41-46.
- Laskowski, R., Berg, B. (2006). Litter decomposition- A guide to carbon and nutrient turnover. *Advances in Ecological Research*. 38: 251-258.
- Liski, J., Morgan, S. (2002). Influence of substrate quality and moisture availability on microbial communities and litter decomposition. [*Open Journal of Ecology*, 4\(8\): 114-118.](#)
- Lupwayi N. Z., Clayton G. W., Donovan G. T., Harker K. N., Turkington T. K., Soon Y. K. (2005). Potassium release during decomposition of crop residues under conventional and zero tillage. *Canadian Journal of Soil Science*, 86: 473–481.
- Lynch J. M. (1990) *'The Rhizosphere.'* (John Wiley & Sons Inc: UK).
- Lynch J. M., Whipps J. M. (1990) Substrate flow in the rhizosphere. *Plant and Soil* 129, 1- 10.
- Malik, M. A., Marschener, P and Khan, K. S. (2012) Addition of organic and inorganic sources to soil –Effects on P pools and microorganisms. *Soil biology and biochemistry* 49, 106-113.
- Manna, M., Bhattacharjya S. (2021). In situ decomposition of crop residues using lignocellulolytic microbial consortia: a viable alternative to residue burning. *Environmental Science and Pollution Research*. 28: 21-26.

- Manzoni, S., Jackson, R. B, Trofymow, J. A. and Porporato, A. (2008). The global stoichiometry of litter nitrogen mineralization. *Science* 321, 684-686.
- Marschner, H. (1995) *Mineral nutrition of higher plants*, 2nd ed, Academic press, San Diego, CA.
- Marschner P., Duong T. T. T., Baumann K. (2005). Frequent addition of wheat straw residues to soil enhances carbon mineralisation rate. *Soil Biology and Biochemistry*. 32: 805-813
- Marschner P., Grierson P., Rengel Z. (2005) Microbial community composition and functioning in the rhizosphere on three Banksia species in native woodland in Western Australia. *Applied Soil Ecology* 28, 191-201.
- Marschner P., Yang C. H., Lieberei R., Crowley D. E. (2001) Soil and plant specific effects on bacterial community structure in the rhizosphere. *Soil Biology and Biochemistry* 33, 1437-1445.
- McLaughlin M. J., Alston A. M., Martin J. K. (1988) Phosphorus cycling in wheat-pasture rotations, II. The role of the microbial biomass in phosphorus cycling. *Australian Journal of Soil Research* 26, 333-342.
- Mishra, B., Sharma, P. K. and Bronson, K. F.(2001) Decomposition of rice straw and mineralization of carbon, nitrogen, phosphorus and potassium in wheat field soil in western Uttar Pradesh. *Journal of the Indian Society of Soil Science* 49, 419-424.
- Moore T. R., Trofymow J. A., Prescott C. E., Fyles J., Titus B. D. (2006). Patterns of carbon, nitrogen and phosphorus dynamics in decomposing foliar litter in Canadian forests. *Ecosystems*, 9: 46-62.
- Müller M. M., Sundman V., Soininvaara O., Merilainen A. (1988) Effects of chemical composition on the release of N from agricultural plant material decomposing in soil under field conditions. *Biology and Fertility of Soils* 6, 78–83.
- Niklinska M., Klimek B. (2007) Effect of temperature on the respiration rate of forest soil organic layer along an elevation gradient in the Polish Carpathians. *Biology and Fertility of Soils* 43, 511-518.
- NRCS (Natural Resource Conservation Service) (2000) Soil Organic Matter Notes, viewed 27th September 2007, <http://taipan.nmsu.edu/mvpfpp/organic.htm>
- NRCS (Natural Resource Conservation Service) (n.d.) Soil Biology, viewed 27th September 2007, http://www.urbanext.uiuc.edu/soil/SoilBiology/soil_food_web.htm

- Oglesby K. A., Fownes J. H. (1992) Effects of chemical composition on nitrogen mineralization from green manures of seven tropical leguminous trees. *Plant and Soil* 143, 127-132.
- Olsen, S. R., Cole, C. V., Watanable, F. S. and Dean, L. A. (1954) *Estimation of available phosphorus in soils by extraction with sodium bicarbonate* USDA Circular 939.
- Osono T., Fukasawa Y., Takeda H. (2003) Roles of diverse fungi in larch needle-litter decomposition. *Mycologia* 95, 820-826.
- Osono T., Takeda H. (2004). Potassium, calcium, and magnesium dynamics during litter decomposition in a cool temperate forest. *J For Res*, 9: 23-31.
- Page, A. L.; Miller, R., and Keeney, D. R. (1982). *Methods of soil analysis: Chemical and microbiological properties*, pp. 595-611.
- Palm C. A., Sanchez P. A. (1991) Nitrogen release from the leaves of some tropical legumes as affected by their lignin and polyphenolic contents. *Soil Biology and Biochemistry* 23, 83-88
- Pangga, G. V., Blair G., Lefroy, R. (2000). Measurement of decomposition and associated nutrient release from straw (*Oryza sativa* L.) of different rice varieties using a perfusion system. *Plant and Soil*, 223: 1-11.
- Paterson E., Sim A., Standing D., Dorward M., McDonalds A. J. S. (2006) Root exudation from *Hordeum vulgare* in response to localised nitrate supply. *Journal of Experimental Botany* 57, 413-420.
- Pirela, H. J. and Tabatabai, M. A. (1988) Sulphur mineralization rates and potential of soils. *Biology and Fertility of Soils* 6, 26-32.
- Ramussen P. E., Parton W. J. (1994). Long term effects of residue management in wheat/fallow. I. Inputs, yield, and soil organic matter. *Soil Sci Soc Am J*, 58:523-530.
- Reinertsen S. A., Elliott L. F., Cochran V. L., Campbell G. S. (1984) Role of available carbon and nitrogen in determining the rate of wheat straw decomposition. *Soil Biology and Biochemistry* 16, 459-464.
- Rustad, L. E., T. G. Huntington, R. D. Boone. (2000). Control on soil respiration: Implication for climate change. *Biogeochemistry*, 48: 1-6.
- Salas, A. M., Elliot, E. T., Westfall, D. G., Clole, C. V. and Six, J. (2003). The role of particulate organic matter in phosphorus cycling. *Soil Science Society of America Journal*. 67, 181-189.

- Sammy Reddy, K., Singh, Muneswar, Swarup, Anand, Rao, A. S. and Singh, K. N. (2002) Sulphur mineralization in two soils amended with organic manures, crop residues and green manures. *Journal of Plant Nutrition and Soil Science* 165, 167-171.
- Schlesinger, W. H., and J. A. Andrews. (2000). Soil respiration and the global carbon cycle. *Biogeochemistry*, 48: 7-20.
- Singh S. P., Sharma B. L., Sharma M. L., (2012). Bio-degradation of crop residues by *Trichoderma* species vis-a` vis nutrient quality of the prepared compost. *Sugar Tech* 14(2):174–180.
- Singh S., Sharma P. K., Singh S. (2021). Nitrogen and sulphur release from added millets and oilseeds residues in Indo-Gangetic black and alluvial soils of Varanasi. *Journal of the Indian Society of Soil Science*, 69: 216-219.
- Singh, Surendra (2018) Available nutrients status and response to sulphur and zinc application in Inceptisols of Varanasi. *Journal of the Indian Society of Soil Science* 66, 116-119.
- Singh, Surendra and Kumar, P. (2012) Soil fertility status of vegetable growing area of Varanasi and pulses growing area of Mirzapur. *Journal of the Indian Society of Soil Science* 60, 233-236.
- Singh, Yadvinder, Singh, B., Ladha, J. K., Khind, C. S., Khera, T. S., and Bueno, C. S. (2004). Effects of residue decomposition on productivity and soil fertility in rice–wheat rotation. *Soil Science Society American of Journal*, 68: 854–864.
- Singh, Yadvinder, Singh, Vijay and Timsina, J. (2005) Crop residues management for nutrient cycling and improving soil productivity in rice based cropping systems. *Advances in Agronomy* 85, 269-407.
- Slovic S. (1997). Tree physiology. In: Huttel R.F., Schaaf W. (editors), *Magnesium deficiency in forest ecosystems*. Kluwer Academic, Dordrecht, 1: 101-214.
- Smith J. L, Papendick R. I., Bezdicsek D. F. (1992). *Soil organic matter dynamics and crop residue management*. Marcel Dekker Inc., pp 65-94.
- Soil Biology and Biochemistry* 2, 446-485.
- Somani, L. L. and Saxena, S. N. (1975) Effects of some organic matter sources on nutrient availability, humus build-up, soil physical properties and wheat yield under field conditions. *Annals of Arid Zone* 14, 149-158.
- Soon Y. K., Arshad M. A. (2002) Comparison of the decomposition and N and P mineralization of canola, pea and wheat residues. *Biology and Fertility of Soils* 36, 10- 17.

- Stegarescu G., Jordi E. G., Kaido S., Karin K., Tõnu T., Alar A., Endla R. (2020). Effect of crop residue decomposition on soil aggregate stability. *Agriculture*, 4: 25-31.
- Stevenson F. J. (1982) Nitrogen in agricultural soils. In 'Agronomy'. (Madison, Wisconsin USA).
- Subbiah, B. V. and Asija, G. L. (1956). A rapid procedure for the estimation of available nitrogen in soils. *Current Sciences*, 25: 259-260.
- Swift M. J., Heal O. W., Anderson J. M. (1979). Decomposition in terrestrial ecosystems. *Blackwell scientific Publications, Oxfords*, 68: 38-52.
- Sylvia D. M., Fuhrmann J. J., Hartel P. G., Zuberer D. A. (2005) '*Principles and applications of soil microbiology*.' (Pearson Education Inc: New Jersey, USA).
- Tabatabai, M. A. (1982) Sulphur. In *Methods of Soil Analysis* (A.L. Page, R.H. Miller and D.R. Kenney, Eds). American Society of Agronomy – American Society of Soil Science, Madison, WI, pp. 501-538.
- Talemos S., Sebsebe D., Zerihun W., Mulugeta L. (2016). Carbon and nutrient release patterns during leaf litter decomposition in Boter-Becho forest, Southwestern Ethiopia. *Journal of Ecosystem & Ecography*, 6: 18-27.
- Talgre, L., Lauringsona, E., Roostalub H., Makke A. (2014). Phosphorus and potassium release during decomposition of roots and shoots of green manure crops. *Biological Agriculture & Horticulture*, 30(4): 264–271.
- Tarafdar J. C., Jungk A. (1987) Phosphatase activity in the rhizosphere and its relation to the depletion of soil organic phosphorus. *Biology and Fertility of Soils* 3, 199–204.
- Thaha A. R., Umrah U. (2020). The role of local isolates of *Trichoderma* sp. as a decomposer in the substrate of cacao pod rind (*Theobroma cacao* L.). *AIMS Agriculture and Food*, 5(4): 825–834.
- Thomas K., Jijeesh C. M., Seethalakshmi K. K. (2014). Litter production, decomposition and nutrient mineralization dynamics of *Ochlandra setigera*: A rare bamboo species of Nilgiri Biosphere Reserve. *Indian Journal of Forestry*, 25: 579-584.
- Trinsoutrot I, Recous S, Mary B, Nicolardot B (2000) C and N fluxes of decomposing ¹³C and ¹⁵N *Brassica napus* L.: effects of residue composition and N content. *Soil Biology and Biochemistry* 32, 1717-1730.
- Van Veen J. A., Ladd J. N., Frissel M. J. (1984) Modelling C and N turnover through the microbial biomass in soil. *Plant and Soil* 76, 257-274.

- Van Veen J. A., Liljeroth E., Lekkerkerk L. J. A. (1991) Carbon fluxes in plant-soil systems at elevated atmosphere CO₂ level. *Ecological Applications* 1, 175-181.
- Vitousek P., Sanford R. L. J. (1986). Nutrient cycling in moist tropical forest. *Annu Rev Ecol Syst*, 17: 137-167.
- Walkley, A. and Black, C. A. (1934). Estimation of organic carbon by chromic acid and titration method. *Soil Science* 37: 29-38.
- Walley F., Yates T. (2002) Guesstimating Soil Nitrogen Release - What Factors Need to be Considered viewed 18th February 2009 at http://www.umanitoba.ca/faculties/agricultural_and_food_sciences/agronomists.conf/2002/pdf/walley.pdf.
- Walli, T. K., Subba Rao A., Singh, M. (1995). Urea Treatment of straw. *Handbook for Straw Feeding Systems*, 8: 272-292.
- Wang Q., Wang S., Huang Y. (2008). Comparisons of litter fall, litter decomposition and nutrient return in a monoculture *Cunninghamia lanceolata* and a mixed stand in southern China. *For Ecol Manage*, 255: 1210-1218.
- Wang X., Zabowski D. (1998) Nutrient composition of Douglas-fir rhizosphere and bulk soil solutions. *Plant and Soil* 200, 13-20.
- Webley D. M., Jones D. (1971) Biological transformation of microbial residues in soil.
- Wieder, W. R., Bonan, G. B., Allison S. D. (2013). Global soil carbon predictions are improved by modelling microbial processes. *Nature Climate Change*, 3(10): 909-912.
- Williams, C. H. and Steinbergs, A. (1959) Soil sulphur fractions as chemical indices of available sulphur in some Australian soils. *Australian Journal of Agricultural Research* 10, 340-352.
- Wood M. (1989) 'Soil biology.' (Chapman & Hall: New York, US).
- Xu J. M., Tang C., Chen Z. L. (2006). The soil of plant residues in pH change of acid soils differing in initial pH. *Soil Biol Biochem*, 38: 709-719.

