

EFFECT OF CROP RESIDUE MANAGEMENT AND GREEN MANURING ON PRODUCTIVITY AND SOIL FERTILITY IN RICE-WHEAT SYSTEM

*A Thesis
Submitted To The
Bidhan Chandra Krishi Viswavidyalaya
in partial fulfillment of the requirements for the degree of Doctor of
Philosophy (Agriculture)*

In
Agronomy

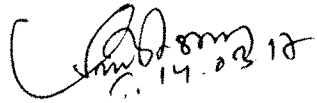
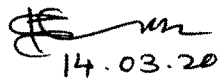
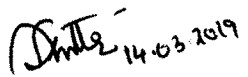
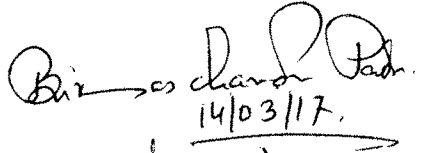
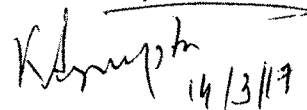
By
Athokpam Kalpana



**DEPARTMENT OF AGRONOMY
FACULTY OF AGRICULTURE
Bidhan Chandra Krishi Viswavidyalaya
Mohanpur, Nadia, West Bengal
2016**

APPROVAL OF THE EXAMINARS FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY (AGRICULTURE) IN AGRONOMY

We, the undersigned, having been satisfied with the performance of **Ms. Athokpam Kalpana**, in the viva voce Examination, conducted today, the ^{14th March,}.....2017, recommend that the thesis be accepted for the award of the degree.

Name	Position	Signature
1. Prof. S. K. Mukhopadhyay	Chairman, Advisory Committee	 14.03.17
2. PROF. S. KARMAKAR BAU, RANCHI	External Examiner	 14.03.2017
3. Dr. M. Ghosh	Member, Advisory Committee	Mukimay Ghosh 14.3.2017
4. Dr. N. Saha	Member, Advisory Committee	 14/3/2017
5. Dr. S. Dutta	Member, Advisory Committee	 14.03.2017
6. Dr. B. C. Patra	Departmental Nominee	 14/03/17.
7. Prof. Kajal Sengupta	Head, Department of Agronomy	 14/3/17

BIDHAN CHANDRA KRISHI VISWAVIDYALAYA
FACULTY OF AGRICULTURE
DEPARTMENT OF AGRONOMY

From:
Dr. S. K. Mukhopadhyay
Professor of Agronomy



P.O. KRISHI VISWAVIDYALAYA
PIN- 741252, NADIA, W. B.
Phone (O) :- (033) 25828407
Fax-033-25828407
Mo: 09477231319

Ref. No.....

Dated....26.05.....2016

CERTIFICATE

This is to certify that the work recorded in this thesis entitled **“Effect of crop residue management and green manuring on productivity and soil fertility in rice-wheat system”** submitted by Ms. Athokpam Kalpana, in partial fulfillment of the requirement for the degree of Doctor of Philosophy (Agriculture) in Agronomy of Bidhan Chandra Krishi Viswavidyalaya, is a faithful and bonafide research work carried out under my supervision and guidance.

The results and investigation reported in the thesis have not so far been submitted for any other degree or diploma. The assistance and help received during the course of investigation have been duly acknowledged.

Dated: ...26.05..... 2016
Mohanpur, West Bengal.

(Prof. S. K. Mukhopadhyay)
Chairman
Advisory Committee

Acknowledgement

A major research work like this is never being the work of anyone alone. The contributions of different people, in different ways, have made this possible. I would like to express my sense of gratitude to all without whose heartfelt inspiration and consistence was indispensable for the completion of present work.

Words are inadequate to express my overwhelming gratitude and sincere thanks to my supervisor, Dr. S. K. Mukhopadhyay, Professor, Department of Agronomy, and Dr. S. Dutta, Associate Professor, Department of Plant Pathology, for their detailed and constructive comments and unconditional support. Their guidance and advice throughout the research investigation, as well as their pain-staking effort in proof reading the drafts, is greatly appreciated. Indeed, without their guidance, it would not have been possible to put the thesis together.

I also take this opportunity to thank the members of my Advisory Committee, Dr. M. Ghosh, Associate Professor, Department of Agronomy and Dr. N. Saha, Associate Professor, Department of Agricultural Chemistry and Soil Science for rendering their invaluable help during the course of investigation.

I also extend my special thank to Dr. Mithu De Roy, Soil Testing Laboratory, P. O. R. S, Ranibagan, Berhampore, Murshidabad, West Bengal and Dr. P. K. Bandopadhyay, Associate Professor, Department of Agricultural Chemistry and Soil Science for their support and valuable suggestion during the course of investigation.

I also feel immense pleasure to reveal my deepest gratitude to Prof. Kajal Sengupta, Head of the Department of Agronomy for his valuable guidance and all sorts of facilities during the course of investigation.

I wish to thank both the teaching and non-teaching staff of the Department of Agronomy, Farm manager and staff of District Seed Farm Kalyani, specially Chandan Da, Anup Da for their help in time of need and to the in-charge and staff members of the library for the use of library facilities whenever required.

I am thankful to all my friends for their constant encouragement and support during my research work and even the smallest help rendered by them is acknowledged. I thank, in particular, Che Bhumita, Che Gangarani, Che Lakshmi, Che Meronbala, Che Zeti, Da Adam, Kounish Da, Da Chandrakumar, Joshna, Diana, Ipsita, Somdatta, Amrita, Umalakshmi, Brendra Da for rendering their help in conducting both my field and laboratory works for my experiment.

Last, but by no means least, to my family members for their unconditional love, fervent prayers and blessings, my father, sisters' and brother for the huge emotional support they gave me throughout my stay away from home and my late mother who inspired me to be the person I am today.

Date 26.05.2016

Mohanpur

Athokpam Kalpana
Athokpam Kalpana

ABSTRACT

Rice-wheat cropping system has emerged as a major cropping system of the Indo-Gangetic Plains (rice bowl and wheat bucket of India). Presently this cropping system has been practiced on nearly 10.3 m ha in India and contributes more than 70% of total cereal production while in West Bengal this system covers about 4.08 lakh hectare and shares about 7.5% of the total cultivated area. However, non judicious use of chemical fertilizers and its potential risks towards soil, environment and plant health are some rising constraints behind the declining productivity of this zone. For this reason nutrient recycling in the soil-plant ecosystem through crop residue incorporation and green manuring may play a great role towards sustainable productive agricultural enterprise and also help as a means of disposal of crop residues instead of burning or removal.

Keeping this in view the present investigation on “Effect of crop residue management and green manuring on productivity and soil fertility in rice-wheat system” was conducted at District Seed Farm, Kalyani, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal during the *kharif* and *rabi* seasons of 2013-14 and 2014-15. The texture of the soil was sandy loam soil with good drainage capacity. The soil had almost neutral pH. Nine treatments were used in RBD design with three replication in this experiment. The treatments were: T₁: rice residue removal (var. IET-4786)-wheat residue removal (var. K-0307), T₂: soil test based fertilizers (NPK) application, T₃: rice residue incorporation-wheat residue removal+T₂, T₄: rice residue removal-wheat residue incorporation+T₂, T₅: rice residue incorporation-wheat residue incorporation+T₂, T₆: green manure+T₂, T₇: rice residue incorporation-wheat residue removal+T₆, T₈: rice residue removal-wheat residue incorporation +T₆, T₉: rice residue incorporation-wheat residue incorporation+T₆.

The specific objectives of this investigation were:

1. To evaluate the effect of crop (rice and wheat) residue management on growth and yield of rice and wheat and productivity of rice-wheat system
2. To work out the change of soil properties (physical, chemical and biological) in rice-wheat system due to crop residue management
3. To work out nutrient use efficiency of the system
4. To compute the energy requirements and economics of different crop residue management practices in rice-wheat system

The important findings emerging out of this experiment are summarized briefly here under:

Growth attributing characters of both rice and wheat were greatly influenced by the treatments in both the years. However, the influences were more pronounced in the second year as compared with that of first year except in case of control (T_1) and sole chemical source of fertilizers treatment (T_2). Significantly higher growth attributing characters namely plant height, number of tillers, LAI and CGR were observed in both rice and wheat crops for the treatments consisting of integration of crop residue incorporation (rice or wheat or both) along with chemical fertilizers followed by green manuring (T_7 , T_8 and T_9) as compared to control (T_1) and sole NPK source (T_2). Again, treatments comprising chemical fertilizers + crop residue incorporation and fertilizers + green manuring (GM) (T_3 , T_4 , T_5 and T_6) were recorded with the higher values of growth attributing characters as compared with T_1 and T_2 .

Significantly higher grain and straw yield and harvest index were recorded for both rice and wheat crops in case of residue integration along with inorganic fertilizers followed by green manuring (T_7 , T_8 and T_9) as compared to sole NPK source (T_2). Green manuring and/or incorporation of crop residues in rice-wheat system increased SOM and SOC (soil organic matter and soil organic carbon) while maintaining high grain yields. Residue integration along with inorganic fertilizers (T_3 , T_4 and T_5) had no significant impact on yield increase for both rice and wheat crops in the first year as compared to application of chemical fertilizers alone (T_2). However, the impact was excellent all through the second year. Integration of both the residues along with green manuring (T_9) gave the highest grain yield for both rice (4.65 t ha^{-1}) and wheat (4.47 t ha^{-1}) crops. Rice + wheat residue incorporation in combination with GM enhanced the grain yield of rice and wheat by 15.67 % and 20.16%, respectively. The maximum system wheat equivalent yields were recorded from T_9 in both the years (8.23 and 9.02 t ha^{-1} , respectively which was 9.15 % and 26.90 % more than that of T_2) and the lowest system wheat equivalent yields were obtained from control (2.55 and 2.32 t ha^{-1} , respectively).

Rice or wheat residues alone or in combination (T_3 , T_4 and T_5) improved the available soil NPK and Zn status as compared to sole inorganic sources (T_2). It was found that the incorporation of rice and wheat straw increased plant recovery of nutrient as well as soil retention in both rice and wheat crops. However, the effect was more pronounced when incorporated with green manuring (T_7 , T_8 and T_9). Significant positive influence of crop residue incorporation alone (T_3 , T_4 and T_5) or in combination with GM

(T₇, T₈ and T₉) was also recorded towards elevated population of *Azotobacter*, total bacteria, fungi and *Actinomycetes* compared to the effect of inorganic fertilizer alone (T₂) and control (T₁).

It has been found that the loss of N was less in those treatments where fertilizer applied along with incorporation of residues with or without green manuring (T₃, T₄, T₅, T₇, T₈ and T₉) and green manuring along with chemical fertilizers (T₆) as compared to fertilizer application alone (T₂) and control (T₁). These might be due to improved nutrient balance of the soil as a result of residues incorporation and green manuring and improved soil physical properties due to residue incorporation and green manuring. The return of rice and wheat residues could recycle up to 20%-30% of the N absorbed by the crops.

Bulk density decreased and soil porosity increased with decrease in bulk density in those treatments involving crop residue (rice or wheat or both) incorporation along with or without green manuring + fertilizers (T₃ to T₉) as compared to the initial values. Green manuring (T₆) had less effect on aggregates stability and formation of macro aggregates, however, when combined with either rice (T₇) or wheat residues (T₈) and with both rice and wheat residues (T₉) increased aggregate ratio, MWD and GMD for controlling water and nutrient movement within the soil.

The treatments with crop residues incorporation (rice or wheat residue or both) + green manuring + fertilizer (T₇, T₈ and T₉) or crop residues + fertilizer (rice or wheat residue or both) (T₃, T₄ and T₅) or green manuring +fertilizer (T₆) proved highly efficient in respect of economic return in terms of B: C ratio and total energy output when compared with sole fertilizer application (T₂) and control (T₁), however, integration of both the residues along with green manuring (T₉) recorded the highest values of both these parameters (2.43 and 2.56 in respect of B: C ratio and 265816.38 and 292447.28 MJ during 1st and 2nd year, respectively). Incorporation of residue was the best in terms of improved soil health, increased wheat yield, monetary return and B: C ratio.

It may be concluded that incorporation of rice and wheat residues in combination with soil test based fertilizer application followed by green manuring can be advantageous in increasing crop yields and nutrient uptake by both rice and wheat crops, in sustaining soil fertility by improving soil physical properties, available nutrients and boosting up soil microbial population thus promoting better soil environment in sandy loam soil of Gangetic alluvial zone of West Bengal. The findings will hopefully encourage farmers for residue incorporation as a means of disposal instead of burning or removal.

LIST OF SYMBOLS & ABBREVIATION USED

@	:At the rate of	%	:Percentage
<	:Greater than	>	:Less than
^o C	:Degree centigrade	^o N	:Degree north
^o E	:Degree east	AMSL	:Above mean sea level
Avg.	:Average	B:C	:Benefit:Cost
C	:Carbon	C.D.	:Critical difference
CFU	:Colony forming unit	cm	:Centimeter
C:N	:Carbon-Nitrogen ratio	CPC	:Carbon preservation capacity
CR	:Crop residue	CRM	:Crop residue management
CRI	:Crown root initiation	cv.	:Cultivar
DAP	:Diammonium phosphate	DAS	:Days after sowing
DAT	:Days after transplanting	DSR	:Direct seeded rice
et al.	:et alii (and others)	FAO	:Food and Agriculture Organisation
Fig.	:Figure	FYM	:Framyard Manure
g	:Gram	GM	:Green Manuring
ha	:Hectare	i.e.	:Id est (that is)
IGP	:Indo-Gangetic Plain	K	:Potassium
kg	:Kilogram	km	:Kilometer
m	:Meter	m ²	:Square meter
mm	:Millimeter	Max.	:Maximum
Min.	:Minimum	MJ	:Mega Joule
m ha	:Million hectare	M ha	:Mega hectare
m t	:Million tonne	M t	:Metric tonne
MOP	:Muriate of potash	N	:Nitrogen
NPK	:Nitrogen phosphorous potassium	NS	:Not significant
P	:Phosphorous	P ₂ O ₅	:Phosphate
pH	:Negative logarithm of hydrogen ions concentration	OC	:Organic carbon
RBD	:Randomized Block design	RS	:Rice straw
Rs.	:Rupees	RW	:Rice-wheat
RWC	:Rice-wheat cropping system	S.Edm	:Standard error mean
SMBC	:Soil microbial biomass carbon	SOM	:Soil organic matter
Sp.	:Species	SSP	:Single Super Phosphate
Sl. N	:Serial number	t	:Tonne
Viz.	:Videlicet (namely)	Mgm ⁻³	:Mega gram per cubic meter
G m ⁻²	:Gram per square meter	day ⁻¹	:Per day
g kg ⁻¹	:Gram per kilogram	ha ⁻¹	:Per hectare
kg ha ⁻¹	:Kilogram per hectare	MJ ha ⁻¹	:Mega Joule per hectare
t ha ⁻¹	:Tonne per hectare	q ha ⁻¹	:Quintal per hectare

CONTENTS

Chapter	Particulars	Page no.
1	INTRODUCTION	1-5
2	REVIEW OF LITERATURE	6-22
2.1	Effect of crop residue management and green manuring on growth and yield of rice and wheat	6
2.1.1	Growth parameter	6-7
2.1.2	Yield attributes	7-9
2.2	Effect of crop residue management and green manuring on nutrient uptake by crops	9-12
2.3	Effect of crop residue management and green manuring on soil properties	12
2.3.1	Physical properties of soil	12-14
2.3.2	Chemical properties of soil	14-19
2.3.3	Biological properties of soil	19-21
2.4	Effect of crop residue management and green manuring on net energy return and economics of rice- wheat system	21-22
2.4.1	Net energy return	21
2.4.2	Economics	21-22
3	MATERIALS AND METHODS	23-37
3.1	Experimental site	23
3.2	Soil characteristics of experimental site	23
3.3	General meteorological features of the experimental site	24-25
3.3.1	Temperature	25
3.3.2	Rainfall	25
3.3.3	Relative humidity	25
3.4	Cropping history of the experimental field	25
3.5	Design and layout of the experiment	26
3.6	Land preparation	29
3.6.1	Rice	29
3.6.2	Seedbed preparation of rice	29
3.6.3	Wheat	29
3.6.4	Layout of the field	29
3.7	Fertilizers application	29
3.7.1	Rice	29

Chapter	Particulars	Page no.
3.7.2	Wheat	29
3.8	Crop residues incorporation	30
3.9	Green manuring	30
3.10	Seed rate	30
3.11	Spacing	30
3.12	Management of crops	31
3.12.1	Seed treatment	31
3.12.2	Sowing	31
3.12.2.1	Sowing of rice	31
3.12.2.2	Transplanting of rice	31
3.12.2.3	Wheat	31
3.12.3	Weeding	31
3.12.3.1	Rice	31
3.12.3.2	Wheat	31
3.12.4	Water management	31
3.12.4.1	Rice	31
3.12.4.2	Wheat	31
3.12.5	Plant protection	32
3.13	Harvesting and threshing	32
3.14	Field observation	32-33
3.14.1	Methods of measuring growth attributing characters	32
3.14.1.1	Plant height	32
3.14.1.2	Leaf area index (LAI)	32
3.14.1.3	Number of tillers per square meter	33
3.14.1.4	Crop Growth Rate (CGR)	33
3.14.2	Methods of measuring yield attributing characters and yield	33
3.14.2.1	Panicle/ Earhead length	33
3.14.2.2	Number of panicle (for rice) and earhead (for wheat) per square meter	33
3.14.2.3	Number of grain per panicle (for rice) and per earhead (for wheat)	33
3.14.2.4	1000- Grain weight	33
3.14.2.5	Grain and straw yield	34
3.14.2.6	Harvest index	34

Chapter	Particulars	Page no.
3.15	Method of chemical analysis of plant samples	34
3.15.1	Estimation of nitrogen	34
3.15.2	Estimation of phosphorous	34
3.15.3	Estimation of potassium	34
3.16	Methods of collecting soil samples for physical and chemical analysis	34-35
3.16.1	Determination of soil bulk density (core sampling method)	35
3.16.2	Determination of soil porosity	35
3.16.3	Determination of various aggregation indices of soil	35
3.16.4	Method of chemical analysis of soil	35
3.16.4.1	Determination of soil pH	35
3.16.4.2	Estimation of organic carbon	35
3.16.4.3	Determination of available nitrogen in soil	35
3.16.4.4	Determination of available phosphorus in soil	35
3.16.4.5	Determination of available potassium in soil	36
3.16.4.6	Determination of available zinc in soil	36
3.17	Methods of analysis for study on soil micro- flora	36
3.17.1	Collection of soil sample	36
3.17.2	Viable count of the micro-organism	36
3.17.2.1	<i>Azotobacter</i>	36
3.17.2.2	Total bacteria	36
3.17.2.3	Fungi	36
3.17.2.4	<i>Actinomycetes</i>	36
3.18	Energy analysis	37
3.18.1	Energy input and output analysis	37
3.19	Economics analysis	37
3.19.1	Cost of cultivation	37
3.19.2	Gross return	37
3.19.3	Net return	37
3.19.4	Benefit: Cost ratio (B: C ratio)	37
3.20	Statistical analysis	37

Chapter	Particulars	Page no.
4	RESULTS AND DISCUSSION	38-91
4.1	Effect of crop residues and green maturing on growth attributing characters of rice	38-48
4.1.1	Plant height	38-40
4.1.2	Number of tillers per square meter of rice	40-42
4.1.3	Leaf Area Index (LAI) of rice	42-44
4.1.4	Crop growth rate (CGR) of rice	44-46
4.1.5	Root dry weight per square meter of rice	46-48
4.2	Effect of crop residue management and green manuring on yield attributing characters of rice	48-50
4.2.1	Number of panicles (m^{-2})	48
4.2.2	Length of panicle (cm)	48
4.2.3	Grains panicle ⁻¹	50
4.2.4	1000-grain weight (g)	50
4.3	Effect of crop residue management and green manuring on grain and straw yield and harvest index of rice	50-53
4.3.1	Grain yield (t ha^{-1})	50-52
4.3.2	Straw yield (t ha^{-1})	52-53
4.3.3	Harvest index (%)	53
4.4	Effect of crop residues and green manuring on total nutrient uptake by rice	53-55
4.4.1	Nitrogen uptake (kg ha^{-1})	53-55
4.4.2	Phosphorous uptake (kg ha^{-1})	55
4.4.3	Potassium uptake (kg ha^{-1})	55
4.5	Effect of crop residues and green manuring on growth attributing characters of wheat	56-64
4.5.1	Plant height	56
4.5.2	Number of tillers per square meter of wheat	56-58
4.5.3	Leaf Area Index (LAI) of wheat	59-61
4.5.4	Crop Growth Rate (CGR) of wheat	61
4.5.5	Root dry weight per square meter of wheat	61-64
4.6	Effect of crop residues and green manuring on yield attributing characters of wheat	64-67
4.6.1	Number of earhead	64-66
4.6.2	Length of earhead	66

Chapter	Particulars	Page no.
4.6.3	Grains per earhead	67
4.6.4	1000- Grain weight	67
4.7	Effect of crop residues and green manuring on grain and straw yield and harvest index of wheat	67-70
4.7.1	Grain yield	67-69
4.7.2	Straw yield	69-70
4.7.3	Harvest index	70
4.8	Effect of crop residues and green manuring on total nutrient uptake by wheat	70-72
4.8.1	Nitrogen uptake (kg ha^{-1})	70-72
4.8.2	Phosphorous uptake (kg ha^{-1})	72
4.8.3	Potassium uptake (kg ha^{-1})	72
4.9	Effect of crop residues and green manuring on wheat system equivalent yield of rice-wheat system	72-74
4.10	Effect of crop residue management on soil properties	74-86
4.10.1	Physical properties	74-76
4.10.1.1	Bulk density and porosity	74-75
4.10.1.2	Soil structural properties	76
4.10.2	Chemical properties of Soil	76-83
4.10.2.1	Soil pH	76
4.10.2.2	Electrical conductivity (dSm^{-1})	79
4.10.2.3	Organic C	79-80
4.10.3	Nutrient availability in the soil	80-83
4.10.3.1	Available nitrogen (kg ha^{-1})	80
4.10.3.2	Available phosphorous (kg ha^{-1})	80-82
4.10.3.3	Available potassium (kg ha^{-1})	82-83
4.10.3.4	Available Zinc (ppm)	83
4.10.4	Effect of crop residues and green manuring on microbial population (log value) per gram of soil	84-86
4.10.4.1	Population of <i>Azotobacter</i> ($\times 10^4$ CFU g^{-1} of soil)	84
4.10.4.2	Population of Bacteria ($\times 10^5$ CFU g^{-1} of soil)	84
4.10.4.3	Population of <i>Fungi</i> ($\times 10^5$ CFU g^{-1} of soil)	86
4.10.4.4	Population of <i>Actinomycetes</i> ($\times 10^5$ CFU g^{-1} of soil)	86

Chapter	Particulars	Page no.
4.11	Effect of crop residues and green manuring on N budget under rice-wheat cropping system for the experimental years	87
4.12	Effect of crop residues and green manuring on net energy return of rice-wheat system	87
4.13	Effect of crop residues and green manuring on benefit: cost ratio of rice-wheat system	90
5	SUMMARY AND CONCLUSION	92-95
6	FUTURE SCOPE OF RESEARCH	96
	BIBLIOGRAPHY	i-xi
	ANNEXURE	

LIST OF TABLES

Table no.	Title of the tables	Page no.
3.1	Physico-chemical properties of the experimental soil	23
3.2	Meteorological observation pertaining during the period of experiment	24
3.3	Cropping history of the experimental field	25
3.4	Details of the experiment	26
3.5	Treatments details	26
3.6	Calendar of field operation	28
4.1	Effect of crop residues and green manuring on plant height of rice	39
4.2	Effect of crop residues and green manuring on number of tillers per square meter of rice	41
4.3	Effect of crop residues and green manuring on leaf area index (LAI) of rice	43
4.4	Effect of crop residues and green manuring on crop growth rate (CGR) of rice	45
4.5	Effect of crop residues and green manuring on root dry weight of rice	47
4.6	Effect of crop residues and green manuring on yield attributing characters of rice	49
4.7	Effect of crop residues and green manuring on grain and straw yield; harvest index of rice	51
4.8	Effect of crop residues and green manuring on nutrient uptake of rice	54
4.9	Effect of crop residues and green manuring on plant height of wheat	57
4.10	Effect of crop residues and green manuring on number of tillers per square meter of wheat	58
4.11	Effect of crop residues and green manuring on leaf area index (LAI) of wheat	60
4.12	Effect of crop residues and green manuring on crop growth rate (CGR) of wheat	62
4.13	Effect of crop residues and green manuring on root dry weight of wheat	63
4.14	Effect of crop residues and green manuring on yield attributing characters of wheat	65
4.15	Effect of crop residues and green manuring on grain and straw yield; harvest index of wheat	68
4.16	Effect of crop residues and green manuring on nutrient uptake of wheat	71

Table no.	Title of the tables	Page no.
4.17	Effect of crop residue management and green manuring on wheat system equivalent yield of rice- wheat system	73
4.18	Effect of crop residues and green manuring on soil bulk density and porosity	75
4.19	Effect of crop residues and green manuring on soil structural properties	77
4.20	Effect of crop residues and green manuring on soil pH, EC and organic C content	78
4.21	Effect of crop residues and green manuring on soil available nutrient	81
4.22	Effect of crop residues and green manuring on soil microbial population	85
4.23	Effect of crop residues and green manuring on N budget of the experiment	88
4.24	Effect of crop residues and green manuring on net energy return of the experiment	89
4.25	Effect of crop residues and green manuring on economics of rice-wheat system	91

LIST OF FIGURE

Fig. no	Title of the figure	Page No./Pages in between
3.1	Monthly Max. and Min. temperature	24-25
3.2	Monthly Max. and Min. relative humidity	24-25
3.3	Monthly rainfall	24-25
3.4	Layout of the experiment	27
4.1	Plant height of rice at different growth stages	41-42
4.2	Number of tillers per square meter of rice at different growth stages	41-42
4.3	Leaf Area Index of rice at different growth	45-46
4.4	Crop growth rate of rice at different growth stages	45-46
4.5	Root dry weight of rice at different growth stages	47-48
4.6	Grain yield of rice	51-52
4.7	Straw yield of rice	51-52
4.8	Plant height of wheat at different growth stages	57-58
4.9	Number of tillers per square meter of wheat at different growth stages	57-58
4.10	Leaf Area Index of wheat at different growth stages	62-63
4.11	Crop growth rate of wheat at different growth stages	62-63
4.12	Root dry weight of wheat at different growth stages	63-64
4.13	Grain yield of wheat	68-69
4.14	Straw yield of wheat	68-69
4.15	Wheat system equivalent yield of the experimental period	73-74
4.16	Soil nutrient availability	81-82
4.17	Population of <i>Azotobacter</i> per gram of rhizosphere soil	85-86
4.18	Population of bacteria gram of rhizosphere soil	85-86
4.19	Population of fungi gram of rhizosphere soil	86-87
4.20	Population of <i>Actinomycetes</i> gram of rhizosphere soil	86-87
4.21	Net energy return of the experiment	89-90

LIST OF PLATE

Plate No.	Title of the plate	Pages in between
1	Field operation in rice field	29-30
2	Field operation in wheat field	29-30
3	Overview of the field	31-32
4	Crop residue incorporation and green manuring operation	31-32
5	Plant sampling of rice and wheat	32-33
6	Soil micro-flora	86-87

CHAPTER 1

INTRODUCTION

INTRODUCTION

Rice and wheat are the world's two most important cereal crops, contributing 45% of the digestible energy and 30% of total protein in the human diet, as well as a substantial contribution to feeding livestock (Evans 1993). During last four decades the growth rates of rice and wheat production in South Asia (2.5% and 5.2% per year, respectively) exceeded the population growth rate (2.22% per year), indicating an increased in per capita availability of these two cereals that strengthen the food security, reduced rural poverty, and increased affordability of food at cheaper prices in the region (Pangali and Shah 1999). This happened due to advent of high yielding cultivars of rice and wheat and their intensive production technology. Singh *et al.* (2002) reported that demand for rice and wheat was expected to grow at 2.5% per year over the next two decades but it will become increasingly more difficult as the per capita rice-wheat growing area in IGP had already shrunk from 1200 m² in 1961 to less than 700 m² in 2001. Inevitably, this encouraged large-scale sequential cropping of rice and wheat in millions of hectares even in non-traditional areas for both the crops. The climate of the IGP has been also favorable for rice and wheat to be grown in a double cropping pattern within one calendar year, rice in the summer and wheat in the winter.

Rice-wheat cropping system (RWC) has emerged as a major cropping system of IGP (rice bowl and wheat bucket of India). This cropping system has been practiced on nearly 13.7 million ha (10.3 m ha in India, 2.2 m ha in Pakistan, 0.5 m ha in Bangladesh, and 0.7 m ha in Nepal) in the Indo-Gangetic plains (Gupta *et al* 2003).

Rice-wheat cropping system of the Indo-Gangetic Plains has played a significant role in the food security of India. This system spread over a vast area spanning from Punjab in the North-west to East up to West Bengal (Singh, Jat and Sharma, 2005). This system occupies around 42 % of the total agricultural area in India (Panigrahy , 2010). These two crops together contribute more than 70% of total cereal production in India from an area of around 25 M ha under wheat and about 40 M ha under rice. The small states of Punjab and Haryana contribute 20% of the total national grain production and 50% and 85% of the government procurements of rice and wheat, respectively (Singh, 2000). With unabated increases in population, more and more land will be required for urbanization, and productivity needs to be increased to meet the rising domestic and industrial demand and also sustainability of this

important cropping system is at risk due to the deterioration of soil health, mounting pressure on natural resources and emerging challenges of climate change. Conservation agriculture involving zero or minimum-tillage and innovations in crop residue management (CRM) to avoid straw burning should assist in achieving sustainable productivity and allow farmers to reduce nutrient and water inputs, and reduce risk due to climate change. High yields of the irrigated RW system have resulted in production of huge quantities of crop residues (CRs). Burning of rice straw is common in north-western parts of India causing nutrient losses, and serious air quality problems affecting human health and safety. Mulch is a good option for rice residue management during the wheat crop, especially with no tillage. Mulch can increase yield, water use efficiency, and profitability, while decreasing weed pressure. Surplus residue from the previous wheat crop can be incorporated into the paddy fields with no adverse effect on rice yield. Long-term studies of the residue recycling have indicated improvements in physical, chemical and biological health of soil. Since CRs contain significant quantities of plant nutrients; their continuous application will have positive effect on fertilizer management in RW system. Other plausible option of CRM lies in utilizing a portion of surplus residue for producing biochar (and co-production of bio-energy) for using as soil amendment to improve soil health, increase nutrient use efficiency and minimize air pollution.

Rice occupied an area of around 43.42 m ha in India with production 106.54 m t. Wheat is the second important staple food crop next to rice. Currently India's total wheat production is 95.91 m t from an area of more than 29.04 m ha (Agricultural Statistics at a Glance, MOA, GOI, 2014).

Geographically, the favourable rice-wheat environment in the Indo-Gangetic plains is located in the western part, where winter environment conditions are suited for wheat, good irrigation infrastructure, marketing facilities are available, and both rice and wheat yields are high. The less favourable rice-wheat environment prevails in the eastern part and are associated with partially irrigated and rainfed system, and a shortage of growing period (winter season) for wheat.

In intensive cropping system timely agricultural operations are key factors to get maximum returns. The farmers are, therefore, gradually shifting from traditional methods to mechanized farming. With the introduction of high yielding varieties and widespread adoption of Green Revolution technologies, rice followed by wheat has

become a dominant crop rotation in India. The total area under rice-wheat system in India is around 20 million hectare and almost 90% of the rice area in Punjab, Haryana and Western Uttar Pradesh is utilized under intensive rice-wheat system. In West Bengal rice-wheat system covers about 4.08 lakh hectare and shares about 7.5% of the total cultivated area (FAO, 2004).

Rice-wheat system has considerable significance to India's food self-sufficiency and food security, but due to intensive application of chemical fertilizer and excessive use of pesticides and irrigation water, the quality of soil health and quality of water become deteriorated day by day which lead to the reduction of crop productivity. For this reason nutrient recycling in the soil-plant ecosystem is an essential component of sustainable productive agricultural enterprise. Although during the last three decades fertilization practices have played a dominant role in the rice-based cropping systems, crop residues (the harvest remnants of the previous crop) can still play an essential role in the cycling of nutrients.

Crop residues mainly rice and wheat, amounting to about 197 million tonnes (m t) in India largely (rice 120 m t and wheat 77 m t) remains in the field and must be managed to provide the greatest advantages. These residues are used as animal feed, composting, thatching for rural homes and fuel for domestic and industrial use. About 25% of nitrogen, 25% phosphorus, 50% of sulphur and 75% of potassium uptake by cereal crops are retained in residues, making them valuable sources of nutrients. Most farmers remove wheat straw for feeding the animals. However, management of the rice straw is a major challenge as it is considered to be a poor feed for the animals owing to high silica content. Combine harvester leaves behind a swath of loose rice residues, which interfere with operations of the seed drill used for sowing wheat. To avoid this problem farmers resort to burning of crop residues, which not only lead to loss of huge biomass but also cause environmental pollution. Farmers in northwest India dispose a large part of rice straw by burning *in situ*. A large portion of the residues, about 140 M t, is burned in field primarily to clear the field from straw and stubble after the harvest of the preceding crop. The problem is severe in irrigated agriculture, particularly in the mechanized rice-wheat system. The main reasons for burning crop residues in field include unavailability of labour, high cost in removing the residues and use of combines in rice-wheat cropping system especially in the Indo-Gangetic plains (IGP).

So there is a need to adopt ways and means to manage these valuable resources. Incorporation of crop residues alters the soil environment, which in turn influences the microbial population and activity in the soil and subsequent nutrient transformations. It is through this chain of events that management of crop residues regulates the efficiency with which fertilizer, water, and other reserves are used in a cropping system.

In the tropics, crop residues have, in fact, played a pivotal role in the maintenance of soil resources at acceptable levels because these are the major sources of C inputs. Tropical agricultural ecosystems are distinct from temperate ones in terms of biological degradation of soils, which results in reduction in organic matter content due to decline in the amount of C inputs from biomass (Stewart and Robinson, 1997). Tropical soils vary widely in their properties and are generally poor in native soil fertility and productivity. The removal of crop residues leads to low soil fertility and thereby decreased crop production. Organic materials such as crop residues offer sustainable and ecologically sound alternatives for meeting the nutrient requirements of crops. In addition to their role as the primary source of C inputs, crop residues, and the way they are managed, have a significant impact on soil physical properties (Boyle *et al.*, 1989). Future increase in food production in the tropics will only be possible through improvement in soil productivity (because there is little scope or no scope for horizontal expansion of cultivated area). Increased concern for the environment and increased emphasis on sustaining soil productivity has resulted in major interest in the maintenance and improvement in soil organic matter in recent years. Proper management and utilization of crop residues and other agricultural wastes will constitute an important factor in achieving this objective.

Again continuously following cereal-cereal or rice-wheat cropping system has led to the deterioration of soil health and indiscriminate water use has resulted in lowering of water table. Hence, it is important to diversify/intensify the system by introducing of leguminous crops like green gram, green manuring crops, cowpea, black gram or pea to restore the soil health and to arrest the fall in water table. In rice-wheat systems, legumes can be introduced as green manure, short duration summer grain crops and fodder crops or as substitute to one of the cereal crops of the system. Residue incorporation along with green manuring has been reported to have greater influence over crop yield and enrichment of soil physicochemical and biological properties by several researchers [Krishna G. Mandal *et al.* (2004), Samra *et al.* (2003) and Gurpreet *et al.* (2007)].

Though a good amount of research work has been done on crop residue management and crop diversification in rice-wheat cropping system in India and abroad, in West Bengal, particularly in the Gangetic alluvial zone, scientific research work done on these aspects is meager.

Keeping all these aspects in view, and in order to exploit the greatest possible advantages of rice and wheat residues, it is considered worthwhile to undertake an investigation to study the effect of crop residue management along with green manuring on productivity and soil fertility in rice-wheat system with the following objectives:

1. To evaluate the effect of crop (rice and wheat) residue management on growth and yield of rice and wheat and productivity of rice-wheat system
2. To work out the change of soil properties (physical, chemical and biological) in rice-wheat system due to crop residue management
3. To work out nutrient use efficiency of the system
4. To compute the energy requirements and economics of different crop residue management practices in rice-wheat system

To fulfill these objectives the growth, development and productivity of rice and wheat and the change in soil properties in relation to the management of crop residues were thoroughly investigated in order to understand the potential of the crop residue management in enrichment of soil fertility and maintaining the sustainability of rice-wheat production system.

CHAPTER 2

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Rice-wheat cropping system (RWC) has emerged as a major cropping system of the Indo-Gangetic plains in the last four decades and played a significant role in the food security of India. However, sustainability of this important cropping system is at risk due to the deterioration of soil health, mounting pressure on natural resources and emerging challenges of climate change. A good amount of research work has been done by several research workers on crop residue management and crop diversification in rice-wheat cropping system in India and abroad. Some salient findings related to the present investigation have been reviewed here.

2.1 Effect of crop residue management and green manuring on growth and yield of rice and wheat

2.1.1 Growth parameter

Mukherjee and Singh (2001) revealed the significant effect of green manuring with *Sesbania* on plant height at 50 and 70 DAP and harvest, but plant heights in all the residue management treatments (residue removal, residue burning, residue incorporation, green manuring + residue removal and green manuring + residue incorporation) were statistically at par with each other at all stages. Summer green manuring of *Sesbania* before rice transplanting in which residue was incorporated recorded significantly more number of tillers at 30 and 50 days after transplanting over residue incorporated, residue burnt and residue removed treatments. Green manured plots showed significantly higher dry matter accumulation in rice than non-green manured plots. Most of the growth parameters of rice increased significantly with increasing nutrient level from recommended to 1.5 times the recommended dose of NPK. Further, additional application of FYM at 10 t ha⁻¹ over recommended NPK showed pronounced effect on the growth parameters compared to the recommended level of nutrients.

Tomar *et al.* (2006) observed that plant height and shoot number and the total harvestable biomass were influenced by N fertilizer and rice residue management practice.

Wang *et al.* (2011) reported that rice straw returning reduced the content and the probability of the soil nitrate nitrogen leaching in the early growing period, promoted the vegetative growth of the paddy by releasing the nitrogen in the later growing period, thus increasing the yield.

Neeraj and Binod (2013) reported that the various rice residue and nutrient management systems significantly affect the plant height and number of tillers per meter and were maximum with 30% additional NPK + recommended NPK over sowing of wheat without incorporation of rice residue and recommended NPK and rice residue incorporation + recommended NPK at wheat sowing during both the years. Among the yield attributes and yield viz. number of effective tillers, length of ear head, numbers of spikelets per spike, grain and straw yield were also recorded maximum with the same treatment.

2.1.2 Yield attributes

Dalel and Om (1992) reported that green manuring increased grain yield of dwarf rice with the best results given by application 0 or 5 days before sowing. In the green manured plots, grain yields increase with up to 90 kg N whereas in the non-manured plots the yield increased with up to 120 kg N.

Misra *et al.* (1996) reported that burning or removal of straw gave similar results, while yield was increased by incorporation of rice and wheat straw, particularly in combination with 20 kg N ha⁻¹ to promote straw decomposition. Green manuring with *Sesbania aculeata* or application of 20 t ha⁻¹ farmyard manure gave the highest yields.

Singh and Sharma (2001) reported that the productivity of rice was significantly higher under wheat-*Sesbania* (green manure)-rice sequence as compared with wheat-rice sequence. On an average green manuring with *Sesbania* resulted in 13.64 % increase in rice grain yield than under wheat-rice sequence. Growth parameters, viz. plant height and dry matter accumulation per hill and yield attributes, viz. number of productive shoots, panicle length, number of fertile spikelets / panicle and 1000-grain weight were significantly higher under green manuring sequence.

Das *et al.* (2002) found that the incorporation of crop residues in rice enhanced the growth, yield attributes and grain yield of rice. Rice straw and wheat straw were equally effective. The grain yield of wheat (cv. Sonalika) increased due to the residual effect of crop residue treatments, although the increase was not significant. The increasing level of NPK applied to rice improved the yield components and grain yield of rice; however, the residual effect on the grain yield of wheat was not significant.

Krishna G. Mandal *et al.* (2004) reported that N at 15-20 kg ha⁻¹ as starter dose with straw incorporation increases yield of wheat and rice compared to burning. Rice

straw incorporation couple with organic manure increases grain yield of wheat and improves soil physical condition. Residue incorporation result more microbial activity than residue removal or burning.

Sandeep *et al.* (2004) observed that deep tillage incorporation of rice residue scaled higher attributes and grain yield. The lowest grain yield was obtained from the residue removed traditionally tilled plot. The number of tillers generated by each plant was highest from the crop receiving retention/ incorporation of residue with conservation and deep tillage. Conservation tillage with residue retention had the lowest test weight and highest shoot mortality. The application of 75% N at sowing and 25% ^N at crop residue incorporation (CRI) was at par in narrowing down the C: N ratio of rice with a starter dose of 20 kg N ha⁻¹ applied during land preparation + 150 kg N ha⁻¹ applied in 2 equal splits during sowing and CRI.

Vinay (2006) reported that the green manure *Sesbania* applied with 100 % of recommended dose of NPK fertilizers gave the maximum yield of rice as well as wheat crop. This treatment also gave the highest net return and benefit: cost ratio and produced significantly higher biomass in terms of rice-equivalent yield. The total uptake of N, P, K and Zn by both the crops increased significantly with the application of fertilizers or their combined use with organic manures. Among the organic manures the overall performance of green-manure was the best, followed by cut rice straw.

Gangwar *et al.* (2006) reported that residue incorporation resulted in highest mean yield (5.86 Mg ha⁻¹) during three year of field studied of wheat after rice system. Maximum mean yield (6.1 Mg ha⁻¹) was obtained in reduced tillage followed by conventional tillage (5.8 Mg ha⁻¹) under residue incorporation in third year and also among crop residue management practices, the highest dry weight of weeds (0.22 Mg ha⁻¹) was recorded under residue incorporation.

Yaduvanshi and Sharma (2007) reported that incorporation of wheat residue 50 days before rice transplanting with green manuring along with the recommended dose of fertilizer was necessary to improve and sustain the productivity of rice-wheat system in areas having sodic water. The commonly adopted practice of burning of wheat residue proved to be the least beneficial.

Mandal and Pal (2009) reported that green manuring increased root length, root volume, root dry weight (i.e. root characters) of rice compared with control. Residual effect of green manuring along with added nitrogen also significantly influenced all the root characters of wheat compared with control. Green manuring and its residual effect

increased most of the yield components except test weight, grain yield and straw yield of rice and wheat compared with control.

Jamshidi and Mahmoodzadeh (2011) reported that by using (stalk shredder + moldboard plow + disk), 3 t ha⁻¹ wheat residue and 500 kg ha⁻¹ nitrogen had the significant effect ($p < 1\%$) on grain yield, which produced 35% more in grain yield. There were significant effects on tillage and interaction between tillage and nitrogen amount ($p < 1\%$) in weed population. Also shredder treatment showed minimum number of weed, which was decreased by 28%. The harvest index was 32/24% where (shredder + moldboard plow + disk), 3 t ha⁻¹ wheat residue and 500 kg ha⁻¹ nitrogen were applied.

Arshadullah *et al.* (2012) reported that maximum plant height (135.66 cm) and numbers of grains spike⁻¹ (140.33), spike length (24.66 cm), number of tillers plant⁻¹ (40.33) and 1000-grain weight (23 g) were recorded at the application of 5 tons wheat straw ha⁻¹ along with 90 kg N ha⁻¹ in rice. Grain yield was the maximum (3.32 t ha⁻¹) at the application of 5 tons wheat straw ha⁻¹ along with 90 kg N ha⁻¹ and 26% more than control treatment.

Jai *et al.* (2014) revealed that crop residue incorporation (CRI) with or without *Sesbania* green manure (SGM) significantly influenced the plant height, number of tillers m⁻², number of grains panicle⁻¹ or ear⁻¹, and 1000-grain weight. Mean yield data of rice and wheat revealed that CRI or crop residue burning (CRB) resulted in slightly greater yield over crop residue removal (CRR) treatment. The CRI + SGM treatment again observed significantly greatest grain yields of 7.54 and 5.84 t ha⁻¹ and straw yields of 8.42 and 6.36 t ha⁻¹ in rice and wheat, respectively, over other crop residue management treatments.

2.2 Effect of crop residue management and green manuring on nutrient uptake by crops

Singh and Sharma (2000) reported that wheat residue incorporation with no nitrogen or inadequate nitrogen (60 kg ha⁻¹) had an adverse effect on productivity and nutrient uptake of rice-wheat cropping system. Residue incorporation also resulted in more recovery of fertilizer N by rice and had a significant residual effect on succeeding wheat. It, thus, indicates that fertilizer nitrogen with residue incorporation was conserved and better utilized by rice and succeeding wheat.

Sharma and Prasad (2001) reported that the incorporation of wheat residue had an adverse effect on the productivity of the rice-wheat cropping system. When it was incorporated along with *Sesbania* green manure, not only did its adverse effect disappear but the response to fertilizer N was also increased. There was no response to fertilizer N when *Sesbania* green manure was incorporated. When wheat residue was incorporated along with *Sesbania* green manuring, rice responded significantly to fertilizer N up to 120 kg N ha⁻¹ in the first year and to 60 kg N ha⁻¹ in the second year and at these levels of N, *Sesbania* + wheat residue gave 0.8 to 1.2 t ha⁻¹ more grain, 0.6-1.0 t ha⁻¹ more straw and 8-15 kg ha⁻¹ more N uptake of rice resulting in 0.04-0.17% more organic C, 3-8 kg ha⁻¹ more available P and 17-25 kg ha⁻¹ more available K content in the soil than wheat residue alone at the same rates of N application. The respective increases caused by *Sesbania* green manure + wheat residue over *Sesbania* green manure alone were 0.3-0.5 t ha⁻¹ in the grain and straw yield, 1-9 kg ha⁻¹ in the N uptake of rice, 0.02-0.10% in organic C, 1-8 kg ha⁻¹ in available P and 35-70 kg ha⁻¹ in available K content in the soil. These treatments also gave higher residual effects in succeeding wheat than wheat residue alone. The incorporation of residues of both wheat and *Sesbania* is thus recommended to eliminate the adverse effect of wheat residue and to increase the beneficial effects of *Sesbania* green manuring.

Sharma *et al.* (2001) reported that incorporation of rice residue before wheat sowing had no significant effect on grain and straw yields and phosphorus uptake of wheat but had a significant residual effect on grain yield and phosphorus uptake in succeeding rice.

Das *et al.* (2003) reported that incorporation of crop residues of either rice (*Oryza sativa* L.) straw or wheat (*Triticum aestivum* L. emend. Firori & Paol.) straw increased the yield and yield components of rice and nutrient uptake and also improved the physico-chemical properties of the soil which provided better soil environment for crop growth. Increasing levels of NPK application increased the yield-attributing characters and nutrient uptake by both the crops which ultimately increased the grain and straw yields thus, 100% NPK levels gave the highest yield. There was no significant effect on physico-chemical properties of soil due to increasing levels of NPK application.

Kachroo and Dixit (2005) reported that incorporation of residues of rice in wheat and wheat in rice not only increased the yield and yield components of rice and wheat but also increased the nutrient uptake besides improving the physico-chemical

and biological properties of the soil which provide better soil environment for growth. For quick and better decomposition the application of *Trichoderma viride* + 20 kg N ha⁻¹ as starter dose influenced the yield, available nutrients, microbial population and physical properties of the soil significantly compared with no starter dose application.

Gupta *et al.* (2007) reported that residues incorporation can enhanced yield under limited P supply situations. The P balance was negative with removal or burning of rice straw, but when both wheat and rice straw were incorporated, the balance was positive at the recommended P level (26 kg P ha⁻¹ to wheat only). Incorporation of residues increased soil inorganic, and organic P; reduced P sorption; and increased P release.

Sharma and Prasad (2008) reported that the incorporation of rice and wheat residues can recycle up to 20%-30% of the N absorbed by the crops. However, their wide C: N ratio can temporarily immobilize native and applied N. The combined use of wheat straw and mung-bean produced an additional 0.5-0.6 t ha⁻¹ protein-rich grain and thus appears to be the most promising residue-management option for rice-wheat cropping systems in South Asia, provided that the transition cropping season between wheat harvest and rice transplanting is long enough.

Neeraj and Binod (2013) revealed that nitrogen uptake by grain and straw influenced significantly by rice residue and nutrient management practices during both the years. Highest nitrogen uptake by grain and straw was recorded under the treatment when rice residue incorporated with 30% additional N + P + K + recommended NPK against sowing of wheat without incorporation of rice residue + recommended NPK and rice residue incorporation + recommended NPK.

Dotaniya *et al.* (2013) revealed that NPK uptake were highest in crop residue incorporation as compare to crop residue remove and burnt in rice-wheat system. Nitrogen balance was negative in all the treatments, and potassium balance also follows same as nitrogen except potassium application with crop residue incorporation. Rice-wheat yield and nutrient uptake were significantly higher in case of crop residue incorporation with nitrogen and potassium application.

Jai *et al.* (2014) reported that dehydrogenase and phosphatase enzymes activities have increased significantly after 3 years as a result of the incorporation of residue plus green manure in rice-wheat system. The mean yield data of rice and wheat crops revealed that incorporation in the field resulted in a slightly higher yield over residue removal. Further, higher grain yield (rice = 7.54 t ha⁻¹, wheat = 5.84 t ha⁻¹) was

recorded in residue plus green manuring treatment. Total uptake of the nutrients by rice-wheat crops in sequence was highest (N 203.70, P 37.20, K 203.60 kg ha⁻¹) in case of crop residue plus green manuring treatment.

2.3 Effect of crop residue management and green manuring on soil properties

Green manure legumes improve microbial biomass and soil organic fertility. Being N₂ fixers, legumes are believed to increase the N fertility of soil (Shah *et al.*, 2003) and improve the soil quality when used as green manure (Biederbeck *et al.*, 2005). Legumes are thus often recommended to include in crop rotation with cereals (Bakht *et al.*, 2009). Among cereals, rice and wheat are the two major staple food crops for the people of developing countries. The rice-wheat cropping system is highly nutrient exhaustive and annually remove more than 650 kg ha⁻¹ of N, P and K. Therefore, cause a considerable depletion of soil nutrients. It is thus believed that the involvement of green manure legumes in rice-wheat system is a viable alternative for sustainable production.

2.3.1 Physical properties of soil

Boparai *et al.* (1992) reported that application of green manure to wetland rice increased the water-stable aggregates between 0.1 and 0.5 mm size by 62%, reduced the soil bulk density, and increased infiltration rate. They also revealed that incorporation of green manure increased root density and grain yield of wheat grown after rice.

Walia *et al.* (1995) reported that the residue management system with rice residue removal, residue burning and residue incorporation for both rice and wheat, compared to removal and burning. The incorporation of crop residues decreased bulk density (0-15cm) and penetration resistance (0-15cm) and increase cumulative infiltration rate. Organic carbon content (0-15cm) was significantly greater where either residues of wheat or rice or both were incorporation.

Samra *et al.* (2003) reported that the incorporation of residues into the soil improved soil properties in the rice-wheat system. Crop residue management produced greater effects on yields in fine-textured soils than in coarse-textured soils. The incorporation of wheat residues, in general, increased the yield of rice and also had a positive residual effect on the yield of subsequent wheat.

Sandeep *et al.* (2004) reported that bulk density of soil under various tillage and residue treatments were significantly large but was narrowed down up to the harvest of

the crop. The bulk density of cultivated plots, irrespective of residue management, recorded just before sowing was lower than the uncultivated plots at a depth of 0-15cm, while at a soil depth of 15-30cm the lower value was recorded from deep incorporation of residue regardless of the tillage type, at a depth of 0-15cm only. Deep tillage incorporation of rice residue scaled higher attributes and grain yield. The lowest grain yield was obtained from the residue removed traditionally tilled plot. The number of tiller generated by each plant was highest from the crop receiving retention/incorporation of residue with conservation and deep tillage.

Saraiya *et al.* (2005) reported that the application of compost prepared from rice residue to wheat decreased the soil bulk density and penetration resistance, and increased the hydraulic conductivity, infiltration rate, organic carbon content, available nitrogen, and grain and straw yield of wheat, compared with the other crop residue treatments. Among the tillage practices, the continuous use of zero tillage for the last 10 years decreased the soil bulk density and penetration resistance, and increased the hydraulic conductivity, infiltration rate, organic carbon content, available nitrogen and the grain and straw yield of wheat compared with the other tillage practices.

Gangwar *et al.* (2006) reported that highest infiltration rate (1.50 cm hr^{-1}) was recorded in residue incorporation followed by residue burning (1.44 cm hr^{-1}), whereas the lowest (0.75 cm hr^{-1}) in zero tillage. Soil bulk density was the highest (1.69 Mg m^{-3}) under zero tillage and the lowest in residue incorporation (1.59 Mg m^{-3}). Residue incorporation increased soil organic carbon and available P while higher available K was monitored in burning treatment during the third year.

Gurpreet *et al.* (2007) evaluated the effect of eight treatments comprised of various combinations of green manure (GM), wheat straw (WS), rice straw (RS), farmyard manure (FYM) and urea alone (control) on physical and hydraulic properties of soil in a rice-wheat experiment (1988-2001) on a loamy sand in Punjab, India and reported that after rice harvest, organic carbon (OC) content in the FYM (0.51%), WS (0.56%) and WS + RS (0.59%) treatments were significantly greater as compared to control (0.42%). With addition of GM to all these treatments; FYM + GM (0.59%), WS + GM (0.60%), WS + RS + GM (0.64%) and GM (0.47%), organic carbon content further increased significantly. Increased OC content of the soil in turn improved its aggregation status, infiltration rate and decreased the bulk density, dispersion ratio and soil strength correspondingly. After wheat harvest mean effects of these organic treatments continued, but their magnitude decreased. The differences in rice yield were

not significant among urea, GM and WS applied alone or in combination. However, FYM + GM + urea produced highest yield. There was no residual effect of the long-term application of GM, WS and RS incorporation in wheat yields, but FYM application to rice showed significant residual effects on wheat.

Reshmi Sarkar and Sandipta Kar (2011) reported that a comparatively lower rate of N along with rice-wheat (RW) residue incorporation in combination with less intensive puddling for rice and medium-intensive tillage for wheat could be opted as sustainable management practices. Thus, the use of comparatively lower rate of N would reduce water pollution from extra leached N and the cost of farming, too. On the other hand, use of RW residue would enrich the soil organic carbon pool and improve the quality of the soil. Use of less intensive tillage along with RW residue application would increase the porosity of the soil, reduce soil erosion, and help sustain the RW system.

Sarkar and Sandipta (2011) evaluated that crop residue incorporation helped decrease the negative impact of intensive tillage by increasing infiltration rate and decreasing soil strength. Incorporation of both rice and wheat residue to lateritic sandy loam helped improve soil quality and sustain yield of rice-wheat system.

Shreyasi *et al.* (2014) revealed the influence of different combinations of tillage and residue management on carbon stabilization in different sized soil aggregates and also on crop yield after 5 years of continuous rice- wheat cropping system on a sandy loam reclaimed sodic soil of north India and concluded that residue incorporation caused a significant increment of 15.65% in total water stable aggregates in surface soil (0-15 cm) and 7.53% in sub-surface soil (15-30 cm) while investigating tillage and residue management effects on soil aggregation, organic carbon dynamics and yield attribute in rice-wheat cropping system under reclaimed sodic soil.

2.3.2 Chemical properties of soil

Beri *et al.* (1992) observed that residue incorporation increased soil N, P, K, available S, DTPA-extractable Fe and organic carbon contents and residue management did not affect DTPA-extractable Cu or soil pH. Incorporating residue resulted in 5-10 times more aerobic bacteria and 1.5-11 times more fungi.

Walia *et al.* (1998) reported that rice residue incorporation resulted in a positive flux of N, P and K when experimented in the soil of Punjab. The incorporation of rice residue resulted in maximum increase in the organic carbon content compared to the

initial value. The management of rice residue could be beneficial through the incorporation method compared to burning and removal.

Prasad *et al.* (1999) observed that incorporation of crop residues also improved soil fertility status as judged by organic carbon and available phosphorus and potassium contents. Residue incorporation was more beneficial than residue burning, which resulted in the loss of valuable plant nutrients.

Sharma *et al.* (2000) revealed that there was a significant reduction in bulk density with significant improvement in water holding capacity, cation exchange capacity, available N, P and S status of soil with addition of crop residues and FYM in rice-wheat sequence. The DTPA extractable Zn, Fe, Mn and Cu and microbial population enhanced significantly due to crop residues and FYM as compared to the chemical fertilizers alone.

Dhiman *et al.* (2000) reported that rice/wheat grain yield was significantly superior with the incorporation of residues of both rice and wheat crops to their burning and removal. The average productivity of the system was the highest ($114.6 \text{ q ha}^{-1}\text{year}^{-1}$) where the residues of both the crops were incorporated, which was 6.0 and $6.2 \text{ q ha}^{-1}\text{year}^{-1}$ higher than from their burning and removal respectively. Higher fertility ($150 + 60 + 25 \text{ kg N, P}_2\text{O}_5 \text{ and ZnSO}_4 \text{ ha}^{-1}$) registered significantly higher grain yield than lower ($100 + 40 + 25 \text{ kg N, P}_2\text{O}_5 \text{ and ZnSO}_4 \text{ ha}^{-1}$). Organic carbon and total nitrogen in the soil increased with the incorporation of crop residues but decreased with their burning.

Aulakh *et al.* (2001) evaluated that rice and wheat residue did not affect grain yields of wheat and rice but residue incorporation did result in reduced recovery efficiency of urea N and green manure N. Rice production was greater with wheat residue incorporation when an average of 86 kg N ha^{-1} of a prescribed 120 kg N ha^{-1} dose was applied as green manure N and the balance as urea N vs. $120 \text{ kg urea N ha}^{-1}$ alone.

Milah *et al.* (2001) evaluated that green manuring had a beneficial impact on pH, organic-C, $\text{NH}_4^+\text{-N}$, and $\text{CO}_2\text{-C}$ of soil and also revealed that $\text{CO}_2\text{-C}$ were comparatively low in plots where inorganic N was supplemented with or without green biomass at later crop growth stages, which might be due to a probable detrimental effect of inorganic N on the microbial population. It is concluded that green manuring

with *Sesbania* spp. of 15 t ha⁻¹ along with inorganic N 20 kg ha⁻¹ might be sufficient for maintaining both satisfactory rice yield and favourable soil environment in acid rice soil under humid subtropical conditions.

Aulakh *et al.* (2001) reported that despite of wider C: N than rice residue, wheat residue additions to flooded rice resulted in greater C sequestration in soil than with rice residue or 40 t green manure ha⁻¹. These results demonstrate that a green manure crop and/or incorporating crop residue in a rice-wheat system have potential to increase SOM while maintaining high grain yields.

Kharub *et al.* (2003) reported that continuous incorporation of *Sesbania aculeata* as green manure increased organic carbon by 8.7%, available N by 12.1%, Olsen's P by 10.1 % and available K by 5.0 % in soil compared to rice-wheat sequence. It also added 97-109 kg N ha⁻¹ and enhanced the wheat-equivalent yield in the rice-wheat system. Electrical conductivity and pH of soil decreased due to the inclusion of green-manure.

Mandal *et al.* (2004) evaluated that incorporation rice straw leads to build up of SOM, soil N, P and K. The major disadvantage of incorporation is the immobilization of inorganic N. However, N at 15-20 kg ha⁻¹ as starter dose with straw incorporation increases yield of wheat and rice compared to burning. They also reported that rice straw incorporation coupled with organic manure increases grain yield of wheat and improves soil physical condition. Residue incorporation results more microbial activity than residue removal or burning. Thus, if residues are managed properly, then it can warrant the improvements in soil properties and the sustainability in crop productivity.

Kumar *et al.* (2004) reported that deep incorporation of rice residue improved the growth and yield attributes, which led to higher grain yield over others. Conservation tillage produced dwarf plants and smaller grains. Management of residue either by deep tillage or by conservation tillage yielded broader flag leaves. The fertility status of soil after wheat harvest in terms of organic carbon, available N, P and K got enriched by the incorporation or retention of residue, irrespective of tillage types, being the highest under conservation tillage.

Kharub *et al.* (2004) evaluated that the soil organic matter contents increased with GM (by 15%) and RS incorporation singly (By 13%) or in combination (by 26.7%) with GM. RS incorporation with or without GM increased the availability of

phosphorus (P) content by 8% and 12% over RS removal and the initial P value. It was also observed that potash (K) content of the soil increased by 1.1 to 14.0% with RS incorporation with or without GM and by 7.0% with RS burning.

Yadvinder *et al.* (2004) revealed that residue incorporation for 10 to 40 d had no effect on wheat yields. Rice yields increased ($0.18\text{--}0.39\text{ Mg ha}^{-1}$) when wheat residue was incorporated with GM. Starter N applied at residue incorporation did not influence wheat yields but decreased N recovery efficiency. Physiological efficiency was higher when rice straw was incorporated in wheat and when wheat straw plus GM were incorporated in rice than when rice straw was incorporated for 10 d or when the straw was burned. The long-term application of rice residue increased C accumulation in soil.

Raju and Reddy (2000) revealed that organic carbon status declined in the control and among the normal fertilized plots, more organic carbon was present in straw incorporated plots. Potassium values were remarkably augmented in all organic fertilized plots but more conspicuous in straw-applied treatments.

Sharma and Sharma (2005) were reported that retention or incorporation of rice, wheat or both crop residues increased soil organic C by 19-32% (absolute increases of 0.06-0.1% organic C) in the top 15 cm soil layer after 2 years (four crops) in comparison with both the initial soil organic C and 2 years of burning the residues of both crops. The other benefits of residue retention were decreased soil strength and lower weed infestation.

Roy *et al.* (2006) reported that the application of rice and wheat straw increased plant recovery as well as soil retention of N fertilizer in both rice and wheat crops. Crop residue incorporated with urea showed no significant increase in rice yield compared to the control but the residual effect of crop residue on succeeding wheat increased crop yield.

Singh and Yadav (2006) revealed that the highest mean grain yield of 33.6 q ha^{-1} was recorded on incorporation of residue, which was respectively 14.72 and 8.64 per cent more than when the residue was removed and retained. Residue incorporation also increased the organic carbon content in the soil by 0.37, 0.35 and 0.31 per cent in residue incorporated, retained and removed treatment respectively. It also increased the organic carbon content in the soil by 17.73 and 5.71 per cent in comparison with residue removed and retained treatment over a period of 2 years.

Vikas *et al.* (2006) revealed that maximum soil available nitrogen, phosphorous, potassium, sulphur and zinc, and minimum bulk density were noticed with substitution of 50 % N by green manure. However, the pH value and EC were almost constant. Integrated use of 50 % NPK and 50 % N through green manuring to rice followed by 100 % NPK to wheat also fetched the maximum net monetary returns (Rs. 34,403 ha⁻¹ year⁻¹) with the benefit: cost ratio of 2.40.

Kumar *et al.* (2008) reported that the incorporation of crop residues along with 50% NPK and FYM or GM contributed towards meeting 50% NPK requirement of rice. Long-term application of crop residues and organic manures increased the soil organic C content of soil. The combined use of crop residues, organic amendments and chemical fertilizers significantly increased the availability of N, P, K, S and micronutrients in soil over chemical fertilizers alone.

Fateh *et al.* (2008) revealed that cultivation of rice and wheat on the recommended dose of NPK fertilizers alone decreased the organic carbon, available P and K content of the soil. Application of FYM, vermicompost, green manuring, and rice residue incorporation alone or in combination with biofertilizers supplemented by NPK fertilizers improved the soil fertility besides maintaining higher sustainable productivity.

Dhaliwal and Walia (2008) reported that higher productivity was obtained when 50 per cent NPK was applied through chemical fertilizers in combination with 50 per cent N through FYM or green manure to get grain yield of 11.0 t ha⁻¹ in rice-wheat system over time. The incorporation of FYM, GM and CR₁ in the soil had beneficial effect on soil health by improving physico-chemical properties besides supplying the macronutrients like N, P and K and increasing the availability of the micronutrients like Zn, Cu, Fe and Mn in the soil. Moreover, the results also revealed that the addition of these manures decreased the bulk density and increased the levels of organic carbon, field capacity, permanent wilting point and available soil moisture.

Fateh *et al.* (2008) evaluated that cultivation of rice and wheat on the recommended dose of NPK fertilizers alone decreased the organic carbon, available P and K content of the soil. Application of green manuring, and rice residue incorporation alone or in combination with biofertilizers supplemented by NPK fertilizers improved the soil fertility besides maintaining higher sustainable productivity.

Yadvinder *et al.* (2009) reported that recycling of rice residue (incorporation and surface mulch) compared with straw burning increased soil organic carbon and the availability of soil P and K. Soil N mineralization at 45 days after incubation was 15-25% higher in straw retention plots compared with on straw burnt plots.

Reshmi Sarkar and Sandipta Kar (2011) evaluated that application of crop residues and intensive tillage increased the N leaching loss; however, it also increased N uptake and yield of rice and wheat crops and resulted in minimal degradation of soil environment. Overall results of loss, uptake, N-use efficiency, and yield attributes of rice and wheat crops indicated that a comparatively lower rate of N along with RW residue incorporation in combination with less intensive puddling for rice and medium-intensive tillage for wheat can be opted as sustainable management practices. Thus, the use of comparatively lower rate of N will reduce water pollution from extra leached N and reduce the cost of farming, too. On the other hand, use of rice and wheat residue will enrich the soil organic carbon pool and improve the quality of the soil. Use of less intensive tillage along with rice and wheat residue application will increase the porosity of the soil, reduce soil erosion, and help sustain the rice-wheat system.

Ramesh Chandra (2011) reported that mean grain and straw yields of wheat for two years and organic C, available N and P in soil at the end following residue incorporation were significantly higher over removal, by 6.6, 4.4, 3.4, 7.2 and 7.8%, respectively. It also increased the microbial population and MBC by 10.2%, in the soil after harvest of second wheat crop irrespective of summer crops, their residue incorporation improved the yield of succeeding wheat and soil properties.

Bahrani *et al.* (2012) reported that residue incorporation significantly increased soil organic carbon (SOC) as well as available K and P content. It was possible to sow red common bean as a double cropping by soil incorporation of 25-50% wheat residues with application of 69 kg N ha⁻¹.

2.3.3 Biological properties of soil

Bhattacharaya *et al.* (1990) reported that green manuring alone encouraged the growth of bacteria, *Actinomycetes* and fungi at the early tillering stage of rice. Following green manuring, the application of further manures decreased the bacterial and fungal populations. The application of ammonium sulphate and rock phosphate, however, stimulated *Actinomycete* growth. By final harvest, application of additional

manures had increased the microbial population as a whole, with bacteria and *Actinomycetes* affected most by application of farmyard manure, and fungi affected most by ammonium sulfate applications.

Bhardwaj and Datt (1995) reported that significant improvements were observed in the microbial biomass, dehydrogenase activity, and bacterial populations in the field soil green-manured for rice for 3 years, compared with fertilized soil.

Jat *et al.* (2004) evaluated that the total soil microbial population count on 30 and 60 days after sowing of wheat was higher under residue incorporation compared to in situ burning and also revealed that bacterial population was higher under rice residue incorporation and inoculated with cellulolytic fungi.

Tilak (2004) reported that the microbial counts, namely bacteria, *Actinomycetes*, fungi, *Azotobacter*, *Azospirillum*, phosphate solubilizing bacteria, the microbial biomass in the soil and nitrogenase activity in the roots were markedly high in soil where green manuring with *S. rostrata*, *S. aculeata* and mung bean was incorporated than in fallow soil. *S. rostrata* increased the microbial biomass by 148.2 and 258.8% with rice and wheat, respectively, at 0-15 cm soil depth. A similar trend was observed with the nitrogenase activity, which was 19.8 and 13.8 times higher than the fallow soil with rice and wheat, respectively, due to *S. rostrata* green manuring. The increase in shoot dry biomass and grain yield due to *S. rostrata* green manuring over no amendment was 3.1 and 2.5 times, respectively with rice, and 1.9 and 2.4 times, respectively, with wheat.

Yuan *et al.* (2011) revealed that long-term chemical fertilizer and crop residue incorporation improved soil quality and fertility, and consequently resulted in the shift of the bacterial micro-ecology and promoted the bacterial diversity and abundance.

Jai *et al.* (2014) revealed that total nitrogen (N), phosphorus (P) and potassium (K) uptake in rice-wheat system was greatest with amounts of 206.7, 37.2, and 205.6 kg ha⁻¹, respectively, in CRI + SGM treatment. Total NPK uptake in rice-wheat system also increased significantly with increase in fertility levels with greatest magnitude by supplying 150% of recommended NPK. This indicates that crop residue management along with *Sesbania* green manuring practice could be a better option for nutrient recycling to sustain the crop productivity and soil health in intensive rice-wheat cropping system in India as well as in similar global agro-ecological situations, especially in China, Pakistan, and Bangladesh.

LiJin *et al.* (2015) revealed that residue incorporation significantly increased MBC (microbial biomass C) by 18.3 % and SOC content of 2-1 mm aggregate by 9.4 %. Residue returning significantly enhanced total bacterial biomass, fungal biomass by 36.0 and 95.9 R% respectively, but decreased microbial stress by 45.9 %.

2.4 Effect of crop residue management and green manuring on net energy return and economics of rice-wheat system.

2.4.1 Net energy return

Baishya and Sharma (1990) revealed that shallow submergence for rice throughout the growing period proved superior to rainfed and irrigation 3 days after subsidence of ponded water as far as net return of energy was concerned. However, the highest energy ratio (output per unit) was observed under rainfed condition. A similar trend was observed in rice and rice-wheat sequence as a whole. Green-manuring of Dhaincha + *Azolla* and green gram + *Azolla*, respectively can minimize mean energy input to the tune of 32110-3600 MJ ha⁻¹ and 600- 655 MJ ha⁻¹ in rice and wheat, respectively.

Raju and Reddy (2000) reported that the highest (121.1 q ha⁻¹) rice-rice system productivity was obtained with the use of *Sesbania* green leaf to substitute 50% NPK need. All organics in conjunction with inorganic fertilizers were superior to sole chemical fertilization in terms of agronomic efficiency. Green-leaf manuring with *Sesbania* resulted in the maximum energy output (1,70,079 MJ ha⁻¹) and with lesser energy (8,292 MJ ha⁻¹) involvement and resulted in the highest energy ratio (19:5).

2.4.2 Economics

Katyal *et al.* (2002) reported that the maximum net returns of Rs. 38,388 ha⁻¹year⁻¹ could be realized at Ludhiana when 75 % recommended NPK + 25 % N through green manuring was applied to rice followed by 75 % N to wheat, whereas the maximum net returns of Rs. 27,061 ha⁻¹year⁻¹ at Jabalpur and Rs. 22,658 ha⁻¹year⁻¹ at Kalyani could be recorded with the use of 50 % recommended NPK + 50 % N through green manuring to rice and 100 % NPK to wheat in rice-wheat system.

Sharma and Sharma (2005) revealed that partial diversification of rice-wheat system by including mungbean during summer (May-June) in the rice-wheat system resulted in an increase in productivity and profitability. The rice-wheat-mungbean cropping system recorded the maximum harvest density index, multiple cropping index

and simultaneous cropping index, indicating higher land use efficiency than the other rice-based cropping systems. In view of higher productivity and more profit obtained with rice-potato-mungbean, rice-clover, rice-rapeseed-mungbean and rice-wheat-mungbean cropping systems as compared to the rice-wheat cropping system, the diversification of this cropping system is recommended for sustainable production.

Khankhane *et al.* (2009) reported that residue incorporation gave highest net monetary return of Rs. 57781 followed by Rs. 51440 and Rs. 48081 per hectare in the burning and straw removal treatments, respectively. The highest B: C of 6.79 was also recorded in the residue incorporation treatment followed by 6.19 and 3.86 in the burning and straw removal treatments, respectively. Herbicide application increased wheat yield and the net monetary return (B: C ratio). Irrespective of straw management practices, no increase in wheat yield was recorded beyond the N dose of 120 kg ha⁻¹. Compared to burning, the incorporation of rice straw significantly increased the organic C, and the bacterial and fungal population in soil. It was concluded that rice straw incorporation 5 tha⁻¹ was best among the given straw management practices in terms of weed density reduction, improved soil health, increased wheat yield, monetary return and B: C ratio.

Kumar *et al.* (2005) revealed that deep incorporation of rice residue either by disc plough or by mould-board plough proved a better option for effective disposal of rice residue and recorded significantly higher grain yield as well as net returns of wheat.

CHAPTER 3

**MATERIALS
AND
METHODS**

MATERIALS AND METHODS

The field experiment reported in this manuscript was carried out to study the effect of crop residue management and green manuring on productivity and soil fertility in rice-wheat system. The experiment was carried out during the *kharif* and *rabi* seasons of 2013-14 and 2014-15. The details of the procedures and agro-techniques adopted during the course of experiment are described in this chapter.

3.1 Experimental site

The experiment was conducted at District Seed Farm, Kalyani, Bidhan Chandra KrishiViswavidyalaya, Mohanpur, Nadia, West Bengal, India. The farm is situated at 22° 56' N latitude and 88° 32' E longitudes and at an altitude 9.75 m above the mean sea level (AMSL). The experimental site was selected under medium- upland situation.

3.2 Soil characteristics of the experimental site

The texture of the soil was sandy loam soil with good drainage capacity. The soil has almost neutral pH. The relevant physico-chemical properties of the soil are presented in Table 3.1.

Table 3.1: Physico-chemical properties of the experimental soil:

A. Physical properties		
Particulars	Values	Method followed
Sand (%)	48.50	International Pipette method (Piper, 1966)
Silt (%)	30.00	
Clay (%)	21.50	
Bulk density (0-15cm), g/cc	1.40	Field method (Bodman and Colman, 1944)
B. Chemical properties		
Particulars	Values	Method followed
Organic carbon (%)	0.45	Walkley and Black Method (Jackson, 1973)
Total Nitrogen (%)	0.05	Modified Kjeldhal method (Jackson, 1973)
Available Nitrogen (%)	227.65	Modified Kjeldhal method (Jackson, 1973)
Available P ₂ O ₅ (%)	19.72	Olsen's Method (Jackson, 1973)
Available K ₂ O (%)	218.96	Flame photometer method (Jackson, 1973)
Soil pH	7.59	Blackman's pH meter (Jackson, 1973)

3.3 General meteorological features of the experimental site

The experimental site falls under sub-tropical humid climate having a short and mild winter but the summer season is humid and receives rainfall with thunderstorm occasionally. The mercury reaches its maximum in the month of May, whereas the coldest day is usually observed during January. The South-West monsoon generally breaks during the first week of June and withdraws from the area during the first week of October. The average annual rainfall is about 1500 mm, 85 % of which is received during June to September and also the humidity is at maximum during this period. The mean monthly temperature ranges from 10 °C to 37 °C.

Table 3.2: Meteorological data during the period of experimentation

Month	Temperature (°C)		Relative Humidity (%)		Rainfall (mm)
	Avg. Max.	Avg. Min.	Avg. Max.	Avg. Min.	
June, 2013	34.2	26.4	94	79	206.8
July, 2013	33.4	26.5	95	81	180.3
August, 2013	32.8	26.0	96	82	314.5
September, 2013	34.1	26.0	97	76	228.4
October, 2013	31.4	23.9	95	79	257.5
November, 2013	30.0	16.4	84	56	00
December, 2013	27.0	12.5	84	59	00
January, 2014	24.5	10.4	86	63	00
February, 2014	28.5	13.7	85	53	28.5
March, 2014	33.9	15.9	86	46	26.2
April, 2014	39.4	24.9	86	38	0.0
May, 2014	37.6	26.7	88	57	80.5
June, 2014	35.4	27.0	93	76	329.5
July, 2014	32.9	26.9	96	83	278.1
August, 2014	34.2	26.5	95	77	281.4
September, 2014	34.0	25.8	95	77	330.5
October, 2014	33.6	23.1	88	68	81.9
November, 2014	32.2	15.9	80	50	0.0
December, 2014	26.7	12.0	86	58	0.0
January, 2015	26.6	11.8	84	58	2.5
February, 2015	31.7	15.6	83	47	13.6
March, 2015	35.5	19.2	82	39	21.4

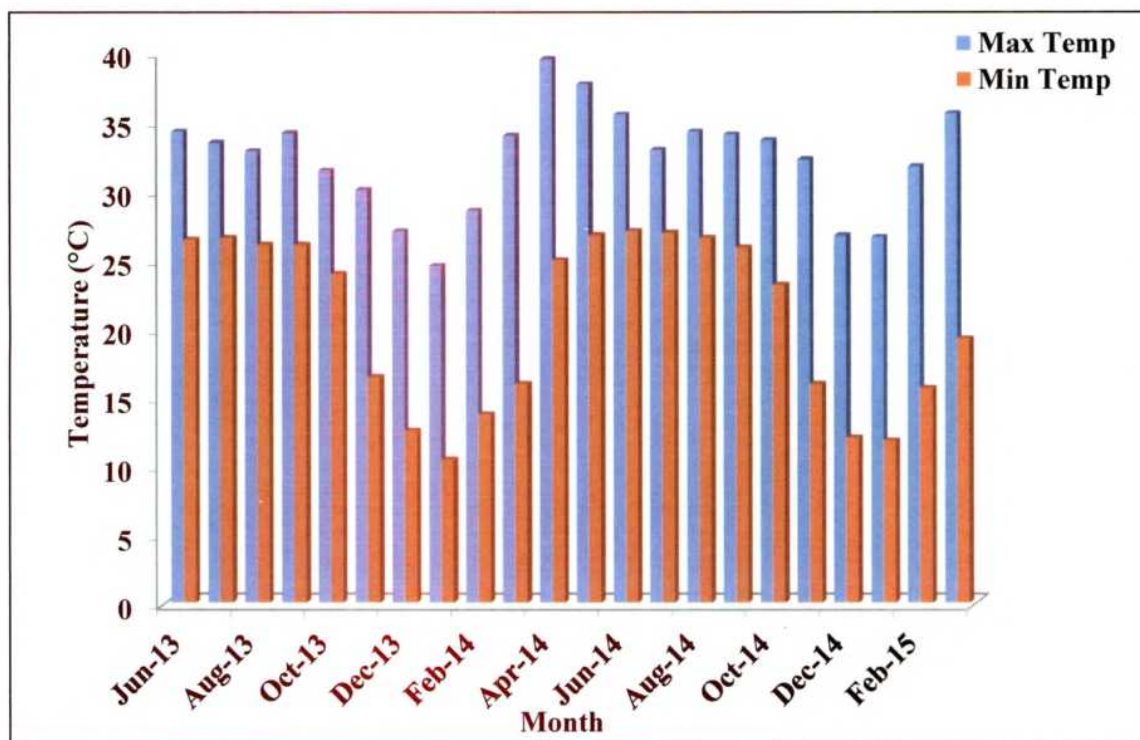


Fig. 3.1 Monthly Max. and Min. temperature

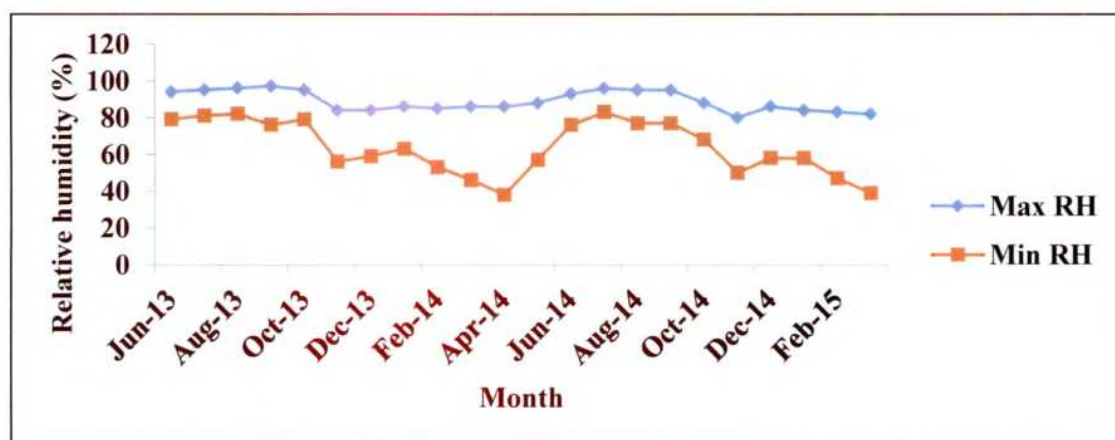


Fig. 3.2 Monthly Max. and Min. relative humidity

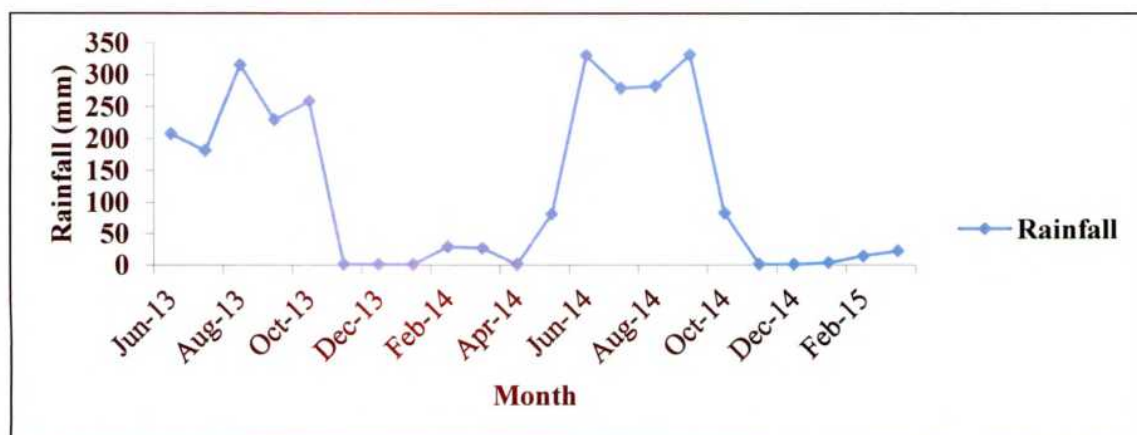


Fig. 3.3 Monthly rainfall

3.3.1 Temperature

Weather conditions during the period of experimentation have been presented in the Table 3.2. The experiment was conducted from June, 2013 to March, 2015. It was observed that mean maximum temperature was highest in the month of June in 2013 (34.2 °C) and in April in 2014 (39.4 °C) whereas the mean minimum temperature was recorded lowest in the month of January during both the years i.e. 2014 and 2015 (10.4 °C and 11.8 °C, respectively). It was also observed that the mean maximum temperature went below 30°C in November in 2013 and in December, 2014. The ideal temperature for sowing wheat is considered to be 22 ± 2 °C and that was available in the month of November in both the years.

3.3.2 Rainfall

Most of the rainfall occurred during June to September in both the years. It varied from 180.3 to 314.5 mm and 278.1 to 330.5 mm during 2013 and 2014, respectively. Total rainfall during these months was measured to be 930 mm and 1219.5 mm in 2013 and 2014, respectively.

3.3.3 Relative humidity

Mean maximum relative humidity was recorded in the month of September (97%) in 2013 and in July, 2014 (96%) whereas the mean minimum relative humidity was found to be in the month of April (38%) in 2014 and in the month of March (39%) in 2015.

3.4 Cropping history of the experimental field

Cropping history of the experimental field for the last three years prior to experimentation was as follows:

Table 3.3: Cropping history of the experimental field

Year	Pre-kharif	Kharif	Rabi
2010	-	Rice	Wheat
2011	-	Rice	Wheat
2012	-	Rice	Wheat

3.5 Design and layout of the experiment

The experiment was laid out in Randomized block design with nine treatments and three replications. Details of the experiment were given in Table 3.4:

Table 3.4: Details of the experiment

Experimental site	: District Seed Farm (AB Block), Kalyani
Design	: RBD
Number of replication	: 3
Treatments	: 9
Numbers of plots	: $3 \times 9 = 27$
Gross plot size	: $2.60 \text{ m} \times 6.0 \text{ m} = 15.6 \text{ m}^2$
Net plot size	: $2.20 \text{ m} \times 6.0 \text{ m} = 13.2 \text{ m}^2$

Table 3.5: Treatment details

Treatments	Particulars
T ₁	Control
T ₂	Soil test based recommended fertilizer (For rice- 80:35:40 NPK kg ha ⁻¹ and for wheat- 140:60:70 N, P ₂ O ₅ and K ₂ O kg ha ⁻¹)
T ₃	Rice residue incorporation + T ₂
T ₄	Wheat residue incorporation + T ₂
T ₅	Rice residue incorporation + Wheat residue incorporation + T ₂
T ₆	Green manuring + T ₂
T ₇	Rice residue incorporation + T ₆
T ₈	Wheat residue incorporation + T ₆
T ₉	Rice residue incorporation + Wheat residue incorporation + T ₆

Table 3.6: Calendar of field operations

Particulars	Dates of operations in first year (2013-14)	Dates of operations in second year (2014-15)
Rice		
Nursery bed preparation	16.06.2013	04.06.2014
Sowing of seed	21.06.2013	10.06.2014
Main field preparation	09.07.2013	02.07.2014
Preparation of layout	13.07.2013	07.07.2014
Basal application of fertilizers	15.07.2013	09.07.2014
Transplanting	16.07.2013	10.07.2014
Irrigation	Nil	Nil
Weeding	04.08.2013	29.07.2014
Top dressing	05.08.2013 26.08.2013	31.07.2014 20.08.2014
Harvesting	20.10.2013	11.10.2014
Incorporation of crop residues	24.10.2013	21.10.2014
Wheat	Dates of operations in first year (2013-14)	Dates of operations in second year (2014-15)
Last ploughing followed by laddering	18.11.2013	16.11.2014
Basal application of fertilizer	20.11.2013	18.11.2014
Sowing of seed	20.11.2013	18.11.2014
Irrigation	22.11.2013 12.12.2013 05.01.2014 29.01.2014 18.02.2014	20.11.2014 10.12.2014 02.01.2014 27.01.2015 16.02.2015
Weeding	10.12.2013 02.01.2014	09.12.2014 31.12.2014
Top dressing	11.12.2013 03.01.2014	09.12.2014 01.01.2015
Harvesting	26.03.2014	23.03.2015
Incorporation of crop residues	28.05.2014	
Sowing of green manuring crop	28.05.2014	
Incorporation of green manure crop	02.07.2014	

3.6 Land preparation

3.6.1 Rice

To achieve good tilth, the land was ploughed repeatedly lengthwise and crosswise with the help of tractor before sowing. Final land preparation was done with the help of power tiller and subsequent laddering was done for proper leveling of the field. The plots were puddle with the help of power tiller.

3.6.2 Seedbed preparation of rice

The wet nursery bed was prepared for raising seedlings. Soaked treated seeds were sown in the seedbed and after emergence about 2 cm depth of water was maintained throughout the nursery period.

3.6.3 Wheat

The land was prepared by repeated ploughing with a power tiller and then leveling was done properly with the help of a wooden log.

3.6.4 Layout of the field

After leveling, the field was laid out as per experimental design. The bunds, irrigation channels were made properly.

3.7 Fertilizers application

3.7.1 Rice

Soil test based fertilizer dose @ 80 kg N, 35 kg P_2O_5 and 40 kg K_2O per hectare was applied except for control plots. The details of the fertilizer application are presented below:

The residues were incorporated in the soil by power tiller after chopping. During incorporation of rice residue (for wheat crop) 20 kg N and *Trichoderma* sp. @ 5 g m^{-2} of crop residue was applied for better decomposition.

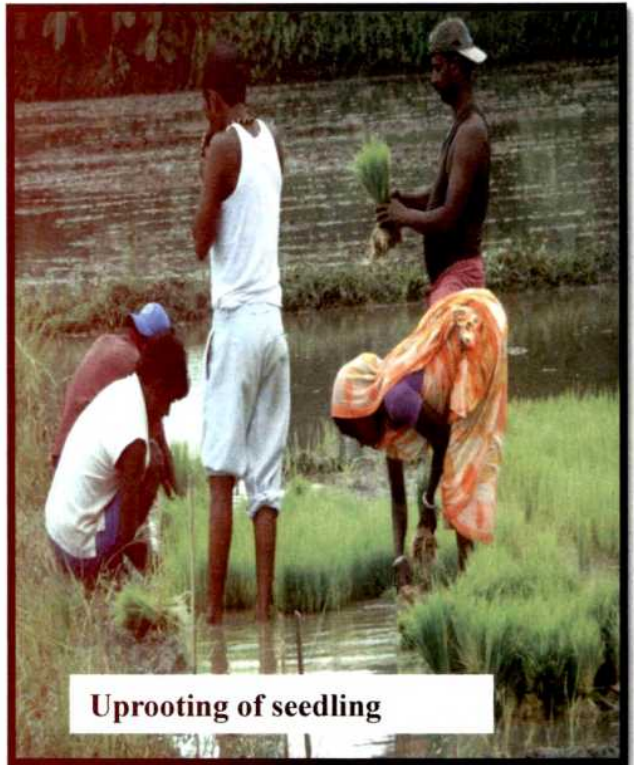
- i) $\frac{1}{4}^{th}$ N + Full P_2O_5 + $\frac{2}{3}^{rd}$ K_2O - applied as basal
- ii) $\frac{1}{2}$ N- applied as first top dressing at tillering stage i.e. at 15 DAT
- iii) $\frac{1}{4}^{th}$ N + $\frac{1}{3}^{rd}$ K_2O - applied as second top dressing at panicle initiation stage

3.7.2 Wheat

Soil test based fertilizer dose i.e. 140 kg N, 60 kg P_2O_5 and 70 kg K_2O per hectare. Nitrogen was applied in three splits and the whole amount of P_2O_5 and K_2O were applied as basal. The details of the fertilizers application are as follows:



Seedling raising



Uprooting of seedling



Land preparation for rice plot

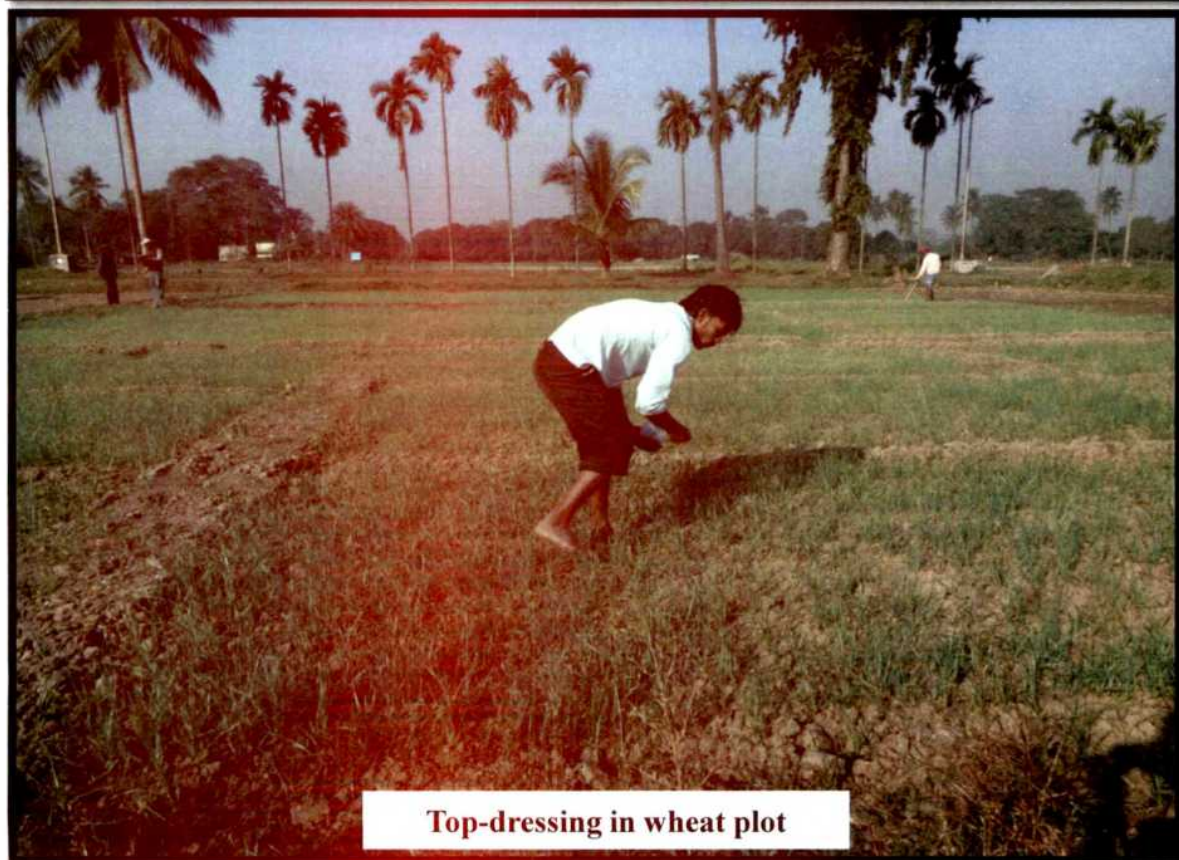


Transplanting of rice seedling

Plate 1: Field operation in rice field



Sowing of wheat



Top-dressing in wheat plot

Plate 2: Field operation in wheat field

- i) $1/3^{\text{rd}}$ N + Full P_2O_5 + Full K_2O - applied as basal
- ii) $1/3^{\text{rd}}$ N- applied as first top dressing at CRI stage i.e. 21 DAS
- iii) $1/3^{\text{rd}}$ N- applied as second top dressing at maximum tillering stage i.e. at 42 DAS

The N, P and K were applied as urea, Single Super Phosphate and Muriate of Potash, respectively.

3.8 Incorporation of crop residues

Crop residues of rice and wheat @ 5 t ha^{-1} were incorporated in the experimental plots as per layout planned after the harvest of each crop and on an average the range of N content in rice and wheat straw was 0.86-1.13 % and 0.78-1.05%, respectively.

For the following rice crop, loose straw was uniformly distributed after wheat harvest. The wheat straws were incorporated after chopping. During incorporation of wheat residue 20 kg N and *Trichoderma* sp. @ 5 g ha^{-1} of crop residue was applied for better decomposition. The same day, *Sesbania* seeds previously soaked overnight in water spread on the soil surface at 30 kg ha^{-1} and mixed with the soil with the help of spades.

3.9 Green manuring

The green manuring crop *Sesbania aculeata* was sown after the harvest of wheat crop in last week of May in the plots as per layout of the experiment where green manuring treatment had to be done. The crop was incorporated in the soil/field at 35 days after sowing and on an average the nitrogen percentage of the GM crop was 2.52%.

3.10 Seed rate

Seed rate for rice was 40 kg ha^{-1} and for wheat was 100 kg ha^{-1} .

3.11 Spacing

Rice: Inter and intra row spacing was maintained at 20 cm.

Wheat: Row to row spacing was maintained at 20 cm.

3.12 Management of crops

3.12.1 Seed treatment

Seeds were treated by Mancozeb @ 2.5 g ha⁻¹ for rice and for wheat seeds were treated with vitavax @ 2 g ha⁻¹.

3.12.2 Sowing

3.12.2.1 Sowing of rice

After the proper seedbed preparation the treated seeds were broadcasted.

3.12.2.2 Transplanting of rice

Age of rice seedling transplanted in the main experimental plots has been mentioned in the Table 3.6. Two to three seedlings per hill were transplanted.

3.12.2.3 Wheat

After the proper land preparation the treated seeds were sown continuously maintaining 20 cm row spacing.

3.12.3 Weeding

3.12.3.1 Rice

One hand weeding was done roughly at three weeks after transplanting.

3.12.3.2 Wheat

One hand weeding was done at twenty one days after sowing. The second was given after another 21 days of first one.

3.12.4 Water management

3.12.4.1 Rice

The crop was mostly grown in rainfed condition.

3.12.4.2 Wheat

One post-sowing irrigation was given to obtain uniform germination as well as establishment of crops. Thereafter, irrigation was given at crown root initiation stage (CRI, 21 DAS), maximum tillering stage (42 DAS), flowering stage (70 DAS) and hard dough stage (90 DAS).

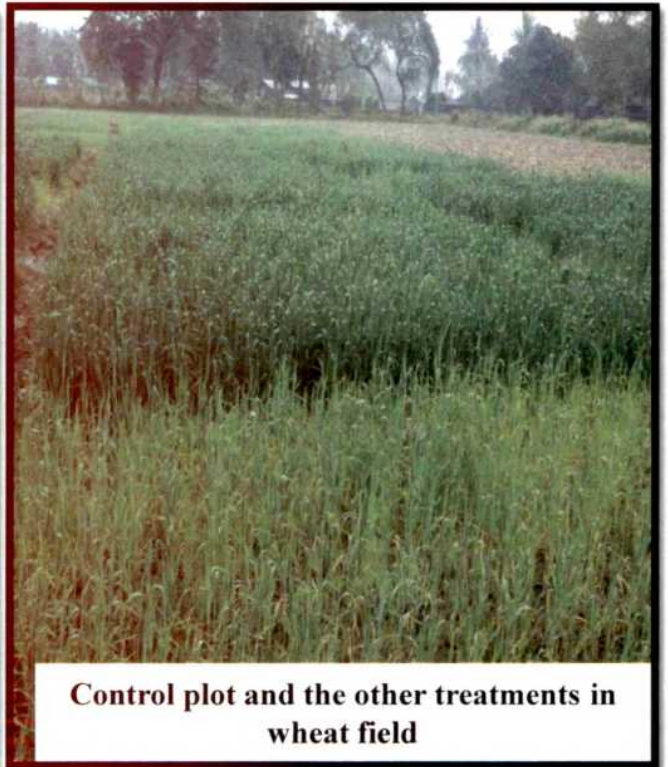
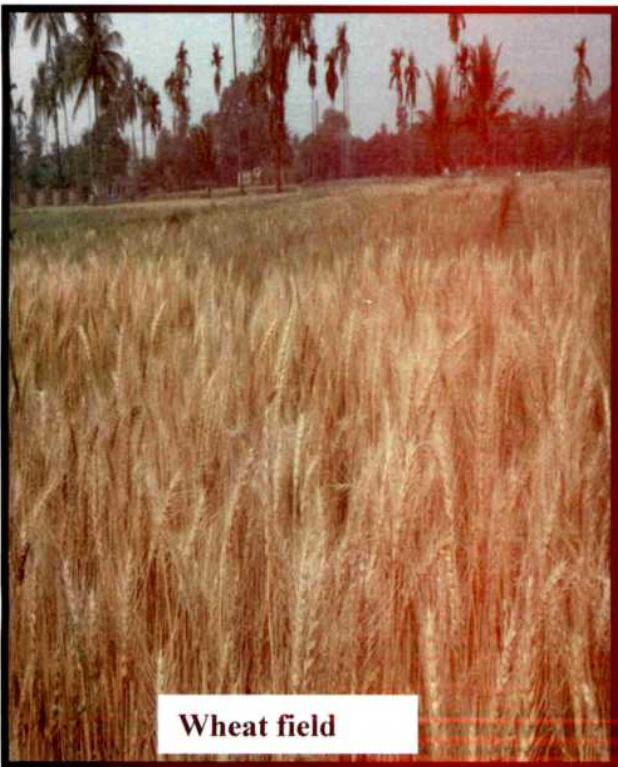
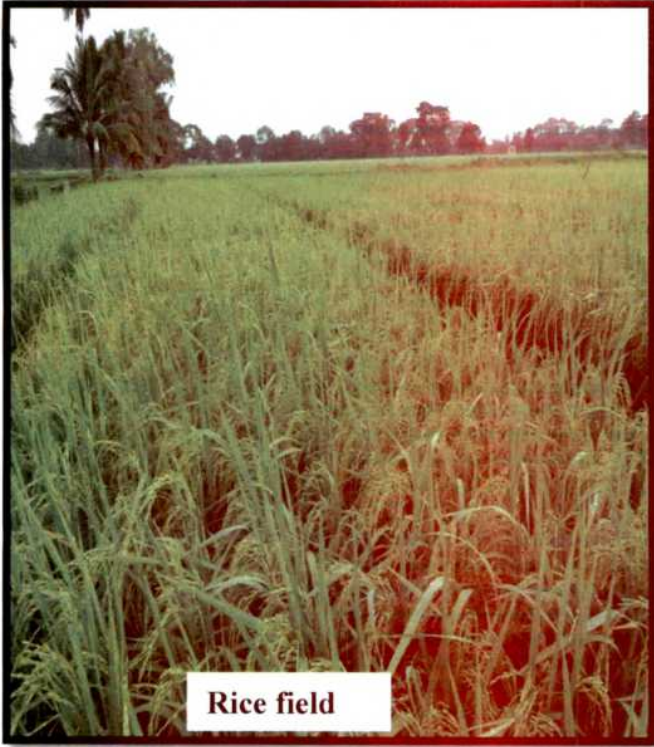


Plate 3: Overview of the field



Spreading of crop residue for incorporation in the plot



Straw incorporated plot and non incorporated plot



Growing of *Sesbania* for green manuring



Cutting down of *Sesbania*

Plate 4: Crop residue incorporation and green manuring operation

3.12.5 Plant protection

During the experimental period there was no severe incidence of pests and diseases on both the crops thus plant protection measures were not taken.

3.13 Harvesting and threshing

Harvesting was done by cutting the crops at ground level by sickles after attaining maturity. Then the plants were tied in small bundles with proper ^{labelling} labeling and kept on the field for drying. After threshing grain and residue samples were collected for noting observations and residues were kept in the plots (@ 5 t ha⁻¹ as per treatments for incorporation.

3.14 Field observation

Field observations for both the crops were taken at twenty five days interval (at 25, 50, 75 and 100 DAT/DAS) till maturity.

3.14.1 Methods of measuring growth attributing characters

3.14.1.1 Plant height

Five plants in each plot were selected at random and tagged for recording plant height. The height of the main shoot was measured in centimeter from ground level up to the tip of the growing point.

3.14.1.2 Leaf area index (LAI)

The leaf area index (LAI) was estimated by area-weight relationship method (Radford, 1967) so treatment wise five tillers were randomly selected from each plot for collecting samples of leaves. Leaf areas of each plot were measured and oven dried for recording dry weight.

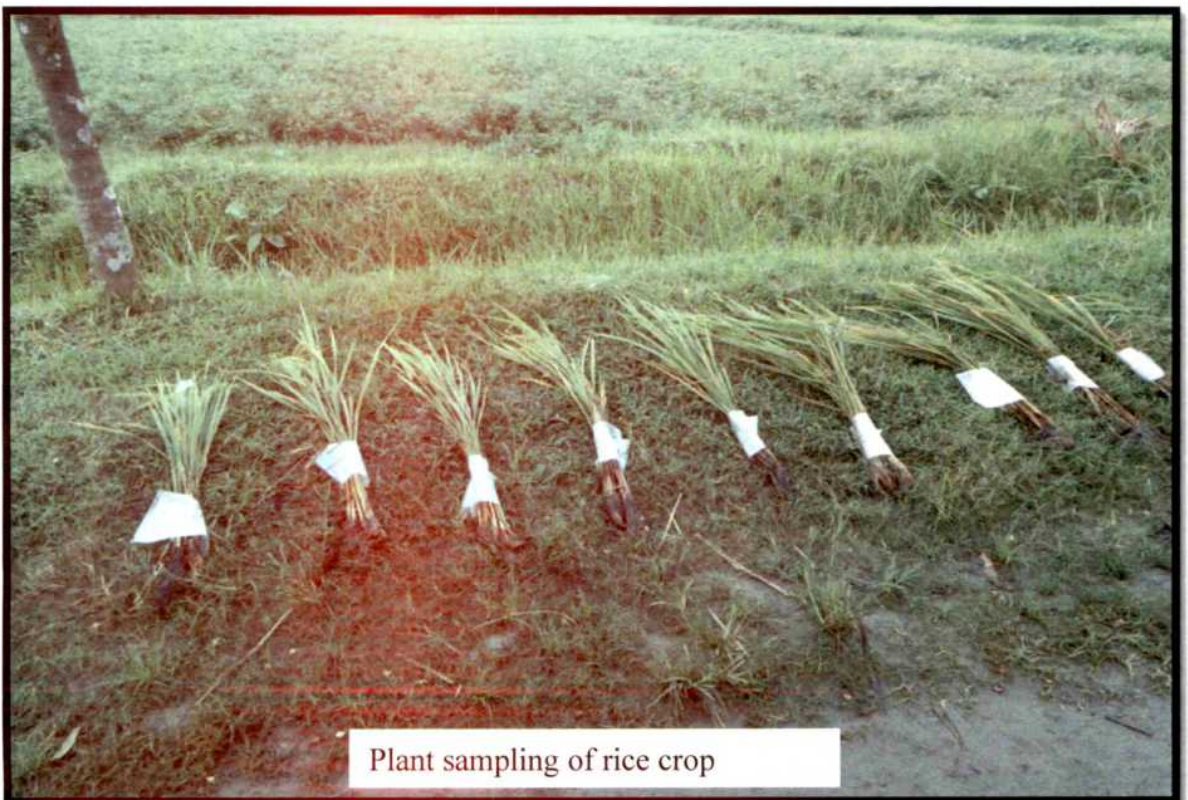
Leaf area index was calculated as follows:

$$\text{LAI} = \frac{\text{Total leaf area for a given}}{\text{Land area considered}}$$

All the above observations were recorded at twenty five days interval beginning from twenty five days after transplanting of rice/ sowing of wheat in all treatments.



Plant sampling of wheat crop



Plant sampling of rice crop

Plate 5: Plant sampling of rice and wheat

3.14.1.3 Number of tillers per square meter

Row length of one meter in each plot was selected and tagged for recording tiller number. Total number of tillers from the demarcated area in each plot was counted at twenty five days interval started from twenty five days after transplanting of rice/sowing of wheat and calculated the number in the square meter area.

3.14.1.4 Crop Growth Rate (CGR)

It indicates the rate at which the crop is growing and is expressed as gram of dry matter produced per day per unit area. It is calculated by using the following formula given by Watson (1947)

$$\text{CGR} = \frac{W_2 - W_1}{T_2 - T_1}$$

Where, W_1 and W_2 are dry weight at time T_1 and T_2 , respectively

3.14.2 Methods of measuring yield attributing characters and yield

3.14.2.1 Panicle/ Earhead length

Length of randomly selected ten panicles/earheads was measured at the time of harvest with a scale.

3.14.2.2 Number of panicle (for rice) and earhead (for wheat) per square meter

Row length of one meter in each plot was selected and total number of panicle/earhead was counted from that area. Later the total number of panicle/earhead per meter square was calculated from it.

3.14.2.3 Number of grain per panicle (for rice) and per earhead (for wheat)

Number of grains per panicle/earhead was recorded from ten randomly selected panicles/earheads from each plot both for rice and wheat. Then average number of grains per panicle/earhead was calculated.

3.14.2.4 1000- Grain weight

To calculate the 1000-grain weight, weight of one hundred dried filled grains from each plot were measured in gram, then the weight were multiplied by ten to find out the 1000-grain weight.

3.14.2.5 Grain and straw yield

After harvesting, threshing was done and then the weight of grain and straw were taken separately for each plot and expressed in tons per hectare. The weight of grain and straw were added to get the total biomass yield.

3.14.2.6 Harvest index

Harvest index of each plot were calculated by the formula given by Donald (1963),

$$\text{Harvest index} = \frac{\text{Economic yield}}{\text{Biological Yield}} \times 100$$

Economic yield indicates the grain yield, whereas biological yield represents the total yields of grain and straw recorded in this experiment.

3.15 Method of chemical analysis of plant samples

Chemical analysis of plant samples were made as stated below:

3.15.1 Estimation of nitrogen

The nitrogen content of the samples was determined by modified Macro and Micro Kjeldahl's method (Jackson, 1973).

3.15.2 Estimation of phosphorous

Phosphorous content of the samples was determined calorimetrically after tri-acid digestions (Jackson, 1973).

3.15.3 Estimation of potassium

Potassium content of the samples was determined by Flame Photometer after tri-acid digestions (Jackson, 1973).

3.16 Methods of collecting soil samples for physical and chemical analysis

Soil samples were taken with the help of soil auger up to 15 cm from ten randomly selected locations in each plot. Then the soil samples were mixed together and dried in shade. The soil samples which would use for chemical analysis were pulverized to pass through 80 mesh sieve and the soil samples which would use for physical analysis were ground not to pass through 50 mesh sieve.

3.16.1 Determination of soil bulk density (core sampling method)

For determination of bulk density, undisturbed soil core from 0-15 cm surface soil layer was collected in stainless steel core sampler (0.05 m diameter and 0.05 lengths) initially before land preparation from the field all over and after the harvest of the crop from each treatment. The soil of the core sampler was then dried in oven at 105⁰ C for 24 hours. Knowing the volume of the soil core sampler and the weight of the oven ^{dried} soil, the bulk density was determined by using the following formula:

$$\text{Bulk density (Bd)} = \frac{\text{Oven dried weight of the soil}}{\text{Volume of the soil core}} \text{ (Mg m}^{-3}\text{)}$$

3.16.2 Determination of soil porosity

Porosity of the soil is calculated from soil bulk density by using the formula

$$\text{Porosity} = \left[1 - \frac{\text{Bulk density}}{\text{Particle}} \right] \times 100, \text{ where particle density} = 2.65 \text{ Mg m}^{-3}$$

3.16.3 Determination of various aggregation indices of soil

The various aggregation indices of soil [aggregate ratio, mean weight diameter (MWD) and geometric mean diameter (GMD)] were determined by wet sieving method.

3.16.4 Method of chemical analysis of soil

3.16.4.1 Determination of soil pH

The pH of the soil samples was determined at 1:2.5, soil: water suspension by Beckman's pH meter (Jackson, 1973).

3.16.4.2 Estimation of organic carbon

Organic carbon content of the soil was determined by Walkley and Black wet digestion method (Jackson, 1973) by using diphenylamine as indicator.

3.16.4.3 Determination of available nitrogen in soil

Total nitrogen content in soil samples was determined by modified macro Kjeldahls method (Jackson, 1973).

3.16.4.4 Determination of available phosphorus in soil

Available phosphorus in soil samples was estimated by Olsen's method (Jackson, 1973).

3.16.4.5 Determination of available potassium in soil

Available potassium in soil samples was extracted by normal neutral ammonium acetate. The potassium content of the soil samples was determined by Flame photometry (Jackson, 1973).

3.16.4.6 Determination of available zinc in soil

Available zinc in soil samples was extracted by diethethylene triamine penta acetic acid (DTPA) extractant and measured the concentration of zinc by atomic absorption spectrophotometer.

3.17 Methods of analysis for study on soil micro- flora

3.17.1 Collection of soil samples

Soil samples were collected from the rhizosphere soil of wheat at harvest. The samples were properly tagged, sealed and carried to the laboratory for isolation of soil micro- flora.

3.17.2 Viable count of the micro-organism

The enumeration of the microbial population was done on agar plates containing appropriate media following serial dilution technique and pour plate method (Pramer and Schmidt, 1965); plates were incubated at 30°C. The counts were taken at 3rd day of incubation. The results were reported as number of cells per gram of soil. Unit is CFU (colony forming unit). The media were as follows:

3.17.2.1 *Azotobacter*

Total number of *Azotobacter* was estimated in Ashby's medium.

3.17.2.2 Total bacteria

For counting of total number of bacteria, Thorntin's agar medium (Thornton, 1922) was used.

3.17.2.3 Fungi

Martin's rose Bengal medium (Martin, 1950) was used for counting of total fungi.

3.17.2.4 *Actinomycetes*

Total number *Actinomycetes* were estimated in Ken-Knight and Munaier's medium.

3.18 Energy analysis

3.18.1 Energy input and output analysis

Energy requirement for a particular field operation may be calculated as the summation of human, bullock and mechanical and/ or electric energy consumed. This analysis was done as suggested by Baishya and Sharma, 1990 and the energy equivalent tables are given in annexure.

Output energy: Energy output from the product was calculated by multiplying the amount of production and its corresponding energy equivalent. Energy output from the by-product was estimated by multiplying the amount of by-product and its corresponding equivalent.

Net energy return: It is the difference between the gross output energy produced and the total energy required to obtain it (input energy).

$$\text{Energy ratio (ER): } ER = \frac{\text{Output energy (MJ ha}^{-1}\text{)}}{\text{Input energy (M J ha}^{-1}\text{)}}$$

3.19 Economics analysis

3.19.1 Cost of cultivation

Total cost of cultivation of each treatment in both experimental years was calculated by considering the cost of each input used during the respective years. The cost of each input used is given in annexure.

3.19.2 Gross return

Gross return from each treatment was calculated with the grain and straw yields with their respective market price during both the years of experimentation.

3.19.3 Net return

It was calculated by deducting cost of cultivation invested in each treatment from the respective gross returns during both the years.

3.19.4 Benefit: Cost ratio (B: C ratio)

It was calculated by dividing the gross return of each treatment with the cost of cultivation invested during both the years of experiment.

3.20 Statistical analysis

To interpret the effect of different treatments, the data collected in two years course of experimentation were analyzed statistically by the methods as Gomez and Gomez (1984). Relevant data were statistically analyzed separately for two years to interpret the results.

For comparison of 'F' values and for determination of critical difference at 5% level of significance, Fischer and Yates Table (1979) were consulted.

CHAPTER 4

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

4.1 Effect of crop residues and green manuring on growth attributing characters of rice

4.1.1 Plant height

Plant height of rice was taken at four growth stages at 25, 50 and 75 DAT and finally at harvest. No significant effect of the treatments was noticed in the first year (2013) however, effect was significant in the second year (2014). The plant height was increased up to 75 DAT in all the treatments and thereafter declined till harvesting (Fig. 4.1).

From the pooled data (Table 4.1), it has been observed that plant height was significantly influenced by the treatments and higher plant height was recorded from the treatment receiving residue incorporation (rice or wheat or both) along with inorganic fertilizers followed by green manuring (T₇, T₈ and T₉) as compared to treatments comprising residue incorporation + fertilizers (T₃, T₄ and T₅) and green manuring + fertilizers application (T₆), sole fertilizers application (T₂) and control (T₁). However, among these treatments T₉ recorded the highest plant height with the mean value of 56.93, 84.10, 109.48 and 109.27 cm (pooled data of two years) at 25, 50, 75 DAT and at harvest respectively but the treatment was found to be statistically at par with treatments from T₂ to T₈ at 25, 50 and 75 DAT however, significantly higher than control T₁. The finding was in accordance with Mukherjee and Singh (2001) who also noticed that plant heights in residue management treatments were statistically at par with each other at all growth stages. The lowest plant height was recorded from T₁ with mean value of 48.02, 67.80, 96.15 and 95.57 cm at 25, 50, 75 DAT and at harvest respectively. At the time of harvesting T₉ has been found to be statistically at par with treatment T₃, T₆, T₇ and T₈ but significantly higher as compared to T₁, T₂, T₄ and T₅. Again effect of T₅, T₄ and T₂ were found statistically non significant but significantly higher than control treatment i.e. T₁. This might be due to enhancement of soil fertility due to crop residue incorporation (rice or wheat or both) and green manuring which in turn influenced plant growth and vigour. Similar, findings were also reported by Singh and Sharma (2001) that growth parameters, viz. plant height and dry matter accumulation per hill were significantly higher under wheat-green manuring-rice sequence. Residue incorporation along with inorganic fertilizers (T₃, T₄ and T₅) also recorded higher plant height when compared with treatments T₁ and T₂. The findings are in accordance with Tomar *et al.* (2006) and Jai *et al.* (2014) who reported that plant

Table 4.1: Effect of crop residues and green manuring on plant height of rice

Treatment	Plant height in cm											
	25 DAT			50 DAT			75 DAT			At harvest		
	2013	2014	Pooled	2013	2014	Pooled	2013	2014	Pooled	2013	2014	Pooled
T ₁	48.80	47.23	48.02	68.60	67.00	67.80	96.87	95.43	96.15	96.43	94.70	95.57
T ₂	54.20	53.87	54.03	79.47	78.80	79.13	104.07	102.87	103.47	103.50	100.73	102.12
T ₃	54.53	54.75	54.64	79.93	82.17	81.05	103.87	107.90	105.88	103.60	105.30	104.45
T ₄	53.23	54.33	53.78	79.53	80.60	80.07	103.53	105.23	104.38	103.13	103.63	103.38
T ₅	54.07	54.50	54.28	80.93	81.53	81.23	103.27	106.70	104.98	102.83	104.63	103.73
T ₆	54.40	55.18	54.79	81.73	82.93	82.33	103.53	109.77	106.65	103.37	108.63	106.00
T ₇	54.40	56.30	55.35	80.77	84.73	82.75	103.33	112.20	107.77	102.70	111.33	107.02
T ₈	55.33	55.53	55.43	81.90	83.43	82.67	104.77	110.40	107.58	103.87	109.97	106.92
T ₉	55.23	58.63	56.93	81.63	86.57	84.10	104.97	114.00	109.48	104.73	113.80	109.27
SEm (±)	1.61	1.85	1.23	2.58	2.62	1.84	2.70	3.20	2.09	2.31	2.60	1.74
CD (5 %)	NS	5.56	3.53	NS	7.85	5.30	NS	9.59	6.03	NS	7.80	5.01

T₁: Control; T₂: Soil test based fertilizers; T₃: Rice residue incorporation + T₂; T₄: Wheat residue incorporation + T₂; T₅: Rice and Wheat residue incorporation + T₂; T₆: Green manuring + T₂; T₇: Rice residue incorporation + T₆; T₈: Wheat residue incorporation + T₆; T₉: Rice and Wheat residue incorporation + T₆

height and shoots growth were influence by residue management practices and N fertilizers.

4.1.2 Number of tillers per square meter of rice

Replication wise number of tillers per square meter was recorded at 25, 50 and 75 DAT and finally at harvest. The highest number of tillers was found at 50 DAT in all the treatments in both the years and gradually declined till harvest (Fig. 4.2). There was no significant influence of treatments on number of tillers in the early growth stage i.e. at 25 DAT in first year. However, significant influence was observed from 50 DAT onwards till harvest. Treatments from T₂ to T₉ have been found to be statistically at par but recorded significantly more tillers than T₁ in all the growth stages in first year. In second year (2014), there was significant influence of treatments on number of tillers at different growth stages. This might be attributed to the enrichment of soil fertility as influenced by management of crop residues along with green manuring which in turn enhanced crop height and vigour. Crop residue incorporation (CRI) with or without *Sesbania* green manure (SGM) significantly influenced the plant height, number of tillers m⁻² was reported by Jai *et al.* (2014).

From the pooled data of both the years, it has been observed that treatments showed significant positive influence on number of tillers at all the growth stages as depicted in Table 4.2. Residue integration (rice or wheat or both) along with inorganic fertilizers followed by green manuring (T₇, T₈ and T₉) were statistically at par with residue integration (rice or wheat or both) along with fertilizers (T₃, T₄ and T₇), green manuring with fertilizers (T₆) and sole fertilizers application (T₂) but significantly superior to control (T₁). However, treatment T₉ (where both the crop residues and green manuring along with inorganic fertilizers were applied) recorded higher number of tillers throughout the growth stages with mean value of 234.17, 315.00, 309.50 and 250.83 m⁻² at 25, 50 and 75 DAT and at harvest, respectively and the lowest number of tillers was recorded from control T₁ (169.17, 233.33, 199.17 and 135.00 m⁻², respectively). Treatment T₉ has been found to be statistically at par with T₂ to T₈. But at 50 DAT, T₉ has been found to be statistically at par with T₃ to T₈ at 25 DAT, 75 DAT and at harvest and significantly superior to T₁ and T₂. Summer green manuring of *Sesbania* before rice transplanting in which residue was incorporated recorded significantly more number of tillers was reported by Mukherjee and Singh (2001). Again treatments from T₃ to T₆ and T₈ have been found to be statistically at par with T₂

Table 4.2: Effect of crop residues and green manuring on tiller number of rice

Tiller number in m ⁻²												
Treatment	25 DAT			50 DAT			75 DAT			At harvest		
	2013	2014	Pooled	2013	2014	Pooled	2013	2014	Pooled	2013	2014	Pooled
T ₁	176.67	161.67	169.17	248.33	218.33	233.33	200.00	198.33	199.17	138.33	131.67	135.00
T ₂	225.00	220.00	222.50	288.33	278.33	283.33	288.33	270.00	279.17	233.33	230.00	231.67
T ₃	226.67	228.33	227.50	288.33	311.67	300.00	288.00	298.33	293.17	235.00	251.67	243.33
T ₄	226.67	226.33	226.50	286.67	298.33	292.50	288.67	281.00	284.83	233.33	243.33	238.33
T ₅	227.00	227.33	227.17	286.67	303.33	295.00	287.00	293.33	290.17	235.00	248.33	241.67
T ₆	226.67	228.67	227.67	288.33	320.00	304.17	287.33	308.33	297.83	233.33	253.33	243.33
T ₇	225.00	234.67	229.83	286.67	333.33	310.00	288.67	326.67	307.67	235.00	265.00	250.00
T ₈	228.33	231.67	230.00	286.67	328.33	307.50	288.33	313.67	301.00	235.00	258.33	246.67
T ₉	226.67	241.67	234.17	288.33	341.67	315.00	287.33	331.67	309.50	233.33	268.33	250.83
SEm (±)	12.36	13.33	9.09	7.63	14.76	8.31	11.13	17.91	10.54	12.84	9.18	7.89
CD (5 %)	NS	39.97	26.19	22.86	44.25	23.93	33.36	53.69	30.37	38.49	27.52	22.73

T₁: Control; T₂: Soil test based fertilizers; T₃: Rice residue incorporation + T₂; T₄: Wheat residue incorporation + T₂; T₅: Rice and Wheat residue incorporation + T₂; T₆: Green manuring + T₂; T₇: Rice residue incorporation + T₆; T₈: Wheat residue incorporation + T₆; T₉: Rice and Wheat residue incorporation + T₆

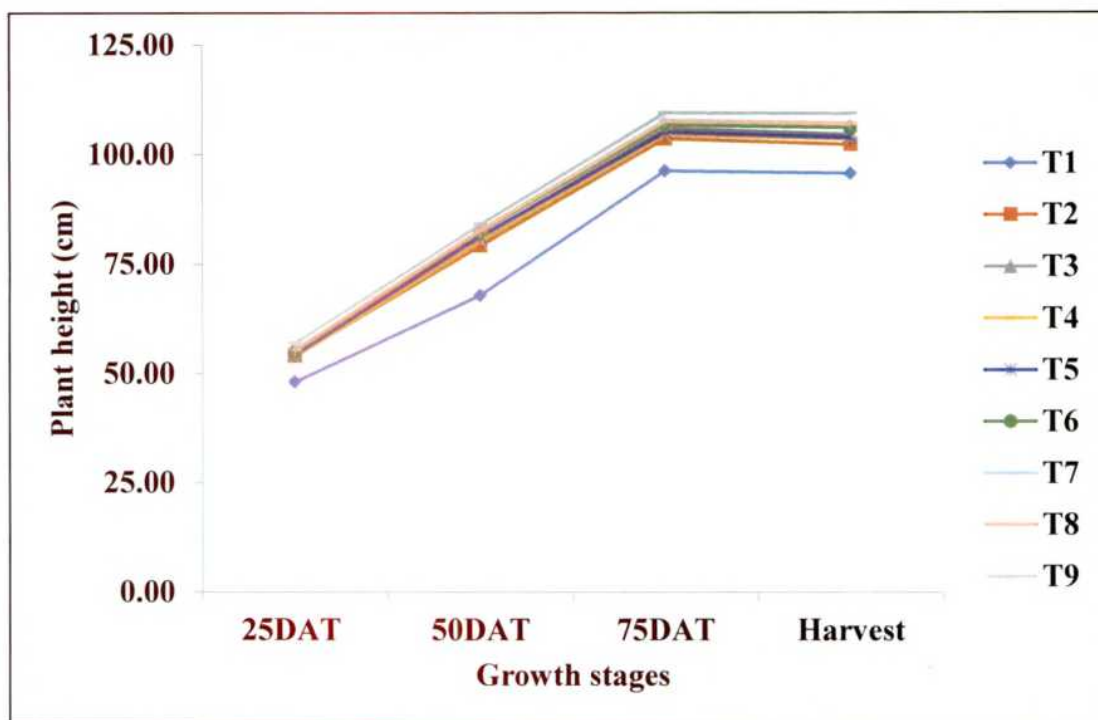


Fig 4.1: Plant height of rice at different growth stages

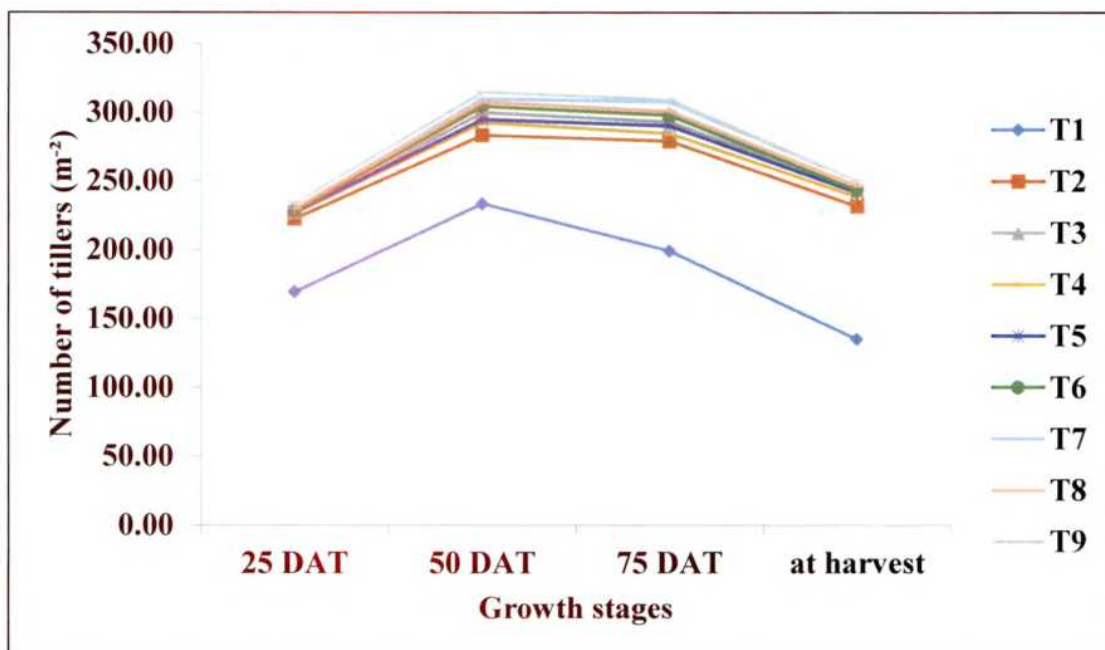


Fig 4.2: Number of tillers per square meter of rice at different growth stages

and significantly higher than T₁. Similar findings were also observed by Sandeep *et al.* (2004) and Arshadullah *et al.* (2012).

4.1.3 Leaf Area Index (LAI) of rice

The data on LAI (Table 4.3) revealed that LAI was significantly influence by the treatments at all the growth stages in both the years except at 25 DAT in first year. LAI was recorded highest at 75 DAT in all the treatments in both the years. Even though there was significant influence of the treatments in the first year (2013), they were statistically at par with the treatments from T₂ to T₉ at all the growth stages in respect of LAI. But, in the second year (2014), the influence of the treatments was significant which might be due to higher plant height and production of more tillers per unit area as affected by crop residues and green manuring. Control (T₁) plots recorded significantly lowest LAI at all the growth stages in both the years.

Significant positive influence of the treatments was observed from the pooled data depicted in the Table 4.3 and Fig. 4.3 at all the growth stages (25, 50 and 75 DAT and at harvest). It was noticed that the treatments comprising residue (rice or wheat or both) incorporation along with green manuring + fertilizers application (T₇, T₈ and T₉) recorded higher mean values of LAI when compared with other treatments. Among these treatments, T₉ recorded higher mean values of LAI i.e. 1.11, 2.98, 3.17 and 2.72 at 25, 50 and 75 DAT and at harvest, respectively. The lowest mean value of LAI has been recorded from T₁ (0.72, 2.11, 2.48 and 1.87 respectively at 25, 50 and 75 DAT and at harvest). Again the treatments having green manuring along with fertilizers have been found to be superior to the treatments where only crop residue (rice or wheat or both) were incorporated along with fertilizers (T₃, T₄ and T₅) followed by the treatment where only fertilizers was applied (T₂). These might be due to better nutrient availability as the result of residues decomposition and green manuring which consequently increased plant height and tillers per unit area. These findings are in accordance with the findings of Das *et al.* (2002) and Wang *et al.* (2011) who found that the incorporation of crop residues in rice enhanced the growth, yield attributes and grain yield of rice. At 25 DAT, T₉ was found to be statistically at par with T₃ (where both the residues were incorporated along with chemical fertilizers) and T₆, T₇ and T₈ (where green manuring + fertilizers or residue (rice or wheat) incorporated along with green manuring + fertilizers were applied) and significantly higher than T₁ to T₄ and T₅. Again, T₃ and T₆ have been found to be statistically at par with T₂, T₄ and T₅ and significantly superior to T₁. At maximum tillering stage i.e. at 50 DAT, T₉ has been found to be statistically at par with T₃, T₆, T₇ and T₈ but significantly higher than

Table 4.3: Effect of crop residues and green manuring on LAI of rice

Treatment	25 DAT			50 DAT			75 DAT			At harvest		
	2013	2014	Pooled	2013	2014	Pooled	2013	2014	Pooled	2013	2014	Pooled
T ₁	0.75	0.68	0.72	2.12	2.09	2.11	2.55	2.41	2.48	1.92	1.83	1.87
T ₂	0.97	0.91	0.94	2.59	2.55	2.57	2.87	2.76	2.82	2.46	2.41	2.43
T ₃	0.98	1.15	1.06	2.62	3.12	2.87	2.82	3.20	3.01	2.42	2.67	2.54
T ₄	0.95	0.93	0.94	2.57	2.90	2.74	2.87	3.00	2.94	2.46	2.52	2.49
T ₅	0.94	0.98	0.96	2.58	3.06	2.82	2.87	3.16	3.01	2.45	2.61	2.53
T ₆	0.96	1.19	1.08	2.63	3.19	2.91	2.89	3.30	3.10	2.46	2.75	2.61
T ₇	0.97	1.23	1.10	2.55	3.34	2.94	2.87	3.46	3.17	2.46	2.93	2.69
T ₈	0.97	1.22	1.09	2.58	3.26	2.92	2.82	3.40	3.11	2.45	2.89	2.67
T ₉	0.97	1.25	1.11	2.58	3.38	2.98	2.84	3.50	3.17	2.47	2.96	2.72
SEm (±)	0.05	0.07	0.04	0.07	0.06	0.05	0.06	0.08	0.05	0.05	0.14	0.07
CD (5 %)	NS	0.21	0.12	0.22	0.18	0.14	0.19	0.25	0.15	0.15	0.42	0.22

T₁: Control; T₂: Soil test based fertilizers; T₃: Rice residue incorporation + T₂; T₄: Wheat residue incorporation + T₂; T₅: Rice and Wheat residue incorporation + T₂; T₆: Green manuring + T₂; T₇: Rice residue incorporation + T₆; T₈: Wheat residue incorporation + T₆; T₉: Rice and Wheat residue incorporation + T₆

T₁, T₂, T₄ and T₅. However, again T₃, T₆, T₇ and T₈ have been found to be at par with T₄ and T₅ and significantly different from T₁ and T₂. At 75 DAT, the effect of T₉ was statistically at par with T₆, T₇ and T₈ but higher than T₁ to T₅. Again T₆ and T₈ were statistically at par with T₃ to T₅ but significantly differed from T₁ and T₂. Treatment T₄ was found to be again at par with T₂. At harvest also T₉ was found to be at par with T₃ and treatments from T₅ to T₈ but higher than T₁, T₂ and T₄. Again T₃, T₅, T₆, T₇ and T₈ have been found to be statistically at par with T₂ and T₄ though T₂ and T₄ were statistically at par with each other.

4.1.4 Crop growth rate (CGR) of rice

Crop growth rates (CGR) were taken at three different growth stages i.e. 25-50 DAT, 50-75 DAT and 75 DAT- till harvest. Maximum CGR was observed at 50-75 DAT in both the years as shown in Table 4.4 and Fig. 4.4. Rapid growth during initial stage and maximum number of tillers might have attributed higher CGR at this stage. There was no significant influence of treatments on CGR in 2013 at 25-50 DAT. However, significant influence was observed at later growth stages when the treatments (T₂ to T₉) recorded significantly higher values over control (T₁) though no significant influence was noticed among these treatments. In second year (2014), influence of treatments was more pronounced except in control (T₁) and the treatment where only chemical fertilizers were applied (T₂) and significant differences were recorded among the treatments where residue incorporation (rice or wheat or both) integrated with green manuring along with fertilizers (T₇, T₈ and T₉) or residue incorporation along with fertilizers (T₃, T₅ and T₄) as compared to sole inorganic sources of nutrients (T₂) and control (T₁). Similar, findings were also reported by Wang *et al.* (2011) who found that rice straw returning promoted the vegetative growth of the paddy by releasing the nitrogen. No significant influence was noticed among the treatments from T₃ to T₉ was in all the growth stages but significantly superior to T₁ and T₂.

From the pooled data as depicted in Table 4.4 significant influence of treatments was observed on CGR. However, the effect of treatments from T₃ to T₉ was statistically at par at 25-50 DAT and 50-75 DAT but significantly higher than T₂ and T₁. Treatment T₉ recorded highest CGR at all the growth stages with the mean values of 7.70, 11.80 and 8.96 g m⁻² day⁻¹ at 25-50 DAT, 50-75 DAT and 75 DAT- at harvest respectively and lowest CGR was recorded from control T₁ with the mean values of 3.91, 4.24 and 1.54 g m⁻² day⁻¹ respectively. At growth stage of 75 DAT- till harvest,

Table 4.4: Effect of crop residues and green manuring on CGR of rice

Treatment	Crop growth rate (CGR) in g m ⁻² day ⁻¹							
	25- 50 DAT			50 - 75 DAT			75 DAT- at harvest	
	2013	2014	Pooled	2013	2014	Pooled	2013	2014
T ₁	4.47	3.35	3.91	4.52	3.96	4.24	1.72	1.37
T ₂	7.27	7.18	7.22	10.90	10.16	10.53	8.21	7.52
T ₃	7.23	7.51	7.37	10.96	12.29	11.62	8.25	9.29
T ₄	7.27	7.31	7.29	10.97	12.11	11.54	8.26	9.03
T ₅	7.23	7.40	7.32	10.95	12.20	11.57	8.21	9.09
T ₆	7.27	7.69	7.48	10.99	12.37	11.68	8.31	9.40
T ₇	7.27	7.97	7.62	11.05	12.53	11.79	8.22	9.56
T ₈	7.27	7.81	7.54	10.94	12.45	11.69	8.28	9.52
T ₉	7.27	8.14	7.70	10.95	12.64	11.80	8.26	9.65
SEm (±)	0.64	0.43	0.39	0.43	0.47	0.32	0.45	0.47
CD (5 %)	NS	1.29	1.11	1.30	1.40	0.92	1.36	1.41

T₁: Control; T₂: Soil test based fertilizers; T₃: Rice residue incorporation + T₂; T₄: Wheat residue incorporation + T₂; T₅: Rice and Wheat residue incorporation + T₂; T₆: Green manuring + T₂; T₇: Rice residue incorporation + T₆; T₈: Wheat residue incorporation + T₆; T₉: Rice and Wheat residue incorporation + T₆

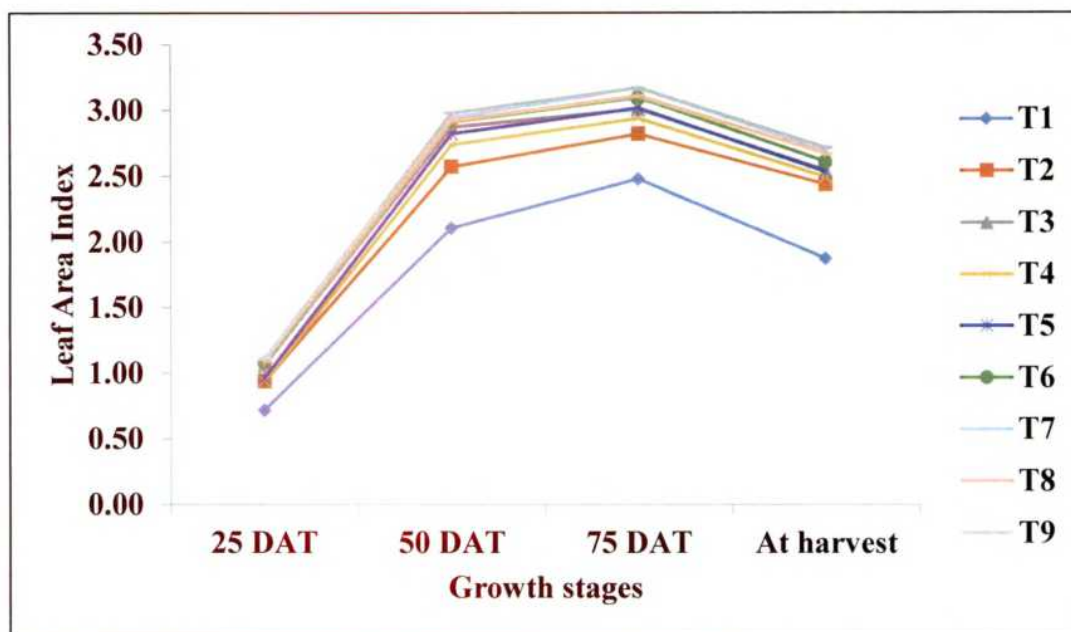


Fig 4.3: Leaf Area Index of rice at different growth

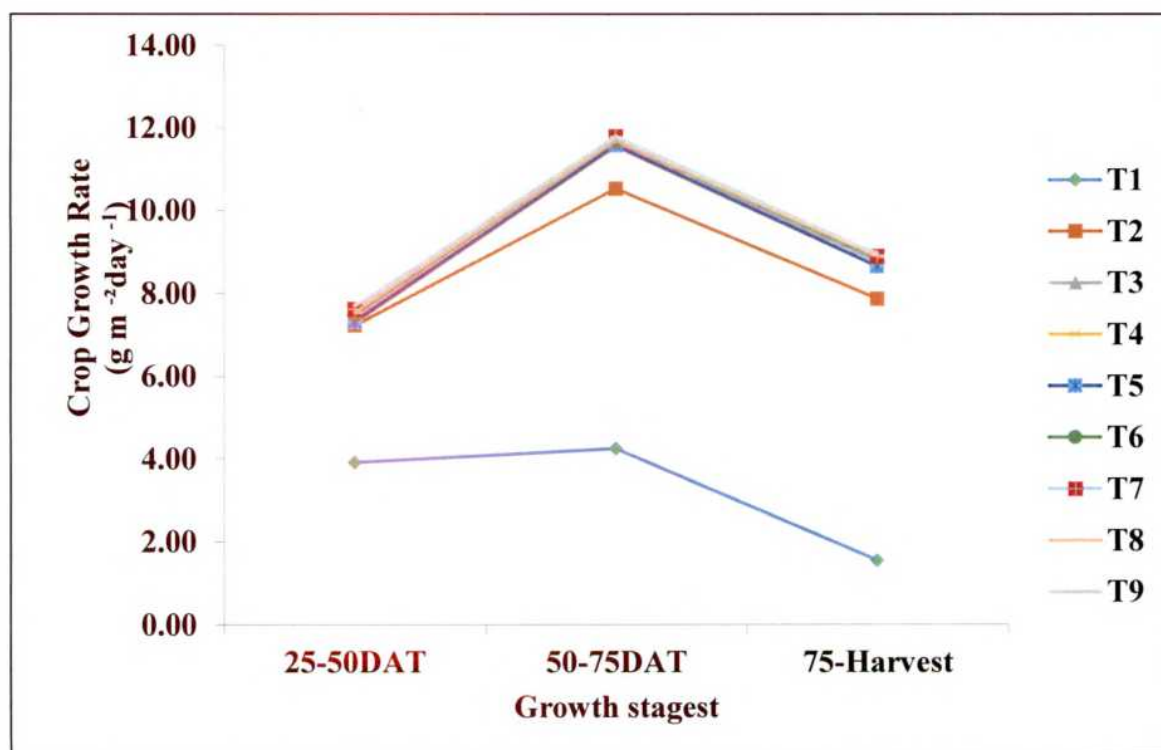


Fig 4.4: Crop growth rate of rice at different growth stages

T₉ was found to be statistically at par with treatments T₃ to T₈ and significantly higher than T₂ and T₁. This might be due to better availability of nutrients as a result of residual effect of crop residue and green manuring. Again, the treatments, namely T₃, T₄ and T₅ where residues along with fertilizers were incorporated were statistically at par with sole inorganic source of nutrient T₂. Similar, findings was also reported by Singh and Sharma (2001) and Arshadullah *et al.* (2012).

4.1.5 Root dry weight per square meter of rice

Plant root growth was recorded at four different growth stages i.e. 25, 50 and 75 DAT and finally at harvest. Maximum root growth was recorded at 50 DAT in all the treatments as maximum numbers of tillers were recorded at this growth stage and decreased thereafter in both the years as shown in Fig. 4.5. Significant influence of treatments was not observed on root growth at early growth stage i.e. at 25 DAT but significant influence of treatments was noticed in later growth stages i.e. at 50 and 75 DAT and at harvest in the first year (2013). However, treatments from T₂ to T₉ were recorded to be statistically at par in the first year but produced significantly higher root weight than control (T₁). Since the rice crop was grown without crop residue management in the first year no significant influence was noticed during this time. However, in the second year (2014) effect of crop residues and green manuring on root growth was found to be much better than first year because of higher plant growth and production of more number of tillers. In the second year, maximum growth of root was recorded from the treatment comprising residue (rice and wheat) incorporation along with green manuring + inorganic fertilizers (T₉) with the mean values of 18.93, 243.15, 235.77 and 191.44 g m⁻² at 25, 50 and 75 DAT and at harvest, respectively and the lowest root growth was recorded from the control treatment T₁ (10.73, 142.08, 111.77 and 110.63 g m⁻², respectively) as depicted in Table 4.5. Similar, findings were also reported by Mandal and Pal (2009) who observed that green manuring increased root length, root volume, root dry weight (i.e. root characters) of rice compared with control. However, root growth was poor as compared to first year which might be due to depletion of soil health because of non incorporation of any organic sources of nutrient in this treatment. At 50 and 75 DAT, the treatments comprising residues (rice or wheat) incorporation along with or without green manuring + fertilizers (T₃, T₄, T₅, T₇ and T₈) and green manuring along with fertilizers (T₆) have been found to be at par with T₉. However, T₉ have been recorded to be statistically superior to T₁ and T₂. Again, T₂ have been found to be at par with treatments T₃ to T₈ and significantly higher than

Table 4.5: Effect of crop residues and green manuring on root growth of rice

Root dry weight in g m ⁻²												
Treatment	25 DAT			50 DAT			75 DAT			At harvest		
	2013	2014	Pooled	2013	2014	Pooled	2013	2014	Pooled	2013	2014	Pooled
T ₁	11.90	9.57	10.73	153.33	130.83	142.08	116.67	106.88	111.77	114.33	106.92	110.63
T ₂	15.25	14.05	14.65	218.33	215.83	217.08	215.33	213.08	214.21	167.50	157.42	162.46
T ₃	15.00	18.18	16.59	219.67	241.88	230.77	214.50	233.33	223.92	169.58	178.33	173.96
T ₄	14.75	15.46	15.10	218.33	226.25	222.29	214.83	221.13	217.98	167.92	165.46	166.69
T ₅	15.83	17.82	16.83	219.33	233.00	226.17	214.33	229.17	221.75	169.67	170.83	170.25
T ₆	15.67	21.07	18.37	220.00	245.08	232.54	215.00	236.67	225.83	167.33	185.00	176.17
T ₇	15.25	22.59	18.92	228.33	260.04	244.19	215.17	252.42	233.79	167.92	207.08	187.50
T ₈	14.92	21.75	18.33	218.33	255.75	237.04	215.83	244.79	230.31	169.08	198.13	183.60
T ₉	14.70	23.16	18.93	219.67	266.63	243.15	215.00	256.54	235.77	167.67	215.21	191.44
SEm (±)	1.51	1.65	1.12	13.62	13.14	9.46	7.57	12.74	7.41	9.13	12.37	7.68
CD (5 %)	NS	4.94	3.21	40.84	39.39	27.26	22.70	38.20	21.35	27.36	37.07	22.14

T₁: Control; T₂: Soil test based fertilizers; T₃: Rice residue incorporation + T₁; T₄: Wheat residue incorporation + T₂; T₅: Rice and Wheat residue incorporation + T₂; T₆: Green manuring + T₂; T₇: Rice residue incorporation + T₆; T₈: Wheat residue incorporation + T₆; T₉: Rice and Wheat residue incorporation + T₆

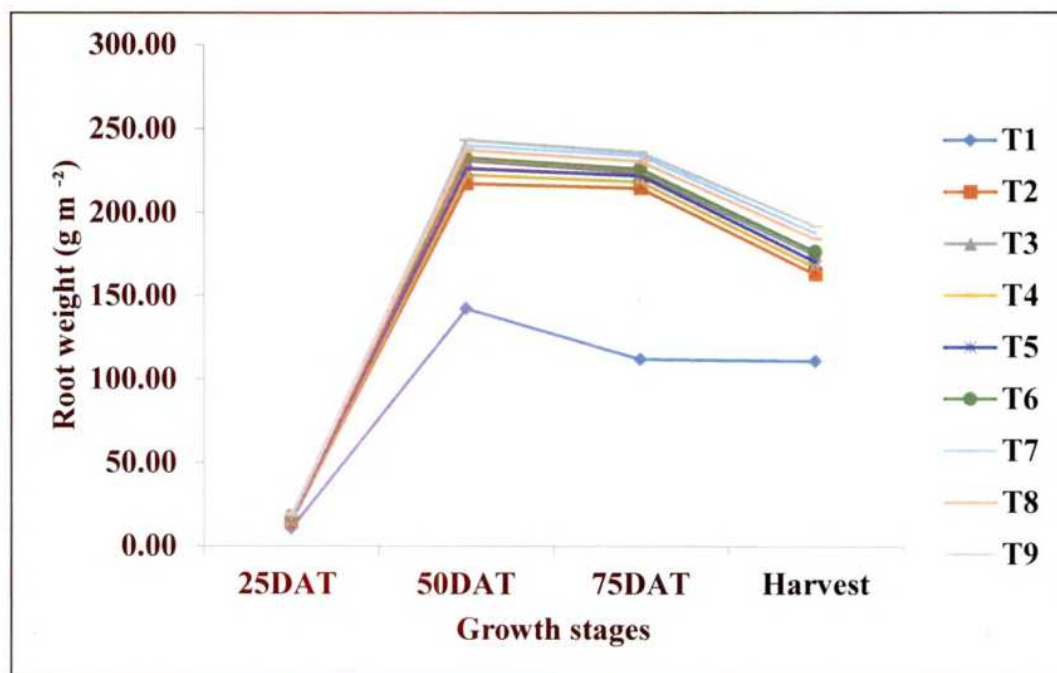


Fig 4.5: Root dry weight of rice at different growth stages

T₁. At harvest, T₉ have been recorded to be statistically at par with treatments T₃ and T₅ to T₈ but significantly higher than T₁, T₂ and T₄. Again treatment T₂ and T₄ have been found to be at par with treatments T₃ and T₅ to T₈ and significantly superior to T₁. The pooled data also followed almost the similar trend as that in second year.

4.2 Effect of crop residue management and green manuring on yield attributing characters of rice

4.2.1 Number of panicles (m⁻²)

Significant influences of treatments on number of panicles have been recorded in both the years. However, in the first year (2013) there were no significant differences among the treatments from T₂ to T₉. But, in second year (2014) the treatment having crop residues (rice and wheat both) incorporated along with green manuring + fertilizers (T₉) accounted for the highest number of panicles m⁻² (255.67) which was statistically at par with the treatments having crop residues (rice or wheat) integrated with green manuring + fertilizers (T₇ and T₈), only green manuring + fertilizers (T₆) and crop residues (rice or wheat or both) incorporation along with fertilizers application (T₃ to T₅) and significantly superior to the treatments where only chemical fertilizers were applied (T₂) and not applied (control T₁) as presented in Table 4.6. Yield attributes, viz. number of productive shoots, panicle length, number of fertile spikelet/panicle and 1000-grain weight were significantly higher under wheat-green manuring-rice sequence were reported by Singh and Sharma (2001). The pooled data also revealed the similar trend as was noticed in the second year. The findings are in accordance with Das *et al.* (2002) who also reported that the incorporation of crop residues in rice enhanced the growth, yield attributes and grain yield of rice.

4.2.2 Length of panicle (cm)

Significant influences of treatments on length of panicles have been observed in both the years. It has been observed that the treatments T₂ to T₉ were statistically at par and significantly superior to T₁, in first year (2013). However in second year (2014) T₉ have been recorded with the highest length of panicle (25.30 cm) which have been found to be statistically at par with treatments T₃ to T₈ and significantly higher than T₁ and T₂ (Table 4.6). Again, treatments T₃ to T₈ have been found to be at par with T₂ and significantly superior to T₁. Similar findings were also reported by Singh and Sharma (2001) and Arshadullah *et al.* (2012).

Table 4.6: Effect of crop residues and green manuring on yield attributes of rice

Treatment		Number of panicles (m ⁻²)			Length of panicles (cm)			Grain panicle ⁻¹			1000-grain weight (g)		
		2013	2014	Pooled	2013	2014	Pooled	2013	2014	Pooled	2013	2014	Pooled
T ₁		100.67	92.00	96.33	19.69	19.19	19.44	64.67	60.97	62.82	18.04	18.17	18.11
T ₂		223.33	220.00	221.67	23.67	23.26	23.47	97.20	98.77	97.98	18.90	18.77	18.84
T ₃		221.87	240.00	230.93	23.45	23.91	23.68	99.03	103.17	101.10	18.67	18.77	18.72
T ₄		224.00	236.67	230.33	24.18	23.49	23.83	97.87	101.77	99.82	18.60	18.73	18.67
T ₅		217.67	238.33	228.00	23.48	23.61	23.55	101.67	103.17	102.42	18.60	18.83	18.72
T ₆		226.33	241.67	234.00	22.87	24.31	23.59	99.17	106.17	102.67	18.70	18.73	18.72
T ₇		218.67	251.67	235.17	23.77	25.11	24.44	101.77	107.97	104.87	18.70	18.47	18.59
T ₈		217.00	245.00	231.00	24.26	24.85	24.56	102.00	106.77	104.38	18.47	18.77	18.62
T ₉		223.33	255.67	239.50	23.87	25.30	24.58	99.27	110.87	105.07	18.90	18.53	18.72
SEm (±)		5.58	7.49	4.67	0.56	0.63	0.42	4.77	4.39	3.24	0.54	0.50	0.37
CD (5 %)		16.71	22.45	13.45	1.69	1.88	1.21	14.29	13.15	9.33	NS	NS	NS

T₁: Control; T₂: Soil test based fertilizers; T₃: Rice residue incorporation + T₂; T₄: Wheat residue incorporation + T₂; T₅: Rice and Wheat residue incorporation + T₂; T₆: Green manuring + T₂; T₇: Rice residue incorporation + T₆; T₈: Wheat residue incorporation + T₆; T₉: Rice and Wheat residue incorporation + T₆

4.2.3 Grains per panicle

A perusal of data presented in Table 4.6 revealed that treatments had significant influence on grains panicle⁻¹ of rice and higher number of grains was counted in the second year in all the treatments except T₁ where no application of fertilizers and organic manures might have depleted soil fertility which in turn decreased the grain number. T₂ to T₉ have been recorded to be statistically at par and significantly superior to T₁ in both the years. However, T₉ have been recorded to be with greater mean value of grains panicle⁻¹ (105.07), might be due to greater length of panicle in T₉. Improved soil health as substantiated by the soil nutrient status (presented later in this chapter) also influenced the crop to produce more grains panicle⁻¹ in this treatment. The lowest mean value has been recorded in T₁ (62.82) as usual because poor fertility status of the control plots. The findings are in accordance with Arshadullah *et al.* (2012).

4.2.4 1000-grain weight (g)

1000-grain weight is an inherent genotypic character; however, it was significantly influenced by various treatments. Treatments from T₂ to T₉ had recorded significantly higher 1000-grain weight compared with control (T₁) with an exception in the first year where T₇ remained at par with T₁. No clear trend was noticed regarding 1000-grain weight of rice; however, higher grain weight was noted in T₂ and T₉ in the first year and in T₅ in the second year. Pooled data revealed that T₂ (application of only 100% chemical fertilizers) had an edge over other treatments regarding influencing grain weight of the crop.

4.3 Effect of crop residue management and green manuring on grain and straw yield and harvest index of rice

4.3.1 Grain yield (t ha⁻¹)

Grain yield was significantly influenced by the treatments in both the years as revealed by the data presented in the Table 4.7. However the influence was more pronounced in the second year except for the treatments T₁ and T₂ as shown in Fig. 4.6 which might be due to better nutrient availability in the plots receiving treatments T₃ to T₉ as a result of the effect of crop residues incorporation (rice or wheat or both) and green manuring. Fertility level in the plots receiving treatments T₁ and T₂ might have depleted over time because of non incorporation/non management of organic sources of nutrients. In the first year (2013), treatments T₂ to T₉ have been found to be statistically at par but significantly greater than control T₁ as most of the yield attributing characters

Table 4.7: Effect of crop residues and green manuring on grain and straw yield and harvest index of rice

Treatment	Grain yield (t ha ⁻¹)			Straw yield (t ha ⁻¹)			Harvest index (%)		
	2013	2014	Pooled	2013	2014	Pooled	2013	2014	Pooled
T ₁	1.13	0.98	1.05	2.30	2.27	2.29	32.88	30.17	31.52
T ₂	4.05	3.99	4.02	5.65	5.49	5.57	41.56	42.10	41.83
T ₃	3.95	4.62	4.28	5.70	6.10	5.90	40.90	43.13	42.02
T ₄	4.02	4.42	4.22	5.62	6.06	5.84	41.71	42.21	41.96
T ₅	4.07	4.55	4.31	5.65	6.04	5.84	41.92	42.97	42.45
T ₆	4.17	4.72	4.44	5.67	6.12	5.90	42.36	43.46	42.91
T ₇	4.12	4.98	4.55	5.62	6.23	5.92	42.38	44.46	43.42
T ₈	3.99	4.86	4.42	5.65	6.19	5.92	41.59	44.01	42.80
T ₉	4.17	5.12	4.65	5.65	6.37	6.01	42.50	44.58	43.54
SEm (±)	0.16	0.20	0.13	0.24	0.31	0.19	1.32	1.33	0.93
CD (5 %)	0.47	0.59	0.36	0.72	0.92	0.56	3.94	3.98	2.69

T₁: Control; T₂: Soil test based fertilizers; T₃: Rice residue incorporation + T₂; T₄: Wheat residue incorporation + T₂; T₅: Rice and Wheat residue incorporation + T₂; T₆: Green manuring + T₂; T₇: Rice residue incorporation + T₆; T₈: Wheat residue incorporation + T₆; T₉: Rice and Wheat residue incorporation + T₆

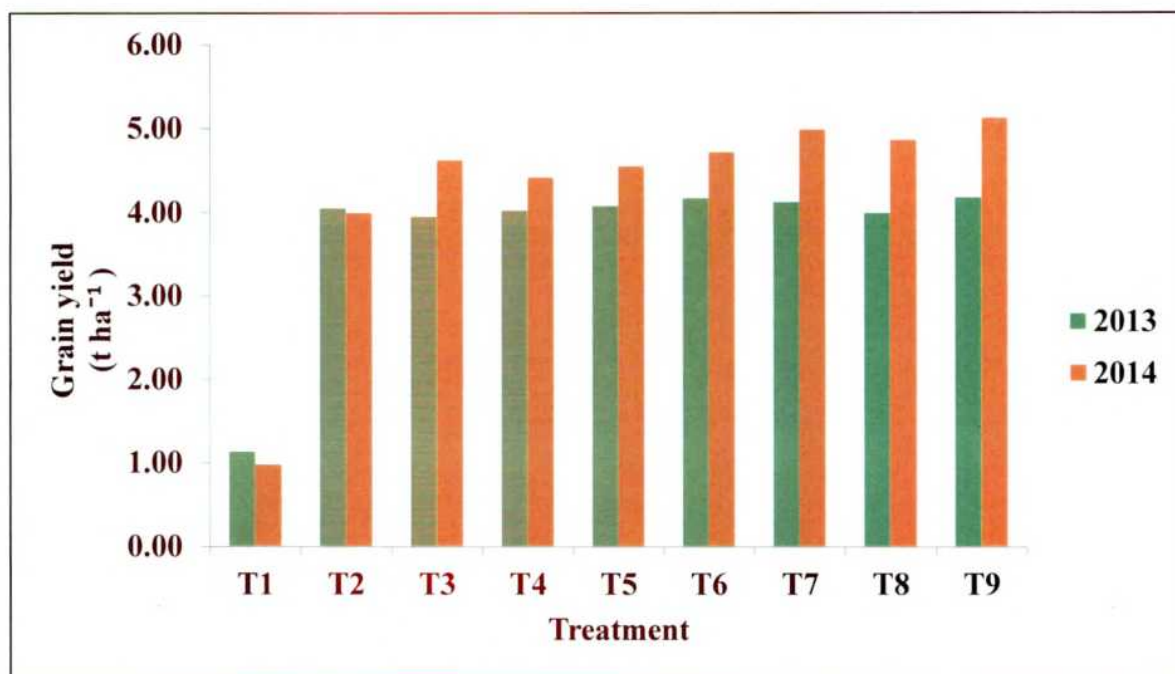


Fig 4.6: Grain yield of rice

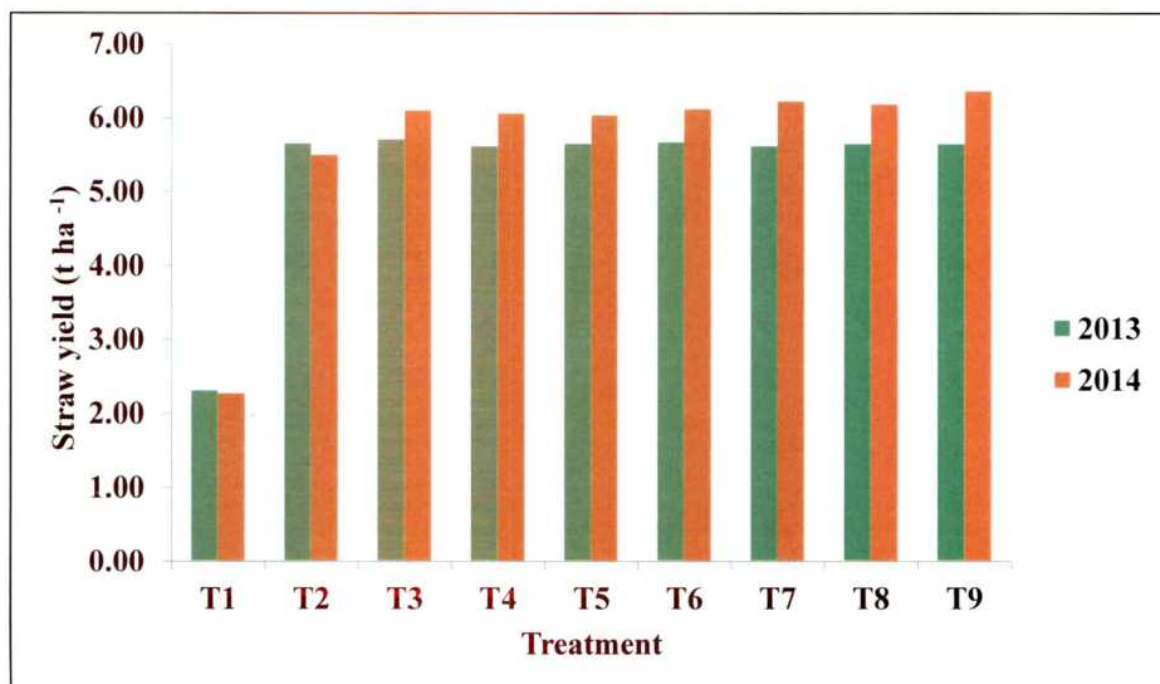


Fig 4.7: Straw yield of rice

followed the same trend as depicted in the above tables. However, T₉ recorded the highest yield (5.12 t ha⁻¹) which was found to be at par with treatments T₃ and treatments from T₅ to T₈ but significantly greater than T₁, T₂ and T₄ in the second year (2014) which was 28.32 % greater yield than that of T₂. Incorporation of wheat residue had an adverse effect on the productivity of the rice-wheat cropping system but when it was incorporated along with *Sesbania* green manure, not only did its adverse effect disappear and gave more grain yield of 0.8- 1.2 t ha⁻¹ but the response to fertilizer N was also increased as reported by Sharma and Prasad (2001). Again, T₃ and T₅ to T₈ have been found to be statistically at par with T₂ and T₄ and significantly superior to T₁. The same trend was noticed when the results were compared in pooled analysis. The results clearly demonstrated that incorporation of both rice and wheat residues along with green manuring and fertilizers produced more influence on yield attributes (effective tillers, grains per panicle, thousand grain weight) which resulted in higher grain yield of rice than incorporation of either rice or wheat residue along with green manuring and fertilizers. Similar, findings were also reported by Vinay (2006) and Jai *et al.* (2014) that crop residue incorporation + green manuring treatment was observed significantly greatest grain yields in rice over other crop residue management treatments. Sole incorporation of rice residues recorded numerically higher values of grain yield as against sole incorporation of wheat straw with or without green manuring. However, sole green manuring along with fertilizers application was found to produce more influence as compared to sole incorporation of rice or wheat residues or both with fertilizer and sole application of chemical fertilizers. The findings are in accordance with the results obtained by Aulakh *et al.* (2001) who observed that green manure crop and/or incorporating crop residue in a rice-wheat system have potential to increased SOM (soil organic matter) while maintaining high grain yields. Again, T₃ and T₅ to T₈ has been recorded to be at par with T₂ and T₄ but significantly greater than T₁. The lowest grain yield has been recorded from control plots (T₁) with the mean value of 1.05 t ha⁻¹.

4.3.2 Straw yield (t ha⁻¹)

Straw yield was significantly influenced in both the years but the influence was more pronounced in second year (2014) especially in the treatments where crop residues (rice or wheat or both) were incorporated along with or without green manuring + fertilizers (T₃ to T₉) as depicted in Table 4.7 and Fig. 4.7 which might be due to enrichment of soil fertility because of crop residue incorporation and green

manuring. Green manuring and its residual effect increased most of the yield components except test weight, grain yield and straw yield of rice compared with control was reported by Mandal and Pal (2009). From the pooled data of both the years also it has been observed the significant influences of the treatments on straw yield. However, T₉ have been recorded with the highest mean straw yield (6.01 t ha⁻¹) though there was no significant difference among the treatments from T₂ to T₉. The findings were in accordance with Das *et al.* (2003) and Jai *et al.* (2014) who reported that crop residue incorporation (CRI) with or without *Sesbani* green manure (SGM) were observed significantly greatest straw yields in rice. The lowest yield was obtained from control T₁ with mean value of 2.29 t ha⁻¹. Lower values of growth and yield attributes might have influenced lower straw yield in control plots receiving no nutrients either in chemical or organic forms what so ever.

4.3.3 Harvest index (%)

Significant influences of treatments on harvest index have also been recorded in both the years. Harvest index followed the same trend as that of grain/straw yield and recorded higher values in the second year (Table 4.7). In T₁ treatment, however, values was lower in the second year. Higher values of harvest index were recorded from the treatment T₉ in both the years (42.50 and 44.58%, respectively). Higher grain yields resulted in higher harvest index in this treatment. However, T₂ to T₉ have been found to be at par but these treatments were significantly superior to T₁.

4.4 Effect of crop residues and green manuring on total nutrient uptake by rice

4.4.1 Nitrogen uptake (kg ha⁻¹)

The result presented in the Table 4.8 revealed that N uptake in rice plant was significantly influenced by the treatments in both the years i.e. at 2013 and 2014. From the pooled data it has been observed that the maximum mean uptake of N (138.80 kg ha⁻¹) was recorded from the treatments comprising incorporation of both crop residues along with green manuring + fertilizers (T₉) and the minimum mean uptake of N was recorded from control (T₁) i.e. 48.35 kg ha⁻¹. This might be due to crop residue management along with *Sesbania* green manuring which improved nutrient recycling and ultimately improved the soil health. The findings are in accordance with Jai *et al.* (2014) who reported that total uptake of the nutrients by rice-wheat crops in sequence was highest (N 203.70, P 37.20, K 203.60 kg ha⁻¹) in case of crop residue plus green manuring treatment. However, T₉ have been found to be statistically at par with the

Table 4.8: Effect of crop residues and green manuring on total nutrient uptake by rice

Treatment	N uptake (kg ha ⁻¹)		P uptake (kg ha ⁻¹)		K uptake (kg ha ⁻¹)	
	2013	2014	Pooled	2013	2014	Pooled
T ₁	49.40	46.33	48.35	4.65	4.37	4.51
T ₂	99.00	101.20	100.10	11.91	12.74	12.33
T ₃	112.00	120.90	116.50	14.87	15.37	15.12
T ₄	107.00	131.80	119.40	15.91	16.88	16.40
T ₅	118.50	132.20	125.30	15.42	16.49	15.96
T ₆	126.50	135.90	131.20	15.92	18.34	17.13
T ₇	118.20	152.00	135.10	17.11	20.08	18.60
T ₈	121.00	138.50	129.80	16.38	17.61	17.00
T ₉	129.20	148.30	138.80	18.31	21.51	19.91
SEm (±)	4.33	5.39	3.45	0.98	0.86	0.65
CD (5 %)	12.98	16.14	9.95	2.93	2.58	1.87

T₁: Control; T₂: Soil test based fertilizers; T₃: Rice residue incorporation + T₂; T₄: Wheat residue incorporation + T₂; T₅: Rice and Wheat residue incorporation + T₂; T₆: Green manuring + T₂; T₇: Rice residue incorporation + T₆; T₈: Wheat residue incorporation + T₆; T₉: Rice and Wheat residue incorporation + T₆

treatments comprising crop residue incorporation (either rice or wheat) along with green manuring + fertilizers (T₇ and T₈) and green manuring + fertilizers (T₆) but significantly higher than treatments T₁ to T₄. Again, T₆, T₇ and T₈ have been observed to be at par with T₃, T₄ and T₅ [crop residue incorporation (either rice or wheat) + fertilizers] but significantly superior to T₁ and T₂.

4.4.2 Phosphorous uptake (kg ha⁻¹)

Influences of the treatments on uptake of phosphorous by rice have been observed in both the years (2013 and 2014) and from the pooled data as summarized in the Table 4.8 the maximum mean uptake of P was observed from T₉ (19.91 kg ha⁻¹) and the lowest from control T₁ (4.51 kg ha⁻¹). It has been noted that the treatments involving integration of crop residues (rice or wheat or both) along with green manuring + fertilizers (T₇, T₈ and T₉) and green manuring + fertilizers (T₆) were recorded with higher P uptake as compared to the treatments comprising only crop residues (rice or wheat or both) + fertilizers (T₃, T₄ and T₅) and sole application of NPK fertilizers (T₂). This might be due to improvement of physico-chemical properties of soil on account of incorporation of crop residues and green manuring. Similar findings are also reported by Jai *et al.* (2014) who revealed that nutrient recycling through incorporation of crop residues and *Sesbania* green manuring along with inorganics greatly improved the crop productivity, nutrient uptake, and biofertility indicators of soil health.

4.4.3 Potassium uptake (kg ha⁻¹)

The result presented in the Table 4.8 revealed that there was significant influences of the treatments on uptake of potassium (K) by rice in both the years and the maximum mean uptake of K has been recorded from T₉ (118.75 kg ha⁻¹) and the lowest has been recorded from T₁ (49.24 kg ha⁻¹). From both the years it has been observed that the treatment where crop residue (rice or wheat or both) were incorporated with or without green manuring had done better as compared to those treatments which received only chemical fertilizers and no chemical fertilizers or crop residues (control treatment). Similar findings were also reported by Dotaniya *et al.* (2013), Jai *et al.* (2014), Kachroo and Dixit (2005).

4.5 Effect of crop residues and green manuring on growth attributing characters of wheat

4.5.1 Plant height

Plant height was recorded at four different growth stages i.e. 25, 50, 75 and 100 DAS. No significant effects of treatments have been recorded in the early growth stage i.e. at 25 DAS on plant height in both the years. But, from 50 DAS to 100 DAS, significant influences of treatments on plant height have been observed. The various rice residue and nutrient management systems significantly affect the plant height was reported by Tomar *et al.* (2006) and Neeraj and Binod (2013). The plant height has been noticed to increase up to 100 DAS and the highest plant height was recorded from the treatment comprising residue incorporation (both rice and wheat) along with green manuring + fertilizers (T₉) with the mean value of 49.12, 88.75 and 93.48 cm at 50, 75 and 100 DAS, respectively and lowest plant height has been recorded from control T₁ i.e. 30.85, 71.53 and 74.87 at 50, 75 and 100 DAS, respectively. However, T₉ have been found to be statistically at par with treatments T₂ to T₈ at 50, 75 and 100 DAS and significantly higher than T₁ in both years as indicated by data presented in the Table 4.9 and Fig. 4.8. The findings are in accordance with Mukherjee and Singh (2001) who reported that the significant effect of green manuring with *Sesbania* on plant height at 50 and 70 DAP and harvest, but plant heights in all the residue management treatments (residue removal, residue burning, residue incorporation, green manuring + residue removal and green manuring + residue incorporation) were statistically at par with each other at all stages.

4.5.2 Number of tillers per square meter of wheat

Replication wise number of tillers per square meter was recorded at 25, 50, 75 and 100 DAS in both the years. Maximum number of tillers were recorded at 50 DAS in both the years after that there was a decline in the number of tillers till harvest. Significant influences of treatments on number of tillers have been observed at all the growth stages in the first year (2013-14). However, treatments from T₂ to T₉ have been found to be statistically at par with each other and significantly greater than T₁. The influences of the treatments have been found to be more pronounced in the second year (2014-15) except in T₁ and T₂ which might be due to improvement of soil nutrient status as a result of incorporation of crop residues and green manuring. Similar, findings were also reported by Neeraj and Binod (2013) that the various rice residue and nutrient management systems significantly affect the plant height and number of tillers per meter. Among the treatments, T₉ have been recorded with the maximum mean values of tiller numbers i.e. 298.58, 398, 392.67 and 300.75 at all the growth

Table 4.9: Effect of crop residues and green manuring on plant height of wheat

Treatment	Plant height in cm											
	25 DAS			50 DAS			75 DAS			100 DAS		
	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled
T ₁	25.53	24.93	25.23	31.46	30.23	30.85	72.33	70.73	71.53	75.13	74.60	74.87
T ₂	27.20	26.87	27.03	45.71	45.00	45.36	84.57	83.60	84.09	90.73	89.17	89.95
T ₃	27.37	27.43	27.40	46.17	48.00	47.08	86.06	86.57	86.31	91.87	92.40	92.13
T ₄	27.27	26.93	27.10	45.80	47.20	46.50	84.61	85.13	84.87	91.40	91.60	91.50
T ₅	27.20	27.40	27.30	46.53	47.93	47.23	85.96	86.17	86.06	91.33	91.87	91.60
T ₆	26.80	27.71	27.26	47.33	48.87	48.10	87.10	87.27	87.18	92.00	92.73	92.37
T ₇	26.73	28.53	27.63	47.95	49.53	48.74	88.41	88.50	88.46	92.40	93.67	93.03
T ₈	27.33	27.90	27.62	47.21	49.00	48.11	87.28	87.67	87.47	92.00	93.27	92.63
T ₉	27.07	28.47	27.77	48.11	50.13	49.12	88.33	89.17	88.75	92.93	94.03	93.48
SEm (±)	1.22	0.81	0.73	1.63	2.17	1.35	2.55	2.73	1.87	2.61	3.21	2.07
CD (5 %)	NS	NS	NS	4.87	6.49	3.90	7.64	8.18	5.38	7.82	9.61	5.95

T₁: Control; T₂: Soil test based fertilizers; T₃: Rice residue incorporation + T₂; T₄: Wheat residue incorporation + T₂; T₅: Rice and Wheat residue incorporation + T₂; T₆: Green manuring + T₂; T₇: Rice residue incorporation + T₆; T₈: Wheat residue incorporation + T₆; T₉: Rice and Wheat residue incorporation + T₆

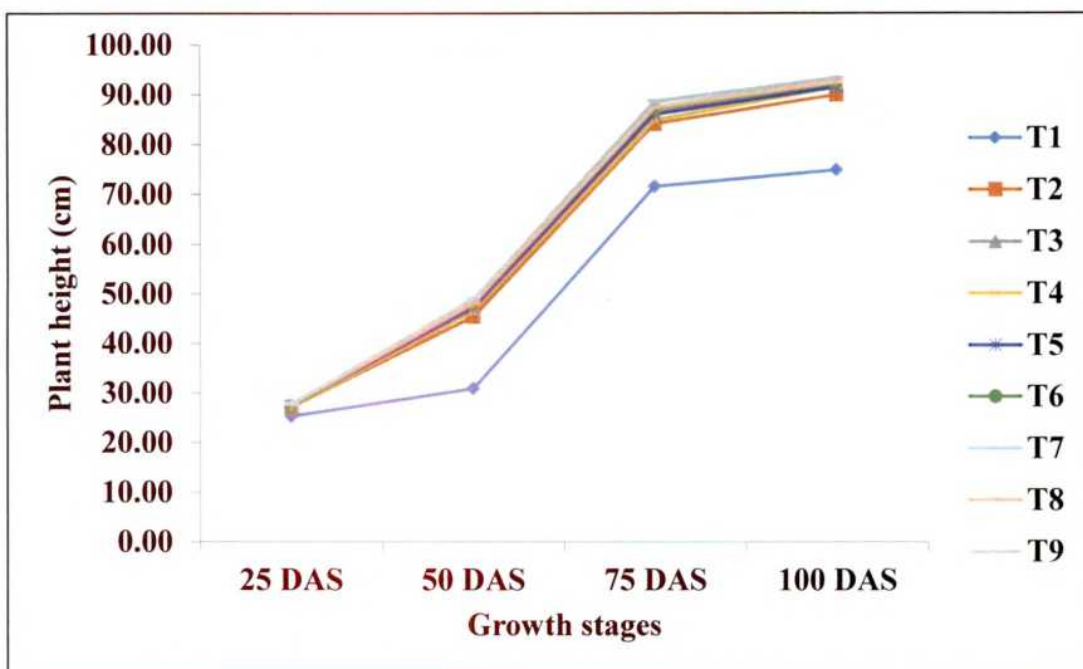


Fig 4.8: Plant height of wheat at different growth stages

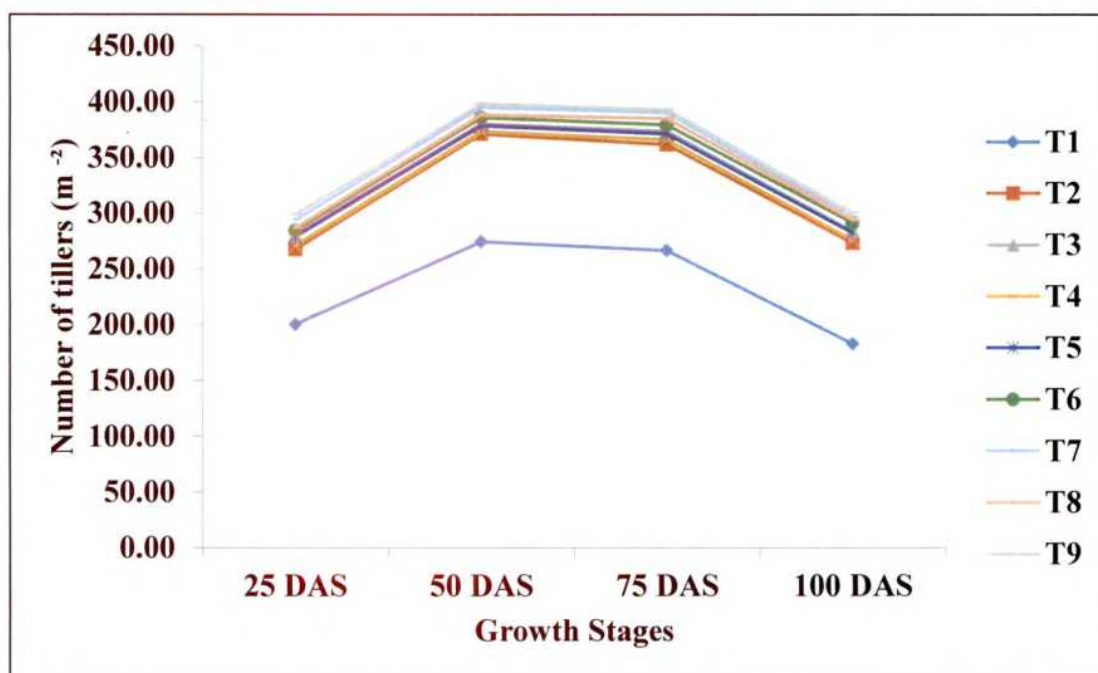


Fig 4.9: Tiller number per square meter of wheat at different growth stages

Table 4.10: Effect of crop residues and green manuring on number of tillers of wheat

Treatment	Number of tillers in m ⁻²											
	25 DAS			50 DAS			75 DAS			100 DAS		
	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled
T ₁	201.33	198.33	199.83	280.00	268.17	274.08	269.33	263.33	266.33	188.33	176.67	182.50
T ₂	269.00	265.00	267.00	372.33	369.17	370.75	364.33	358.50	361.42	273.33	272.50	272.92
T ₃	276.17	284.50	280.33	376.83	383.00	379.92	370.67	375.83	373.25	281.00	287.03	284.02
T ₄	269.33	271.67	270.50	371.83	374.17	373.00	364.17	367.67	365.92	274.17	277.67	275.92
T ₅	276.67	280.00	278.33	376.83	379.83	378.33	369.33	372.50	370.92	281.33	283.17	282.25
T ₆	280.67	287.00	283.83	382.50	388.33	385.42	376.83	381.33	379.08	290.83	291.67	291.25
T ₇	289.17	298.00	293.58	388.83	400.90	394.87	383.33	396.73	390.03	293.33	300.50	296.92
T ₈	281.00	292.17	286.58	382.07	394.17	388.12	376.50	393.17	384.83	292.50	295.50	294.00
T ₉	288.33	308.83	298.58	388.00	408.00	398.00	382.17	403.17	392.67	294.00	307.50	300.75
SEm (±)	16.49	15.98	11.48	14.24	13.96	9.97	11.73	16.52	10.13	13.99	18.07	11.43
CD (5 %)	49.43	47.92	33.08	42.68	41.84	28.72	35.16	49.51	29.18	41.93	54.18	32.92

T₁: Control; T₂: Soil test based fertilizers; T₃: Rice residue incorporation + T₂; T₄: Wheat residue incorporation + T₂; T₅: Rice and Wheat residue incorporation + T₂; T₆: Green manuring + T₂; T₇: Rice residue incorporation + T₆; T₈: Wheat residue incorporation + T₆; T₉: Rice and Wheat residue incorporation + T₆

stages (25, 50, 75 and 100 DAS, respectively) and the lowest mean values have been obtained from control T₁ i.e. 199.83, 274.08, 266.33 and 182.50, respectively) as depicted in the Table 4.10 and Fig. 4.9. The pooled data also revealed the same trend as that of second year. The findings are in accordance with Sandeep Kumar *et al.* (2004) who reported that the number of tillers generated by each plant was highest from the crop receiving retention/incorporation of residue with conservation and deep tillage.

4.5.3 Leaf Area Index (LAI) of wheat

Observations on LAI have been recorded at four distinct growth stages i.e. 25, 50, 75 and 100 DAS and maximum LAI was recorded at 75 DAS in all the treatments in both the years and there was declined thereafter. In first year (2013-14), at 25 DAS, influence of treatments did not differ significantly but from 50 DAS onwards till 100 DAS significant influence of treatments on LAI was noted. At 50 and 75 DAS of first year, the treatments from T₂ to T₉ have been noticed to be statistically at par and significantly superior to control T₁. The observation revealed that there was not much effect of incorporation of crop residues in the first year. A sort of immobilization of nutrients might have operational during the initial stage. But at 100 DAS, effect of T₃ and treatments from T₅ to T₉ has been found to be at par among themselves while significantly higher than T₁. Again, effect of T₃, T₅, T₆ and T₈ has been observed to at par with T₂ and T₄. Whereas, effect of the treatments except for T₂ and T₁ was comparatively higher in second year (2014-15) as revealed by the data presented in the Table 4.11 and Fig.4.10, treatment T₉ comprising crop residues (both rice and wheat) incorporation along with green manuring + fertilizers have been recorded with the maximum LAI values i.e.1.65, 3.13, 3.82 and 2.76 at all the growth stages (25, 50, 75 and 100 DAS, respectively) and the lowest values were obtained from control T₁(1.19, 2.35, 2.84 and 1.81, respectively). At 100 DAS, T₉ have been recorded to statistically at par with treatments T₆, T₇ and T₈ and significantly higher than T₁ to T₅. Again, T₆, T₇ and T₈ have been found to at par with T₃, T₄ and T₅ but significantly superior to T₁ and T₂. Again, T₂ have been found to significantly greater than T₁. The pooled data also revealed the similar trend as was noticed in the second year. Sole application of chemical fertilizers (T₂) and non-application of fertilizers both had negative effect on crop growth in the second year. Deterioration of physicochemical properties of soils might have rendered negative impact on growth parameters. The findings are in accordance with Fateh *et al.* (2008) who reported that cultivation of rice and wheat

Table 4.11: Effect of crop residues and green manuring on LAI of wheat

Treatment	25 DAS			50 DAS			75 DAS			100 DAS		
	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled
T ₁	1.26	1.19	1.23	2.45	2.35	2.40	3.00	2.84	2.92	1.87	1.81	1.84
T ₂	1.30	1.26	1.28	2.65	2.64	2.64	3.36	3.29	3.33	2.12	2.09	2.10
T ₃	1.30	1.50	1.40	2.71	2.94	2.82	3.42	3.65	3.54	2.23	2.49	2.36
T ₄	1.29	1.40	1.34	2.65	2.89	2.77	3.36	3.60	3.48	2.13	2.35	2.24
T ₅	1.30	1.49	1.40	2.71	2.91	2.81	3.42	3.63	3.52	2.24	2.44	2.34
T ₆	1.31	1.54	1.42	2.73	3.02	2.88	3.48	3.72	3.60	2.31	2.55	2.43
T ₇	1.28	1.64	1.46	2.74	3.11	2.92	3.55	3.79	3.67	2.40	2.69	2.54
T ₈	1.32	1.60	1.46	2.72	3.09	2.91	3.48	3.76	3.62	2.32	2.64	2.48
T ₉	1.29	1.65	1.47	2.75	3.13	2.94	3.54	3.82	3.68	2.41	2.76	2.58
SEm (±)	0.04	0.05	0.03	0.06	0.09	0.06	0.08	0.12	0.07	0.07	0.08	0.05
CD (5 %)	NS	0.16	0.09	0.17	0.28	0.16	0.24	0.36	0.21	0.20	0.25	0.15

T₁: Control; T₂: Soil test based fertilizers; T₃: Rice residue incorporation + T₂; T₄: Wheat residue incorporation + T₂; T₅: Rice and Wheat residue incorporation + T₂; T₆: Green manuring + T₂; T₇: Rice residue incorporation + T₆; T₈: Wheat residue incorporation + T₆; T₉: Rice and Wheat residue incorporation + T₆

on the recommended dose of NPK fertilizers alone decreased the organic carbon, available P and K content of the soil. Treatments consisting of crop residues, green manuring and crop residues along with green manuring exerted more influence in the second year as compared to first year. This might have happened due to proper decomposition of residues and green manures because of availability of longer time and consequent upon enrichment of nutrient status of experimental soils. The findings are in harmony with Sharma *et al.* (2001) who reported that incorporation of rice residue before wheat sowing had no significant effect on grain and straw yields and phosphorus uptake of wheat but had a significant residual effect on grain yield and phosphorus uptake in succeeding rice.

4.5.4 Crop Growth Rate (CGR) of wheat

Crop growth rate (CGR) was recorded at 0-25, 25-50, 50-75 and 75-100 DAS and the maximum CGR was obtained at 50- 75 DAS from all the treatments in both the years as depicted in the Table 4.12. Though, the effect was more pronounced in the second the year (2014-15) in case of the treatments consisting of crop residue (rice or wheat or both) incorporation with or without green manuring + fertilizers (T_3 to T_9) because of production of higher number of tillers and attainment of higher plant height in second year as shown in Fig. 4.11. In the first year (2013-14), it has been noticed that there was no significant influence on CGR among the treatments except for control treatment (T_1). Whereas, in the second year (2014-15), T_9 (comprising of incorporation of both rice and wheat crop residues along with green manuring + fertilizers) recorded maximum CGR at all the growth stages i.e. 0-25, 25-50, 50-75 and 75-100 DAS with the values of 4.21, 7.84, 8.80 and 4.72 $\text{gm}^{-2}\text{day}^{-1}$, respectively and the lowest values were obtained from the control where fertilizers were not applied (T_1). At 75-100 DAS, T_9 have been found to be at par with T_6 , T_7 and T_8 but significantly higher than T_1 to T_5 . However, T_6 , T_7 and T_8 have been recorded to at par with T_2 to T_5 but significantly superior to T_1 . Similar trend of second year in respect of CGR was noted from the pooled data. The findings were in accordance with Wang *et al.* (2011).

4.5.5 Root dry weight per square meter of wheat

Observations on root growth were taken at four different growth stages (25, 50, 75 and 100 DAS) and the maximum growth was obtained at 50 DAS and declined thereafter in irrespective of all the treatments in both the years. The data undoubtedly revealed that the crop attained peak growth which could also be substantiated from the

Table 4.12: Effect of crop residues and green manuring on CGR of wheat

Crop growth rate (CGR) in g m ⁻² day ⁻¹												
Treatment	0-25 DAS			25- 50 DAS			50 - 75 DAS			75- 100 DAS		
	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled
T ₁	2.17	1.68	1.92	4.02	3.06	3.54	4.29	3.38	3.84	1.61	0.98	1.29
T ₂	3.41	3.36	3.38	6.78	6.58	6.68	7.20	7.00	7.10	3.04	2.92	2.98
T ₃	3.45	3.78	3.62	6.99	7.17	7.08	7.39	8.25	7.82	3.12	3.57	3.35
T ₄	3.41	3.69	3.55	6.77	6.84	6.80	7.20	7.57	7.39	2.92	3.38	3.15
T ₅	3.47	3.73	3.60	6.95	7.03	6.99	7.37	8.09	7.73	3.12	3.48	3.30
T ₆	3.55	3.87	3.71	7.36	7.45	7.41	7.71	8.39	8.05	3.24	3.66	3.45
T ₇	3.64	4.11	3.87	7.45	7.69	7.57	7.86	8.66	8.26	3.28	4.56	3.92
T ₈	3.57	3.99	3.78	7.28	7.56	7.42	7.73	8.45	8.09	3.26	4.26	3.76
T ₉	3.63	4.21	3.92	7.42	7.84	7.63	7.86	8.80	8.33	3.28	4.72	4.00
SEm(±)	0.09	0.18	0.10	0.28	0.27	0.20	0.26	0.27	0.19	0.24	0.37	0.22
CD (5 %)	0.27	0.54	0.29	0.83	0.82	0.56	0.77	0.81	0.54	0.73	1.12	0.64

T₁: Control; T₂: Soil test based fertilizers; T₃: Rice residue incorporation + T₂; T₄: Wheat residue incorporation + T₂; T₅: Rice and Wheat residue incorporation + T₂; T₆: Green manuring + T₂; T₇: Rice residue incorporation + T₆; T₈: Wheat residue incorporation + T₆; T₉: Rice and Wheat residue incorporation + T₆

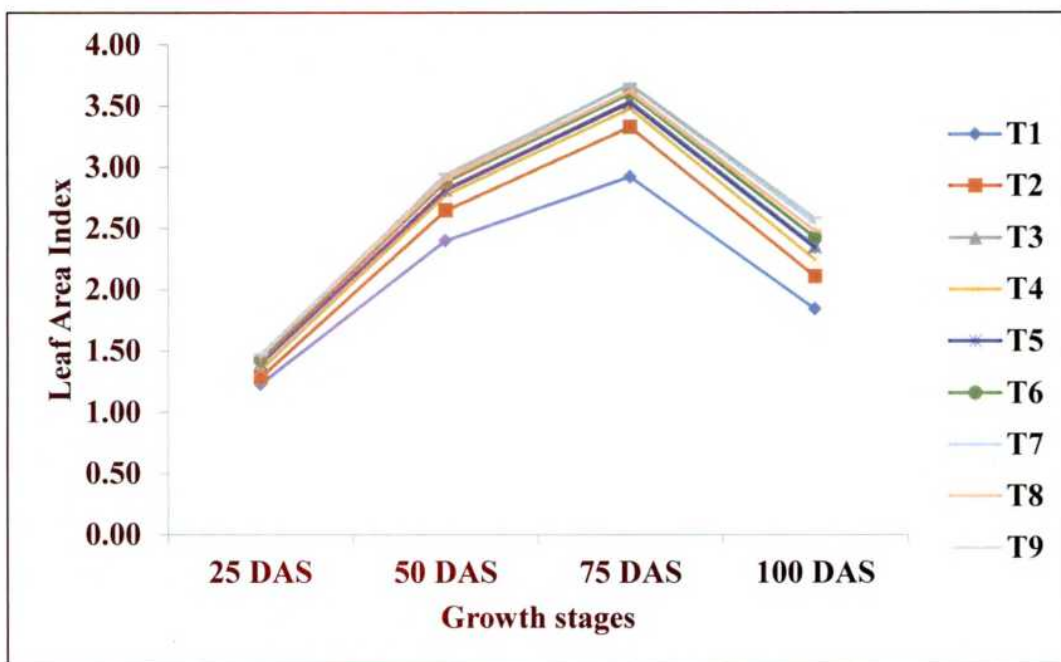


Fig 4.10: Leaf Area Index of wheat at different growth stages

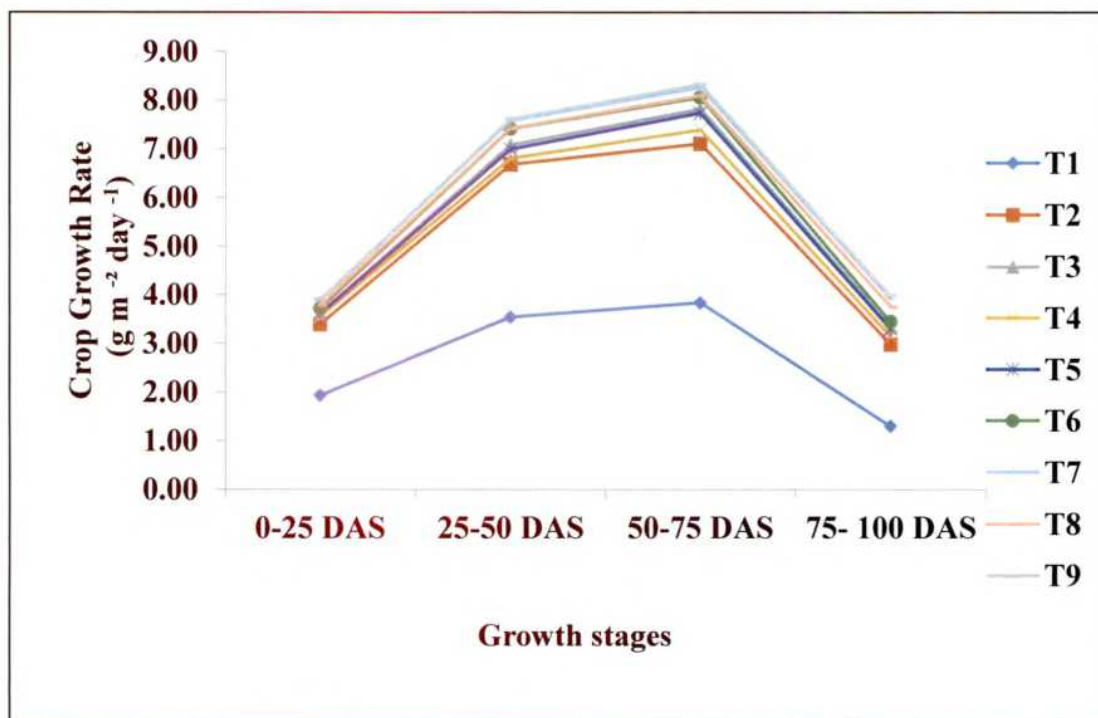


Fig 4.11: Crop growth rate of wheat at different growth stages

Table 4.13: Effect of crop residues and green manuring on root dry weight of wheat

Root dry weight in g m ⁻²											
Treatment	25 DAS			50 DAS			75 DAS			100 DAS	
	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled	2013-14	2014-15 Pooled
T ₁	14.67	13.63	14.15	95.00	79.67	87.34	71.33	66.82	69.08	63.00	59.75 61.38
T ₂	17.67	17.00	17.33	103.83	101.85	102.84	99.05	94.23	96.64	90.15	83.43 86.79
T ₃	19.67	24.87	22.27	106.00	116.27	111.14	102.54	112.68	107.61	95.33	99.20 97.27
T ₄	17.67	20.20	18.93	104.17	106.07	105.12	100.00	102.47	101.23	90.57	92.10 91.33
T ₅	19.62	23.00	21.31	105.83	111.23	108.53	102.71	108.37	105.54	95.50	96.68 96.09
T ₆	20.00	27.33	23.67	109.17	120.47	114.82	105.97	117.43	111.70	100.07	102.93 101.50
T ₇	21.33	33.23	27.28	112.40	128.95	120.67	110.19	127.13	118.66	106.53	110.73 108.63
T ₈	20.50	30.10	25.30	109.50	126.02	117.76	106.00	121.25	113.63	100.67	106.37 103.52
T ₉	21.33	34.53	27.93	112.17	135.40	123.78	110.00	132.97	121.48	106.51	113.02 109.77
SEm (±)	1.28	2.58	1.44	2.21	3.84	2.21	3.80	7.98	4.42	4.04	4.60 3.06
CD (5 %)	3.82	7.74	4.15	6.62	11.50	6.38	11.39	23.92	12.73	12.10	13.79 8.81

T₁: Control; T₂: Soil test based fertilizers; T₃: Rice residue incorporation + T₂; T₄: Wheat residue incorporation + T₂; T₅: Rice and Wheat residue incorporation + T₂; T₆: Green manuring + T₂; T₇: Rice residue incorporation + T₆; T₈: Wheat residue incorporation + T₆; T₉: Rice and Wheat residue incorporation + T₆

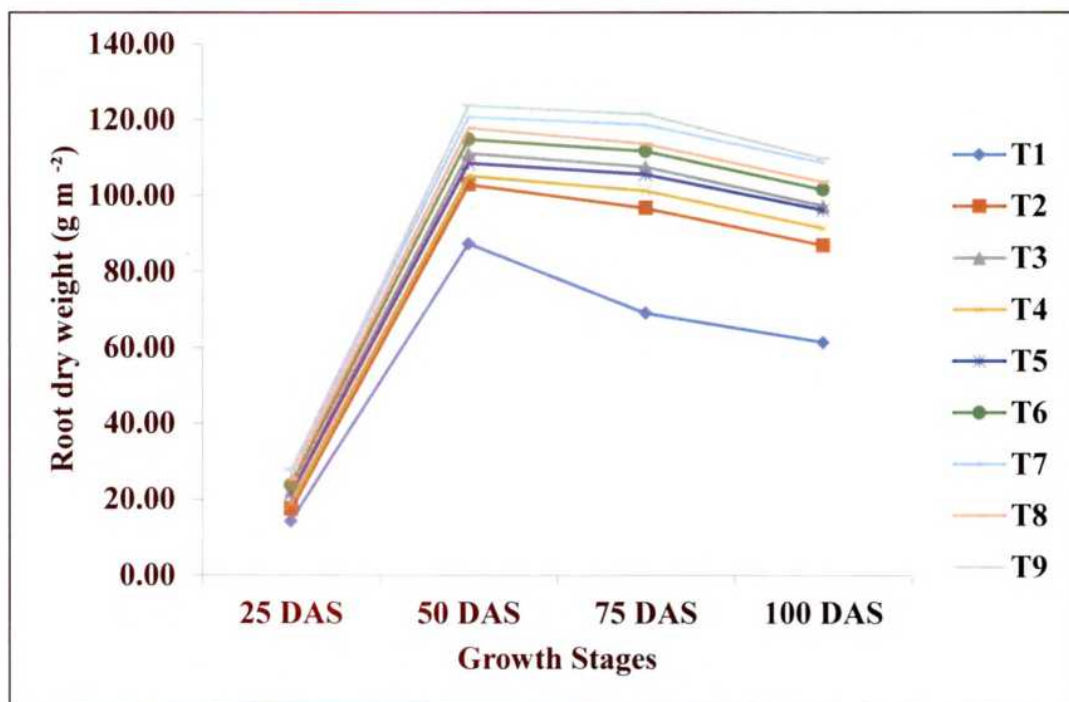


Fig 4.12: Root dry weight of wheat at different growth stages

accomplishment of maximum tiller numbers at this growth stage. Treatment effect was more pronounced in the second year except for the treatments T₁ and T₂ where no amendments of organic substances were done. In the first year (2013-14), it has been found that the treatments T₃ and T₅ to T₉ were at par with treatments T₂ and T₄ but significantly greater than T₁ at all the growth stages. It has been recorded the treatment involving integration of crop residues (rice or wheat or both) incorporation with green manuring + fertilizers (T₇, T₈ and T₉) were found superior to the treatment comprising only green manuring + fertilizers (T₆), the treatments in receipt of only crop residues (rice or wheat or both) incorporation + fertilizers without green manuring (T₃, T₄ and T₅), T₂ comprising of only fertilizers and control T₁ in the second year (2014-15). However, T₉ have been found to be superior to T₇ and T₈ with the maximum root growth values of 34.53, 135.40, 132.97 and 113.02 g m⁻² at 25, 50, 75 and 100 DAS, respectively, even though, they have been found to statistically at par while registering superiority to T₁ and T₂ significantly at all the growth stages. But at 50 DAS, maximum root growth was obtained at T₉ which was found to be significantly higher than treatments T₁ to T₆ and treatments, namely T₇ and T₈ have been observed to be at par with T₃, T₅ and T₆. Again, T₃ and T₅ have been found to at par with T₂ and T₄ but significantly greater than control T₁. The results worked out from the pooled data of two years followed the similar trend as that of the trend of second year as depicted in the Table 4.13 and Fig. 4.12. The findings are in accordance with Mandal and Pal (2009) who reported that green manuring increased root length, root volume, root dry weight (i.e. root characters) compared with control. Similar, findings were also reported by Boparai *et al.* (1992).

4.6 Effect of crop residues and green manuring on yield attributing characters of wheat

4.6.1 Number of earheads

The data on number of earheads per square meter as affected by treatments have been presented in the Table 4.14. The influence of the treatments except for T₂ and T₁ was found to be more pronounced in the second year (2014-15). Depletion of soil fertility in treatments having non- incorporation of organic form of nutrients after two crop cycles (wheat and rice) might be responsible for lowering microbial activity which in turn rendered lower values in these treatments. The findings are in accordance with Dhiman *et al.* (2000) who reported that organic carbon and total nitrogen in the soil increased with the incorporation of crop residues but decreased with their burning and removal. In the first year (2013-14), the treatment from T₂ to T₉ produced significantly

Table 4.14: Effect of crop residues and green manuring on yield attributes of wheat

Treatment	Number of earheads (m ⁻²)			Length of earhead(cm)			Grain earhead ⁻¹			1000-grain weight (g)		
	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled
T ₁	116.80	110.53	113.67	7.16	7.08	7.12	33.91	33.60	33.76	38.37	38.55	38.31
T ₂	224.51	221.80	223.15	8.44	8.34	8.39	41.28	39.97	40.63	39.14	39.70	39.42
T ₃	237.47	239.73	238.60	8.57	8.69	8.63	42.04	42.32	42.18	39.57	40.07	39.82
T ₄	221.63	235.10	228.37	8.51	8.56	8.53	41.40	41.75	41.58	39.18	39.70	39.44
T ₅	241.53	238.70	240.12	8.39	8.59	8.49	41.85	42.09	41.97	39.30	40.40	39.85
T ₆	243.07	240.83	241.95	8.65	8.81	8.73	42.57	42.75	42.66	39.47	40.57	40.02
T ₇	245.43	242.20	243.82	8.61	8.96	8.78	43.00	43.57	43.28	39.80	40.33	40.07
T ₈	243.33	241.80	242.57	8.63	8.84	8.74	42.64	42.88	42.76	40.10	40.83	40.47
T ₉	245.93	251.80	248.87	8.93	9.15	9.04	43.57	44.21	43.89	40.20	40.87	40.53
SEm (±)	7.87	7.02	5.28	0.29	0.25	0.19	1.75	1.67	1.21	1.23	1.17	0.85
CD (5 %)	23.60	21.06	15.20	0.87	0.76	0.55	5.25	5.01	3.49	NS	NS	NS

T₁: Control; T₂: Soil test based fertilizers; T₃: Rice residue incorporation + T₂; T₄: Wheat residue incorporation + T₂; T₅: Rice and Wheat residue incorporation + T₂; T₆: Green manuring + T₂; T₇: Rice residue incorporation + T₆; T₈: Wheat residue incorporation + T₆; T₉: Rice and Wheat residue incorporation + T₆

higher number of earheads as compared to the control plots; however no significant difference was noted among the treatments from T₂ to T₉. Whereas, in second year (2014-15), the same trend was noticed though T₉ having integration of both crop residues of rice and wheat with green manuring + fertilizers produced maximum number of earheads per square meter (251.80) as compared to other treatments and the lowest was obtained from T₁ (110.53). The treatment was significantly superior to T₂ also (sole fertilizer applied plots). Higher number of tillers in this treatment influenced production of higher number of earheads. The number of tillers generated by each plant was highest from the crop receiving retention/incorporation of residue with conservation and deep tillage was also reported by Sandeep *et al.* (2004). This might be due to residual effect of crop residue incorporation and green manuring in the first year which lead to improvement in soil fertility. The findings are in accordance with Das *et al.* (2002) who reported that there were increased in yield attributes due to the residual effect of crop residue treatments, although the increase was not significant. The pooled data also followed the similar trend as that of second year.

4.6.2 Length of earhead

The effect of treatments on length of earhead of wheat followed similar trend as was recorded in respect of effect of treatments on number of earheads per square meter of wheat. The ear length was higher in plots treated with crop residues (both rice and wheat) and green manure + fertilizers (T₉) with the mean value of 9.04 cm than the plots exposed to other treatments (T₁ to T₈). Though in the first year (2013-14), no significant difference was noticed among T₂ to T₉ treatments but in the second year (2014-15) the treatment produced significantly higher earhead length as compared to T₂ as presented in Table 4.14 (where crop residues were removed and received only chemical fertilizers), which indicated that with the passage of time soil fertility improved because of residue incorporation along with GM and fertilizer. The observation is substantiated with the findings of Arshadullah *et al.* (2012) who noted maximum panicle length in treatment receiving straw incorporation @ 5 t ha⁻¹ along with 90 kg N ha⁻¹. Significantly lowest earhead length was noted in control treatment with the mean value of 7.12 cm. Plots receiving no fertilizers and crop residues (T₁) and only fertilizers without crop residues (T₂) produced lower earhead length in the second year indicated depletion of fertility status of the soil because of comparatively poor physico-chemical and biological properties of soils in these treatments.

4.6.3 Grains per earhead

The data presented in the Table 4.14 revealed the same trend of impact of the treatments on the yield parameters like number of earheads per square meter, length of earhead and grains per earhead. T₉ recorded significantly higher grains per earhead (44.21) as compared to T₂ in the second year (2014-15). Higher length of earhead might have attributed to more grains per earhead in this treatment.

4.6.4 1000-Grain weight

1000-grain weight is an important index of grain health. The effect of treatments on 1000-grain weight was found to be non-significant in both the years. Though this is basically a genotypic character, the residues and GM treated plots produced comparatively healthier grains as compared to control plots (T₁) and sole fertilizer treated plots (T₂) and higher 1000-grain weight was noted in plots treated with residues and green manure + fertilizers (T₉) than the plots exposed to other treatments (T₁ to T₈) as presented in Table 4.14. Microbial activity would have increased due to residue decomposition helped the crop to attain good vigour and to produce healthy seeds.

4.7 Effect of crop residues and green manuring on grain and straw yield and harvest index of wheat

4.7.1 Grain yield

A gradual increase in grain yield commensurate with increasing amount of crop residues and GM was noticed in both the years though the magnitude was slightly higher in the second year (2014-15) in irrespective of all the treatments (Table 4.15). It was also observed that the treatments involving residue incorporation of rice or wheat or both + fertilizers (T₃, T₄ and T₅) and residue incorporation (rice or wheat or both) along with green manuring + fertilizers (T₇, T₈ and T₉) enhanced yield over control (T₁) and sole fertilized plots (T₂) to a variable degree (Fig. 4.13). However, there was no significant difference among the treatments from T₂ to T₈. Only T₉ treatment (comprising both crop residues of rice and wheat along with GM and fertilizer) which produced the highest grain yield (4.35 and 4.59 t ha⁻¹, respectively) in both the years was found to be statistically superior to treatment of sole fertilizer application (T₂) but remained at par with treatment from T₃ to T₈. Higher number of earheads, length of earhead, and number of grains per earhead and 1000-grain weight altogether influenced higher production of grains in this treatment (T₉). The findings are in agreement with

Table 4.15: Effect of crop residues and green manuring on grain and straw yield and harvest index of wheat

Treatment	Grain yield (t ha ⁻¹)			Straw yield (t ha ⁻¹)			Harvest index (%)		
	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled
T ₁	1.50	1.44	1.47	3.03	3.03	3.03	33.02	32.21	32.62
T ₂	3.78	3.66	3.72	5.20	4.87	5.03	42.20	42.93	42.56
T ₃	3.89	4.02	3.95	5.26	5.34	5.30	42.56	43.14	42.85
T ₄	3.78	3.99	3.88	5.16	5.28	5.22	42.10	42.93	42.52
T ₅	3.94	4.09	4.02	5.33	5.41	5.37	42.55	42.94	42.75
T ₆	4.08	4.21	4.15	5.32	5.53	5.43	43.45	43.26	43.35
T ₇	4.19	4.29	4.24	5.37	5.61	5.49	43.90	43.30	43.60
T ₈	4.05	4.25	4.15	5.30	5.59	5.45	43.40	43.04	43.22
T ₉	4.35	4.59	4.47	5.59	5.69	5.64	43.85	44.63	44.24
SEm (±)	0.17	0.21	0.13	0.31	0.22	0.19	1.28	1.43	0.96
CD (5 %)	0.52	0.62	0.39	0.92	0.67	0.55	3.85	4.28	2.76

T₁: Control; T₂: Soil test based fertilizers; T₃: Rice residue incorporation + T₂; T₄: Wheat residue incorporation + T₂; T₅: Rice and Wheat residue incorporation + T₂; T₆: Green manuring + T₂; T₇: Rice residue incorporation + T₆; T₈: Wheat residue incorporation + T₆; T₉: Rice and Wheat residue incorporation + T₆

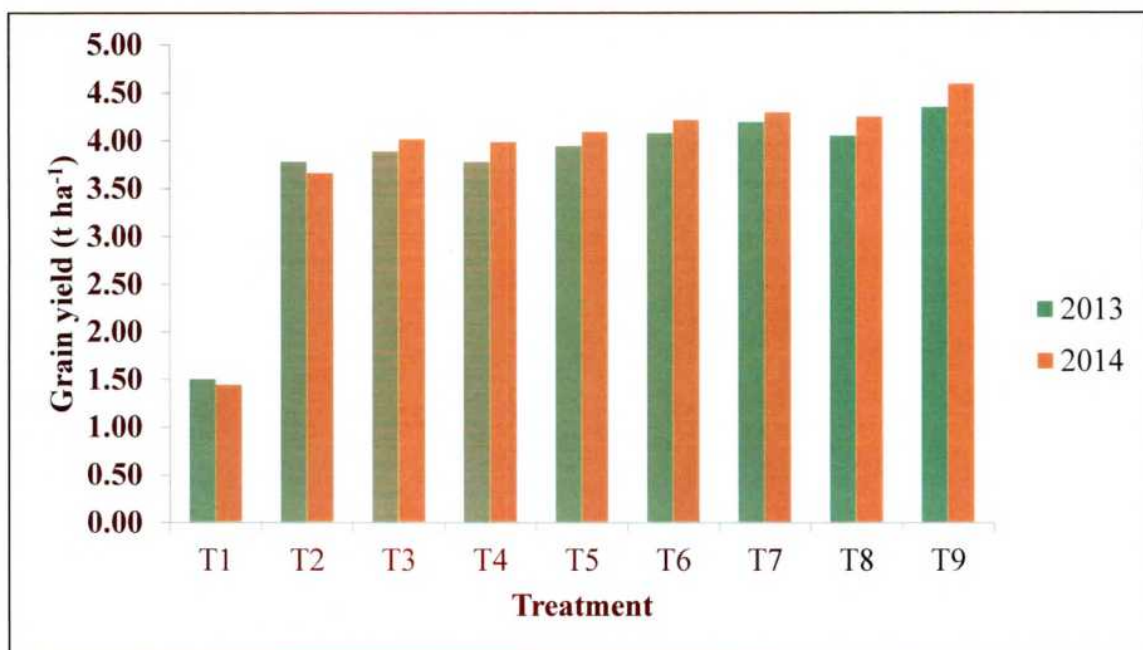


Fig 4.13: Grain yield of wheat

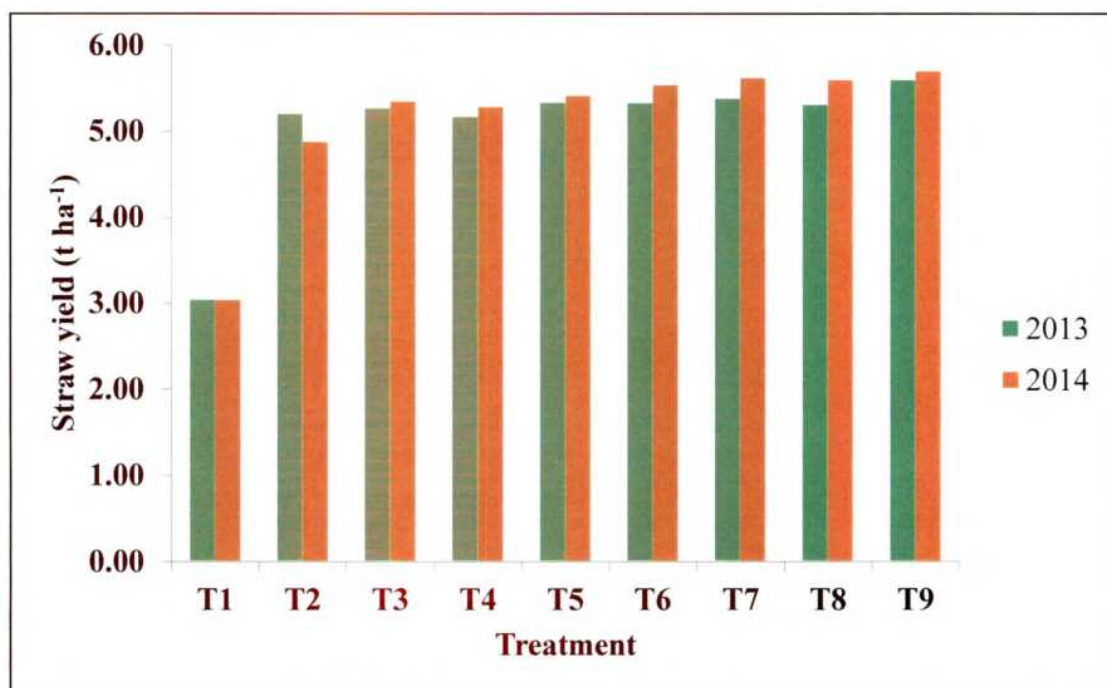


Fig 4.14: Straw yield of wheat

Gangwar *et al.* (2006) who reported that residue incorporation resulted in highest mean yield (5.86 Mg ha^{-1}) of wheat in rice-wheat system during three years of field study. Sandeep Kumar *et al.* (2004) also observed that deep tillage incorporation of rice residue scaled higher attributes and grain yield. Rice + wheat residue incorporation in combination with GM (T_9) enhanced the grain yield of wheat by 20.16% as compared to sole chemical fertilizers source (T_2). A decreasing trend of crop yield was noted in control plots (T_1 , receiving no fertilizers and crop residues) and sole NPK fertilized plots (T_2), which also revealed the deterioration of soil health or poor fertility status over time if not amended with organic form of nutrients such as incorporation of crop residues or green manuring. The findings are in agreement with Sharma and Sharma (2005) who reported that retention or incorporation of rice, wheat or both crop residues increased soil organic C by 19-32% (absolute increases of 0.06-0.1% organic C) in the top 0-15cm soil layer after 2 years (four crops) in comparison with both the initial soil organic C and 2 years of burning the residues of both crops. In the second year (2014-15), all the treatments (from T_3 to T_9) produced higher grain yield which indicated that residue incorporation along with GM and fertilizers produced more impact if allowed some more time for decomposition rather than in a short span of time for decomposition.

The results clearly demonstrated that incorporation of both rice and wheat residues along with green manuring and fertilizers produced more influence on yield attributes and grain yield of wheat than incorporation of either rice or wheat residue along with green manuring and fertilizers. Again sole green manuring along with fertilizers application was found to produce more influence as compared to sole incorporation of rice or wheat residues or both with fertilizers (T_3 , T_4 and T_5) and sole application of chemical NPK fertilizers (T_2). Similar, findings were also reported by Singh and Sharma (2000).

4.7.2 Straw yield

All the treatments from T_2 (sole chemical fertilizers) to T_9 produced significantly higher straw yield over control (T_1), though no significant differences were observed among these treatments in the first year (2013-14). In the second year (2014-15) T_9 produced significantly higher straw yield over control (T_1) and T_2 . Higher grain yield realized from the treatments seem to be associated with higher straw yield. T_9 have been recorded with the highest straw yield of 5.69 t ha^{-1} in the second year and

accounted for 16.84 % higher straw yield over sole chemical fertilizers treated plots and control, respectively as depicted in Table 4.15 and Fig. 4.14. The lowest straw yield was recorded from the control T_1 i.e. 3.03 t ha^{-1} . However, T_9 have been found to at par with treatments T_3 to T_8 . Again, it has been observed that T_3 to T_6 (either rice or wheat residue or both along with GM + fertilizers and GM + fertilizers) were at par with T_2 but significantly superior to T_1 . The pooled data also depicted almost the similar trend like the second year. Similar, findings were also reported by Mandal and Pal (2009) and Jai *et al.* (2014) who reported that incorporation of crop residue along with green manuring produced higher grain and straw yield.

4.7.3 Harvest index

Amendments of crop residues (rice or wheat or both) along with 100% chemical fertilizers produced significantly higher harvest index as compared to control (T_1) though remained at par with 100% chemical fertilizers alone (T_2) or non-amended plots. Incorporation of crop residues showed less effect whereas green manuring scored higher values as compared to sole residue incorporation but in combination increased the efficiency of residues in achieving higher harvest index. The findings are in conformity with the observation of Mandal *et al.* (2004) who opined that combined use of rice or wheat straw and inorganic fertilizer increased the yield of rice and wheat in rice-wheat system (Table 4.15).

4.8 Effect of crop residues and green manuring on total nutrient uptake by wheat

4.8.1 Nitrogen uptake (kg ha^{-1})

The results summarized in the Table 4.16 revealed that the total uptake of N by wheat crop was significantly influenced by the treatments in both the years (2013-14 and 2014-15). The pooled data shows that the maximum mean uptake of N was recorded from T_9 ($131.80 \text{ kg ha}^{-1}$) and the minimum mean uptake from control T_1 (45.20 kg ha^{-1}). It also revealed that crop residues incorporation with or without green manuring + fertilizers (T_3 to T_9) were recorded with the higher uptake values of N as compared with the treatment comprising only NPK fertilizers (T_2). This might be due to improvement in nutrient cycling as the result of incorporation of crop residue incorporation and green manuring. Improvement of soil environment encouraged proliferation of roots might have resulted in absorption of more nutrients from extensive area. The findings are in accordance with Dotaniya *et al.* (2013) who reported that NPK uptake were highest in crop residue incorporation.

Table 4.16: Effect of crop residues and green manuring on total nutrient uptake by wheat

Treatment	N uptake (kg ha ⁻¹)		P uptake (kg ha ⁻¹)		K uptake (kg ha ⁻¹)	
	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled
T ₁	48.00	42.30	45.20	4.95	4.69	4.82
T ₂	85.50	78.80	82.20	10.77	10.39	10.58
T ₃	94.70	100.90	97.80	14.78	15.04	14.91
T ₄	96.00	104.60	100.30	14.44	14.60	14.52
T ₅	105.00	111.80	108.40	15.26	15.49	15.38
T ₆	110.20	119.70	115.00	16.21	16.57	16.39
T ₇	112.20	120.90	116.60	16.61	17.19	16.90
T ₈	111.30	120.00	115.70	17.62	18.45	18.04
T ₉	125.00	138.50	131.80	19.23	19.68	19.46
SEm (±)	4.76	4.41	3.25	1.22	1.06	0.81
CD (5 %)	14.27	13.23	9.35	3.66	3.19	2.33
				4.84	3.67	3.04
				14.51	11.01	8.75

T₁: Control; T₂: Soil test based fertilizers; T₃: Rice residue incorporation + T₂; T₄: Wheat residue incorporation + T₂; T₅: Rice and Wheat residue incorporation + T₂; T₆: Green manuring + T₂; T₇: Rice residue incorporation + T₆; T₈: Wheat residue incorporation + T₆; T₉: Rice and Wheat residue incorporation + T₆

4.8.2 Phosphorous uptake (kg ha^{-1})

The phosphorous (P) uptake by wheat crop was significantly influenced by the treatments in both the years as shown in the Table 4.16. From the pooled data it has been found that the maximum mean uptake of P was recorded from T_9 and the lowest were recorded from control T_1 (19.46 and 4.82 kg ha^{-1} , respectively). However, T_9 was statistically at par with T_8 and significantly superior to T_1 to T_7 . Again, T_8 have been found to be statistically at par with T_3 and T_5 to T_7 . It has also been found that T_3 , T_5 and T_6 were at par with T_2 but significantly superior to T_1 . The findings are in accordance with Kachroo and Dixit (2005) who also reported that incorporation of residues of rice before sowing of wheat and wheat before transplanting of rice not only increased the yield and yield components of rice and wheat but also increased the nutrient uptake by these crops.

4.8.3 Potassium uptake (kg ha^{-1})

The pooled data presented in the Table 4.16 showed that the highest mean uptake of potassium (K) was noted from incorporation of the both crop residues along with green manuring + fertilizers (T_9) with the value of $106.89 \text{ kg ha}^{-1}$ and the lowest mean value was recorded from control T_1 (39.34 kg ha^{-1}). The uptake of total K in wheat plant under different treatments was observed to be in similar trend with that of total P uptake. The findings are in accordance with Arshadullah *et al.* (2012) who also studied that residue incorporation along with N starter combated salinity and sodicity by enhanced uptake of Ca and K.

4.9 Effect of crop residues and green manuring on wheat system equivalent yield of rice-wheat system

System equivalent yield of rice-wheat system in terms of wheat equivalent yield in both the years (2013-14 and 2014-15) as evaluated in Table 4.17 and Fig. 4.15 revealed that in both the years the treatments comprising integration of crop residues (rice or wheat or both) along with or without green manuring + fertilizers and green manuring + fertilizers (T_3 to T_9) have been recorded with higher wheat equivalent yield of the system as compared to control T_1 . However, the treatments where crop residues (rice or wheat or both) were incorporated along with green manuring + fertilizers (T_7 , T_8 and T_9) were found to have greater influence on wheat equivalent yield of the system as compared to the treatments where crop residues (rice or wheat or both) were incorporated without green manuring + fertilizers (T_3 , T_4 and T_5). Again, in the

Table 4.17: Effect of crop residues and green manuring on system equivalent yield of rice-wheat system

Treatment	First year (2013-14)			Second year (2014-15)			
	Rice grain yield (t ha ⁻¹)	Wheat grain yield (t ha ⁻¹)	Wheat equivalent yield of rice (t ha ⁻¹)	Wheat equivalent yield of the system (t ha ⁻¹)	Rice grain yield (t ha ⁻¹)	Wheat grain yield (t ha ⁻¹)	Wheat equivalent yield of rice (t ha ⁻¹)
T ₁	1.13	1.5	1.05	2.55 (2.75)	0.98	1.44	0.88
T ₂	4.05	3.78	3.76	7.54 (8.12)	3.99	3.66	3.59
T ₃	3.95	3.89	3.66	7.55 (8.14)	4.62	4.02	4.16
T ₄	4.02	3.78	3.73	7.51 (8.09)	4.42	3.99	3.97
T ₅	4.07	3.94	3.78	7.73 (8.32)	4.55	4.09	4.09
T ₆	4.17	4.08	3.87	7.95 (8.56)	4.72	4.21	4.24
T ₇	4.12	4.19	3.83	8.02 (8.64)	4.98	4.29	4.48
T ₈	3.99	4.05	3.71	7.76 (8.35)	4.86	4.25	4.37
T ₉	4.17	4.35	3.88	8.23 (8.86)	5.12	4.59	4.61

*Price of rice is Rs.13 kg⁻¹ and Rs.13.5 kg⁻¹ in first and second year, respectively, Price of wheat is Rs 14kg⁻¹ and Rs 15 kg⁻¹ in first and second year, respectively

** Values in the parenthesis are rice equivalent yield of the system

T₁: Control; T₂: Soil test based fertilizers; T₃: Rice residue incorporation + T₂; T₄: Wheat residue incorporation + T₂; T₅: Rice and Wheat residue incorporation + T₂;

T₆: Green manuring + T₂; T₇: Rice residue incorporation + T₆; T₈: Wheat residue incorporation + T₆; T₉: Rice and Wheat residue incorporation + T₆

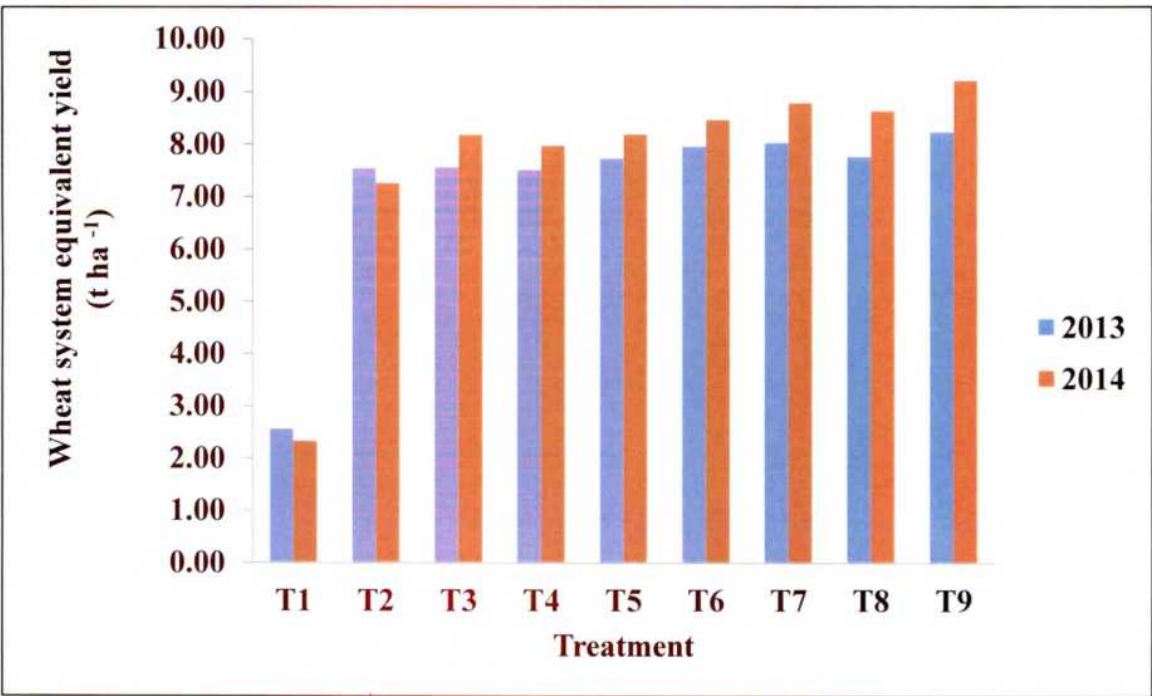


Fig 4.15: Wheat system equivalent yield of the experimental period

treatment T₆ where only green manuring was done along with fertilizers recorded higher wheat equivalent yield of the system than treatment receiving only crop residues and fertilizers (T₃, T₄ and T₅) in both the years. It is interesting to note that sole rice straw incorporation with or without GM had slightly higher influence over sole incorporation of wheat straw on wheat equivalent yield of the system. The maximum wheat equivalent yield of the system was recorded from T₉ in both the years (8.23 and 9.20 t ha⁻¹, respectively). High rice and wheat yield produced from the treatment T₉ attributed more wheat equivalent yields of the system in this treatment. The lowest wheat equivalent yields were obtained from control T₁ in both the years (2.55 and 2.32 t ha⁻¹, respectively). When system wheat equivalent yields of first and second year were compared, it has been observed that the system equivalent yield of the treatments T₃ to T₉ were found to be increased whereas the treatments with chemical fertilizers only (T₂) and without chemical fertilizers (control, T₁) were found to have decreased system equivalent yields. Enrichment of soil nutrient status over time in residue treated plots increased the crop yields of rice and wheat and influenced the system wheat equivalent yields accordingly. Reverse trend of soil status was noticed in treatments T₂ and T₁ which was reflected in the crop yields and also in wheat equivalent yields of the system.

4.10 Effect of crop residue management on soil properties

4.10.1 Physical properties

4.10.1.1 Bulk density and porosity

There were not much change in soil bulk density and porosity as presented in the Table 4.18, however, it has been observed that bulk density seem to decrease in case of the treatments consisting of crop residue (rice or wheat or both) incorporation along with or without green manuring + fertilizers and green manuring + fertilizers (T₃ to T₉) as compared to the initial values and increase in bulk density has also been observed in case of treatment where only chemical fertilizers were applied (T₂) and the control (T₁). The addition of green manure or crop residue decreased the bulk density and increased the levels of organic carbon, field capacity; permanent wilting point and available soil moisture were reported by Boparai *et al.* (1992), Walia *et al.* (1995) and Dhaliwal and Walia (2008). Whereas, porosity increases in those treatments which were getting crop residue (rice or wheat or both) incorporation along with or without green manuring + fertilizers and green manuring + fertilizers (T₃ to T₉). These might be

Table 4.18: Effect of crop residues and green manuring soil bulk density and porosity

Treatments	Bulk density (Mg cm ⁻³)	Porosity (%)
Initial	1.27	51.93
Final values		
T ₁	1.28	51.79
T ₂	1.28	51.86
T ₃	1.26	52.36
T ₄	1.27	52.23
T ₅	1.26	52.38
T ₆	1.26	52.45
T ₇	1.26	52.58
T ₈	1.26	52.49
T ₉	1.26	52.6

T₁: Control; T₂: Soil test based fertilizers; T₃: Rice residue incorporation + T₂; T₄: Wheat residue incorporation + T₂; T₅: Rice and Wheat residue incorporation + T₂; T₆: Green manuring + T₂; T₇: Rice residue incorporation + T₆; T₈: Wheat residue incorporation + T₆; T₉: Rice and Wheat residue incorporation + T₆

due to incorporation of crop residues and green manuring which might lead to increase in soil organic matter content.

4.10.1.2 Soil structural properties

The structural parameters increased from its initial values indicating the influence of crop residues including roots on soil structural formation (T_1 to T_9) as presented in the Table 4.19. Results indicated that fertilizers alone (T_2) or in combination with rice residues (T_3) and wheat residues (T_4) had an effect on soil structure. Residues incorporated plot (T_3 , T_4 and T_5) increased not only more macro aggregates and stability of aggregates but also the mean weight diameter (MWD) and geometric mean diameter (GMD) that might have influenced the water retention and grain yield. Residue incorporation caused a significant increment of 15.65% in total water stable aggregates in surface soil (0-15 cm) and 7.53% in sub-surface soil (15-30 cm) was reported by Shreyasi *et al.* (2014). On the other way, green manuring plot (T_6) had less effect on aggregates stability and formation of macro aggregates, however, when combined with either rice (T_7) or wheat residues (T_8) and even both (T_9) residue increased aggregate ratio, MWD and GMD for controlling water and nutrient movement within the soil. Results also found an effect of fertilizers on the decomposition of crop residues in presence or absence of green manuring to produce more macro aggregates or higher aggregates stability with an increased aggregates size diameter to retain soil moisture as well as nutrients.

4.10.2 Chemical properties of Soil

4.10.2.1 Soil pH

The treatment effects were found non-significant for soil pH all throughout the experimental period as presented in the Table 4.20. However, a decreasing trend of pH for the treatments comprising of crop residues (rice or wheat or both) incorporation along with or without green manuring (T_3 to T_9) was observed as compared to control (T_1) and sole fertilizers treatment (T_2). The findings were in accordance with Kharub *et al.* (2003) who reported that pH of soil decreased due to the continuous inclusion of incorporation of green-manure as soil amendments under a rice-wheat cropping system.

Table 4.19: Effect of crop residues and green manuring on soil structural properties

Treatment	AR	AS (%)	MWD (mm)	GMD (mm)
Initial	0.225	0.174	0.541	0.618
Final values				
T ₁	0.347	0.253	0.577	0.677
T ₂	0.516	0.328	0.632	0.678
T ₃	0.538	0.335	0.788	0.719
T ₄	0.612	0.370	0.772	0.727
T ₅	0.727	0.410	0.785	0.732
T ₆	0.139	0.115	0.693	0.699
T ₇	0.343	0.249	0.693	0.716
T ₈	0.484	0.281	0.640	0.719
T ₉	0.962	0.476	0.822	0.778

* AR= Aggregate ratio; AS= Aggregate stability; MWD= Mean weight diameter; GMD= Geometric mean diameter

T₁: Control; T₂: Soil test based fertilizers; T₃: Rice residue incorporation + T₂; T₄: Wheat residue incorporation + T₂; T₅: Rice and Wheat residue incorporation + T₂;

T₆: Green manuring + T₂; T₇: Rice residue incorporation + T₆; T₈: Wheat residue incorporation + T₆; T₉: Rice and Wheat residue incorporation + T₆

Table 4.20: Effect of crop residues and green manuring on soil pH, EC and organic C content

Treatment	pH			EC (dSm ⁻¹)			Soil organic C (%)		
	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled
T ₁	7.52	7.54	7.53	0.160	0.172	0.166	0.42	0.35	0.39
T ₂	7.53	7.50	7.52	0.185	0.179	0.182	0.44	0.40	0.42
T ₃	7.48	7.46	7.47	0.182	0.174	0.178	0.52	0.58	0.55
T ₄	7.44	7.46	7.45	0.180	0.180	0.180	0.45	0.55	0.50
T ₅	7.45	7.43	7.44	0.180	0.170	0.175	0.52	0.60	0.56
T ₆	7.42	7.38	7.40	0.178	0.182	0.180	0.46	0.54	0.50
T ₇	7.40	7.36	7.38	0.182	0.184	0.183	0.51	0.66	0.59
T ₈	7.41	7.43	7.42	0.183	0.185	0.184	0.45	0.68	0.57
T ₉	7.43	7.36	7.40	0.182	0.178	0.180	0.55	0.68	0.62
SEm (±)	0.05	0.08	0.06	0.11	0.08	0.09	0.07	0.06	0.07
CD at 5%	NS	NS	NS	NS	NS	NS	NS	0.19	0.22

*Initial: pH-7.59, EC-0.175 dSm⁻¹, organic C-0.45 %
T₁: Control; T₂: Soil test based fertilizers; T₃: Rice residue incorporation + T₂; T₄: Wheat residue incorporation + T₂; T₅: Rice and Wheat residue incorporation + T₂; T₆: Green manuring + T₂; T₇: Rice residue incorporation + T₆; T₈: Wheat residue incorporation + T₆; T₉: Rice and Wheat residue incorporation + T₆

4.10.2.2 Electrical conductivity (dSm^{-1})

Influences of treatments on electrical conductivity of the soil have found to be not significant in both the years as depicted in the Table 4.20. Similar trend was observed for EC as that of soil pH.

4.10.2.3 Organic C

There was no significant influence of treatments on organic C content of the soil in the first year (2013-14) but significant influences have been observed in the second year (2014-15) as given in Table 4.20. Even though there were no significant influences of the treatments in the first year, the highest organic C content was recorded for the treatment T₉ where crop residues (both rice and wheat) were incorporated along with green manuring + fertilizers and the lowest was recorded for control T₁. However, in the second year, residue incorporation (rice or wheat) along with green manuring and combine application of both rice and wheat residues exerted significant positive effect on soil organic C content and the highest organic C content was recorded for the treatment T₉ and T₈ (0.68%) and the lowest was recorded for the control treatment T₁ (0.35 %). It is probably due to the fact that addition of carbonaceous substances in soil which on decomposition added organic matter and increased organic C. Long-term application of crop residues and organic manures increased the soil organic C content was reported by Balwinder *et al.* (2008). Similar, findings were also reported by Fateh *et al.* (2008) who reported that cultivation of rice and wheat by the recommended dose of NPK fertilizers alone decreased the organic carbon of the soil. Again, T₃, T₄ and T₆ have been found to be at par with T₂ and T₁ with respect to soil organic C. The findings were in accordance with Sharma and Sharma (2005) who reported that retention or incorporation of rice, wheat or both crop residues increased soil organic C by 19-32% (absolute increases of 0.06-0.1% organic C) in the top 15cm soil layer after 2 years (four crops) in comparison with both the initial soil organic C and 2 years of burning the residues of both crops.

From the pooled data analysis it has been observed that the treatment T₉ having crop residues (rice and wheat) incorporation along with green manuring + fertilizers showed highest organic C content and the lowest were recorded for the control T₁. This might be due to the buildup of micro-flora which feed on the residue/GM and thereby lead to the mineralization of the added residue in presence of N-fertilizers and C sequestration. Similar, findings of increased level of soil organic C/SOM has been

observed by several workers on incorporation of crop residues and or green manure [Aulakh *et al.* (2001); Mandal *et al.* (2004); Raju and Reddy, (2006)].

4.10.3 Nutrient availability in the soil

4.10.3.1 Available nitrogen (kg ha^{-1})

The influences of the treatments on soil available N at harvest of the wheat crop have been found to be significant for both the years as compared to T_1 and T_2 as shown in Table 4.21 and Fig. 4.16. In the first year (2013-14), T_9 has been recorded with highest available N (258.7 kg ha^{-1}) and the lowest value was obtained for control T_1 (148.5 kg ha^{-1}). However, T_9 has been found to be statistically at par with T_3 , T_5 , T_7 and T_8 but significantly greater than T_1 , T_2 , T_4 , and T_6 . In the second year also (2014-15), incorporation of green manuring along with combined application of both the residues (T_9) has been recorded with the highest soil N availability (298.6 kg ha^{-1}) and the lowest was obtained for control T_1 (107.6 kg ha^{-1}). Green manuring and residues incorporation (rice or wheat or both) alone or in combination (T_3 to T_9) exerted positive influence on soil available N as compared to control T_1 and sole fertilizers source T_2 . However, T_9 has been found to be at par with T_6 , T_7 and T_8 but significantly superior to T_1 to T_5 . Again T_6 has been observed to be at par with T_3 , T_4 and T_5 and significantly greater than T_1 and T_2 .

From the pooled data analysis it has been observed that the integration of residues incorporation (rice or wheat or both) along with green manuring + fertilizers (T_7 , T_8 and T_9) showed higher soil available N than other treatments. Among them treatment T_9 , having both crop residues incorporated along with green manuring + fertilizers has been found to have higher mean soil N availability (278.6 kg ha^{-1}) which was found statistically at par with T_7 and T_8 . The lowest mean value of soil N availability was obtained for control T_1 (128.1 kg ha^{-1}). However, T_7 and T_8 have been found to be at par with T_3 to T_6 and significantly greater than T_1 and T_2 . Similar, findings were also reported by Beri *et al.* (1992), Kharub *et al.* (2003) and Kumar *et al.* (2004). Increase in soil available N content may be the outcome of mineralization of added residues/GM in the presence of N- fertilizer by the soil microbes.

4.10.3.2 Available phosphorous (kg ha^{-1})

Green manuring and crop residues incorporation (rice or wheat or both) alone or in combination had significant positive influence on soil available P for the year 2014-15 as compared to control or sole application of fertilizers. However,

Table 4.21: Effect of crop residues and green manuring on nutrient availability in the soil

Treatment	Available N (kg ha ⁻¹)			Available P (kg ha ⁻¹)			Available K (kg ha ⁻¹)			Available Zn (ppm)		
	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled
T ₁	148.5	107.6	128.1	55.5	45.6	50.6	80.5	60.2	70.4	0.565	0.524	0.544
T ₂	227.7	208.5	218.1	64.5	66.0	65.3	90.2	106.8	98.5	0.572	0.518	0.545
T ₃	255.4	262.2	258.8	72.6	85.8	79.2	108.5	110.5	109.5	0.585	0.612	0.598
T ₄	230.6	266.3	248.4	65.3	85.6	75.5	95.5	111.2	103.4	0.58	0.628	0.604
T ₅	250.3	260.6	255.4	76.5	90.6	83.6	106.4	130.4	118.4	0.582	0.586	0.584
T ₆	234.6	282.7	258.6	65.4	85.2	75.3	98.4	125.0	111.7	0.578	0.648	0.613
T ₇	255.4	291.5	273.4	77.5	98.6	88.1	106.8	136.8	121.8	0.583	0.724	0.653
T ₈	238.6	298.5	268.5	66.8	95.5	81.2	100.2	140.2	120.2	0.578	0.635	0.606
T ₉	258.7	298.6	278.6	76.5	108.3	92.4	110.3	152.6	131.5	0.588	0.824	0.706
SEm (±)	7.52	6.05	6.48	2.66	3.02	2.94	2.88	3.15	3.09	0.04	0.042	0.035
CD (5 %)	22.55	18.21	19.43	7.95	9.06	8.81	8.58	9.37	9.27	NS	0.112	0.105

T₁: Control; T₂: Soil test based fertilizers; T₃: Rice residue incorporation + T₂; T₄: Wheat residue incorporation + T₂; T₅: Rice and Wheat residue incorporation + T₂; T₆: Green manuring + T₂; T₇: Rice residue incorporation + T₆; T₈: Wheat residue incorporation + T₆; T₉: Rice and Wheat residue incorporation + T₆

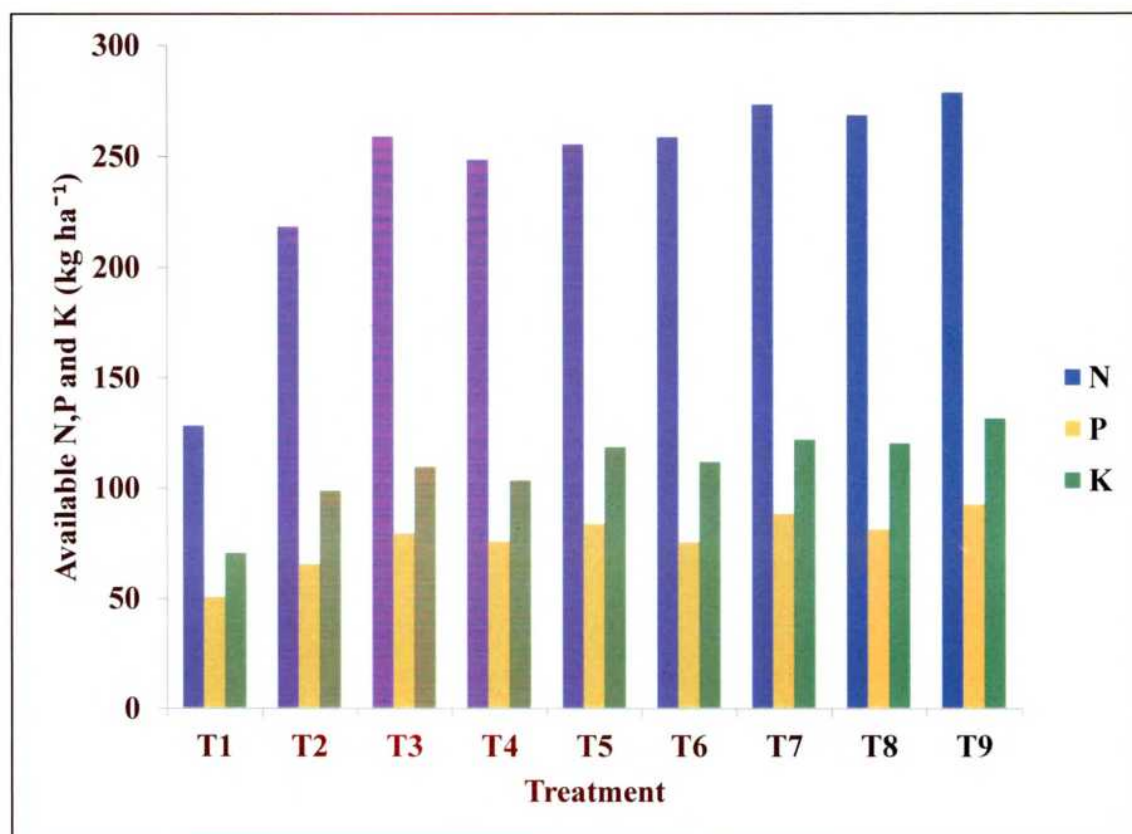


Fig 4.16: Soil nutrient availability

in the first year i.e. on 2013-14 the influence was positive but not at significant level for all the treatments as depicted in Table 4.21 and Fig. 4.16. In first year (2013-14), T₇ has been found with the highest soil available P and the lowest was recorded from T₁. But, T₇ has been found to be at par with T₃, T₅ and T₉ and significantly higher than T₁, T₂, T₄ and T₆. Again, T₃ was found to be at par with T₂, T₄ and T₆ but superior to T₁. Whereas, in second year (2014-15) it has been observed that the treatments which were comprised of crop residue (rice or wheat or both) incorporation along with green manuring + fertilizers (T₇, T₈ and T₉) were found to superior to the treatments comprising of only crop residues (rice or wheat or both) incorporation with fertilizers (T₃, T₄ and T₅) followed by green manuring + fertilizers (T₆) and then chemical fertilizers only (T₂) and at last was the control (T₁). Incorporation of crop residue lead to build up of soil available N, P and K were also reported by Mandal *et al.* (2004) and Kumar *et al.* (2004). However, among the treatments T₇, T₈ and T₉, it has been found that T₉ where both the crop residues were incorporated along with green manuring + fertilizers, have been recorded with greater soil available P (108.30 kg ha⁻¹) and significantly higher than T₇ and T₈. But, T₇ and T₈ were found to be statistically at par with T₅ and significantly greater than T₁ to T₄ and T₆. Again, T₆ has been observed to be at par with T₃, T₄ and T₆ but superior to T₁ and T₂. From the pooled data analysis similar trend as that of second year has been recorded. Application of crop residues and GM in the presence of fertilizers might have triggered the population buildup of phosphate solubilizing micro-organism thereby increasing the soil available P level.

4.10.3.3 Available potassium (kg ha⁻¹)

Incorporation of green manuring alone or in combination with crop residues (rice or wheat or both) (T₆ to T₉) contributed towards significantly positive build up of soil available potassium (K) as compared to control (T₁) and sole source of fertilizers (T₂) as shown in the Table 4.21 and Fig. 4.16. In both the years and for the pooled data analysis, T₉ has been recorded with the highest soil available K values (110.30, 152.60 and 131.50 kg ha⁻¹, respectively) and the lowest value was recorded for the control T₁ (80.50, 60.20 and 70.40 kg ha⁻¹, respectively). This might be due to release of non exchangeable K on account of addition of crop residue and green manuring. In the first year (2013-14), T₉ has been found to be statistically at par with T₃, T₅ and T₇ but significantly higher than that of T₁, T₂, T₄, T₆ and T₈. Again, T₃, T₅ and T₇ have been found to be at par with T₄, T₆ and T₈ but significantly superior to T₁ and T₂. But, in

second year (2014-15) T₉ has been found to be statistically at par with T₇ and T₈ but significantly greater than that of T₁ to T₆. Continuous incorporation of *Sesbania aculeata* as green manure increased available K by 5.0 % in soil compared to rice-wheat sequence was reported by Kharub *et al.* (2003). Again, T₇ has been recorded to be at par with T₅ and T₆ but significantly superior than that of T₁ to T₄. The treatment T₅ and T₆ were again found to be at par with T₂ to T₄ but significantly higher than that of T₁. The findings were in accordance with Kumar *et al.* (2004) who reported that available N, P and K got enriched by the incorporation of residue, irrespective of tillage types, being the highest under conservation tillage. Similar, findings were also reported by Balwinder *et al.* (2008), Fateh *et al.* (2008) and Bahrani *et al.*, (2012). From the consecutive two years pooled data analysis almost similar trend with that of second year was observed.

4.10.3.4 Available Zinc (ppm)

Green manuring and/or residue incorporation had not shown any significant influence on soil available Zn content at wheat harvest for the first year (2013-14) as compared to sole fertilizers application (T₂). However, in the second year it has been revealed that green manuring + fertilizers (T₆) as well as green manuring + crop residues incorporation + fertilizers (T₇ to T₉) had significantly positive effect on soil available Zn content as compared to control T₁ and sole fertilizers source T₂ as presented in the Table 4.21. The treatment having both the crop residues incorporation along with green manuring + fertilizers (T₉) was recorded with the highest available Zn (0.824 ppm) and the lowest value was recorded for T₂ where only chemical fertilizers were applied (0.518 ppm) in the second year (2014-15). However, T₉ has been found to be statistically at par with T₇ where rice residue were incorporated along with green manuring + fertilizers but significantly greater than other treatments i.e. T₁ to T₆ and T₈. Again, T₇ was observed to be at par with T₃ to T₆ and T₈ but significantly greater than that of T₁ and T₂. Dhaliwal and Walia (2008) also reported that the incorporation of GM and crop residue in the soil has beneficial effect on soil health by improving physico-chemical properties besides supplying the macronutrients like N, P and K and increasing the availability of the micronutrients like Zn, Cu, Fe and Mn in the soil. From the pooled data analysis the similar trend has also been noticed as that of second year. Addition of crop residues and or GM might have flourished the micro-flora that helps in released of soil Zn which was otherwise unavailable.

4.10.4 Effect of crop residues and green manuring on microbial population (log value) per gram of soil

4.10.4.1 Population of *Azotobacter* ($\times 10^4$ CFU g⁻¹ of soil)

Green manuring and crop residues incorporation alone or in combination (T₃ to T₉) exerted positive significant influence on soil *Azotobacter* population for both the years as compared to control T₁ and sole fertilizers T₂ as presented in Table 4.22 and Fig. 4.17. From the pooled data it has been noticed that integration of both crop residues along with green manuring + fertilizers (T₉) was recorded with maximum mean population of *Azotobacter* (14.13×10^4 CFU g⁻¹ of soil) and the lowest population have been recorded for the control plot T₁ (3.40×10^4 CFU g⁻¹ of soil). The treatments comprising of green manuring (T₆ to T₉) were observed with higher population of *Azotobacter* as compared with the treatment getting only crop residues (T₃ to T₅) or fertilizers (T₂). Again, T₃, T₄ and T₅ have been recorded with the greater population as compared to T₂ and T₁. The findings were in confirmation with the findings of Tilak (2004).

4.10.4.2 Population of Bacteria ($\times 10^5$ CFU g⁻¹ of soil)

Influences of the treatments including GM/ crop residues incorporation or in combination (T₃ to T₉) were found to be significant for both the years as compared to control T₁ and sole fertilizers T₂ as shown in Table 4.22 and Fig. 4.18. However, the bacterial population was found to increase in those treatments where crop residues (rice or wheat or both) were incorporated along with or without green manuring + fertilizers (T₃, T₄, T₅, T₇, T₈ and T₉) and green manuring + fertilizers (T₆) whereas the bacterial population were found to reduce in case of sole fertilizers (T₂) and control (T₁) in the second year (2014-15) than that of initial value (45×10^5 CFU g⁻¹ of soil). This might be due to the increase in organic C content of the soil as a result of crop residue incorporation and green manuring. The highest mean bacterial population were recorded for T₉ (74.30×10^5 CFU g⁻¹ of soil) where crop residues were incorporated along with green manuring and the lowest were recorded for control T₁ (43.15×10^5 CFU g⁻¹ of soil). The findings were in accordance with Bhattacharrya *et al.* (1990) who reported that green manuring alone encouraged the growth of bacteria in the soil and Beri *et al.* (1992) also reported that incorporation of crop residue resulted in 5-10 times more aerobic bacteria in the soil. The pooled data analysis for consecutive two years follows the same trend as that of second year.

Table 4.22: Effect of crop residues and green manuring on microbial population (log value) per gram of soil

Treatment	<i>Azotobacter</i> × 10 ⁴ (CFU)			Bacteria × 10 ⁵ (CFU)			Fungi × 10 ⁵ (CFU)			<i>Actinomyces</i> × 10 ⁵ (CFU)		
	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled
T ₁	4.48 (4.65)	2.59 (4.41)	3.40 (4.53)	48.75 (6.69)	38.19 (6.58)	43.15 (6.63)	2.61 (5.42)	4.00 (5.60)	3.23 (5.51)	14.39 (6.16)	23.28 (6.37)	18.28 (6.26)
T ₂	3.50 (4.54)	3.84 (4.58)	3.66 (4.56)	50.00 (6.70)	37.67 (6.58)	43.45 (6.64)	2.36 (5.37)	3.57 (5.55)	2.90 (5.46)	21.43 (6.33)	23.23 (6.37)	22.34 (6.35)
T ₃	8.71 (4.94)	17.91 (5.25)	12.50 (5.10)	65.31 (6.81)	59.57 (6.77)	62.37 (6.79)	3.39 (5.53)	5.96 (5.77)	4.50 (5.65)	39.99 (6.60)	37.67 (6.58)	38.82 (6.59)
T ₄	7.05 (4.85)	22.39 (5.35)	12.56 (5.10)	61.52 (6.79)	53.46 (6.73)	57.28 (6.76)	3.03 (5.48)	6.54 (5.82)	4.46 (5.65)	37.33 (6.57)	31.33 (6.50)	34.20 (6.53)
T ₅	8.31 (4.92)	20.28 (5.24)	12.11 (5.08)	65.01 (6.81)	57.54 (6.76)	60.39 (6.78)	3.47 (5.54)	5.60 (5.75)	4.41 (5.64)	40.92 (6.61)	39.26 (6.59)	40.09 (6.60)
T ₆	6.83 (4.83)	26.06 (5.42)	13.34 (5.12)	52.00 (6.72)	76.21 (6.88)	62.95 (6.80)	2.94 (5.47)	7.94 (5.90)	4.83 (5.68)	38.37 (6.58)	60.39 (6.78)	48.19 (6.68)
T ₇	8.67 (4.94)	21.18 (5.33)	12.91 (5.11)	66.22 (6.82)	63.97 (6.81)	65.01 (6.81)	3.66 (5.56)	5.93 (5.77)	4.66 (5.67)	46.13 (6.66)	46.88 (6.67)	46.45 (6.67)
T ₈	6.79 (4.83)	26.24 (5.42)	13.34 (5.12)	59.29 (6.77)	71.61 (6.85)	65.16 (6.81)	3.57 (5.55)	6.50 (5.81)	4.82 (5.68)	38.01 (6.58)	51.05 (6.71)	44.06 (6.64)
T ₉	8.77 (4.94)	22.70 (5.36)	14.13 (5.15)	64.26 (6.81)	86.10 (6.93)	74.30 (6.87)	4.06 (5.61)	6.03 (5.78)	4.94 (5.69)	41.87 (6.62)	52.00 (6.72)	46.67 (6.67)
SEm (±)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01
CD (5 %)	0.02	0.02	0.02	0.03	0.02	0.02	0.04	0.04	0.04	0.05	0.04	0.04

*Initial population: *Azotobacter*, bacteria, fungi and *Actinomyces* population were 4.67×10^4 , 45.0×10^5 , 3.67×10^5 and 35.67×10^5 (CFU) respectively.
** Values in the parenthesis are log transform values
T₁: Control; T₂: Soil test based fertilizers; T₃: Rice residue incorporation + T₂; T₄: Wheat residue incorporation + T₂; T₅: Rice and Wheat residue incorporation + T₂; T₆: Green manuring + T₂; T₇: Rice residue incorporation + T₆; T₈: Wheat residue incorporation + T₆; T₉: Rice and Wheat residue incorporation + T₆

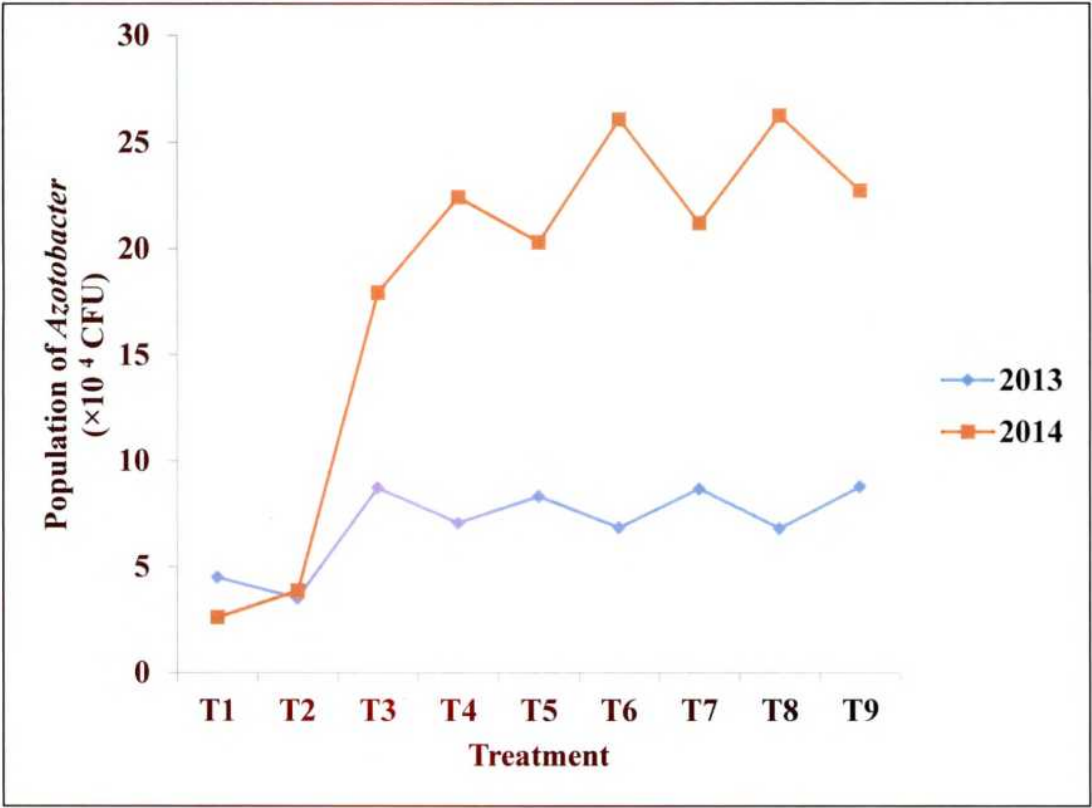


Fig 4.17: Population of *Azotobacter* per gram of rhizosphere soil

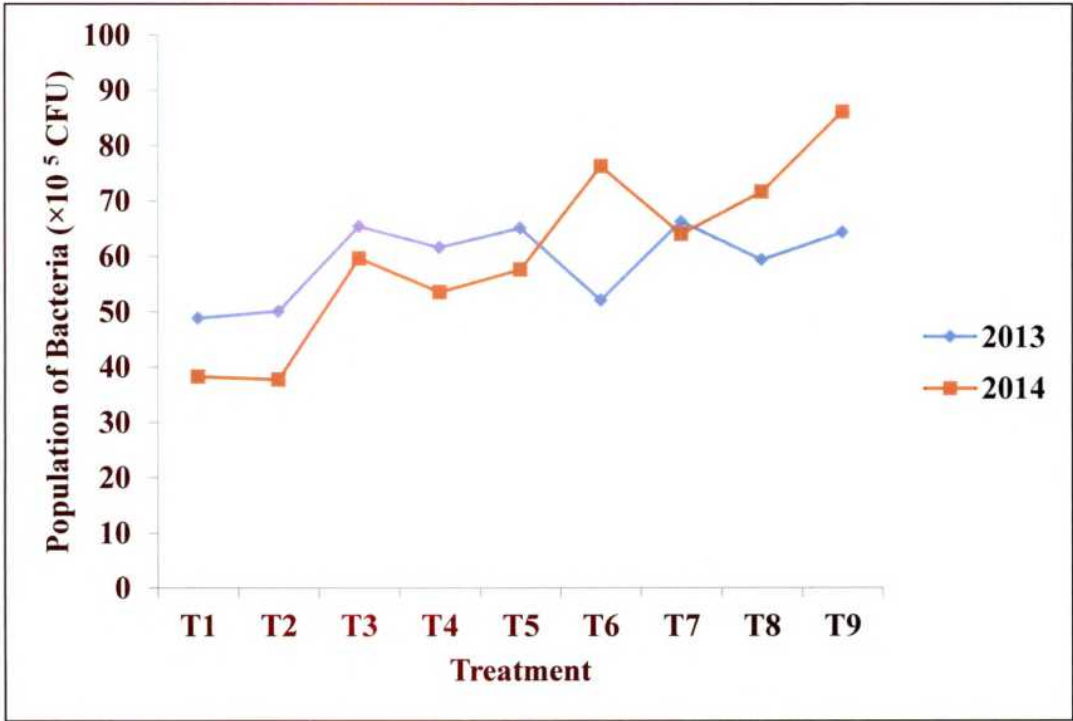


Fig 4.18: Population of bacteria per gram of rhizosphere soil

4.10.4.3 Population of *Fungi* ($\times 10^5$ CFU g⁻¹ of soil)

The fungal populations were significantly influenced by the treatments in both the years as presented in Table 4.22 and Fig. 4.19. Higher fungal populations were observed in the second year as compared to first year. From the pooled data analysis, it has been observed that the treatment T₉ where both the crop residues were incorporated along with green manuring + fertilizers reflected the highest mean fungal population (4.94×10^5 CFU g⁻¹ of soil) and the treatment T₂ where only chemical fertilizers were applied resulted in lowest mean fungal population (2.90×10^5 CFU g⁻¹ of soil). The treatments consisting of green manuring (T₆ to T₉) were found to have higher population of fungi per gram of soil as compared to those without green manuring. The findings are in accordance with Bhattacharrya *et al.* (1990) who reported that green manuring alone encouraged the growth of bacteria, *Actinomycetes* and fungi. Again, those treatments where crop residues (rice or wheat or both) were incorporated (T₃, T₄ and T₅) have been noticed with higher fungal population as compared to sole fertilizers T₂ and control T₁. Incorporating residues resulted in 1.5-11 times more fungal growth was reported by Beri *et al.* (1992). This might be due to increase in organic matter as the result of incorporation of crop residues and green manuring.

4.10.4.4 Population of *Actinomycetes* ($\times 10^5$ CFU g⁻¹ of soil)

Perusal of the data as depicted in the Table 4.22 and Fig. 4.20 revealed that GM and crop residues incorporation alone or in combination + fertilizers had significant positive influenced on the population of *Actinomycetes* for both the years. The population has been noticed to increase in the second year (2014-15) as compared with the first year (2013-14). From the pooled analysis, it has been observed that T₆ reflected the maximum mean population of *Actinomycetes* (48.19×10^5 CFU g⁻¹ of soil) and T₁ reflected the lowest *Actinomycetes* population (18.28×10^5 CFU g⁻¹ of soil). Treatments consisting of green manuring and crop residues (rice or wheat or both) i.e. T₃ to T₉ have been recorded with greater population of *Actinomycetes* as compared to T₁ and T₂. The findings were in accordance with Sharma *et al.* (2000) who reported that and microbial population enhanced significantly due to crop residues as compared to the chemical fertilizers alone.

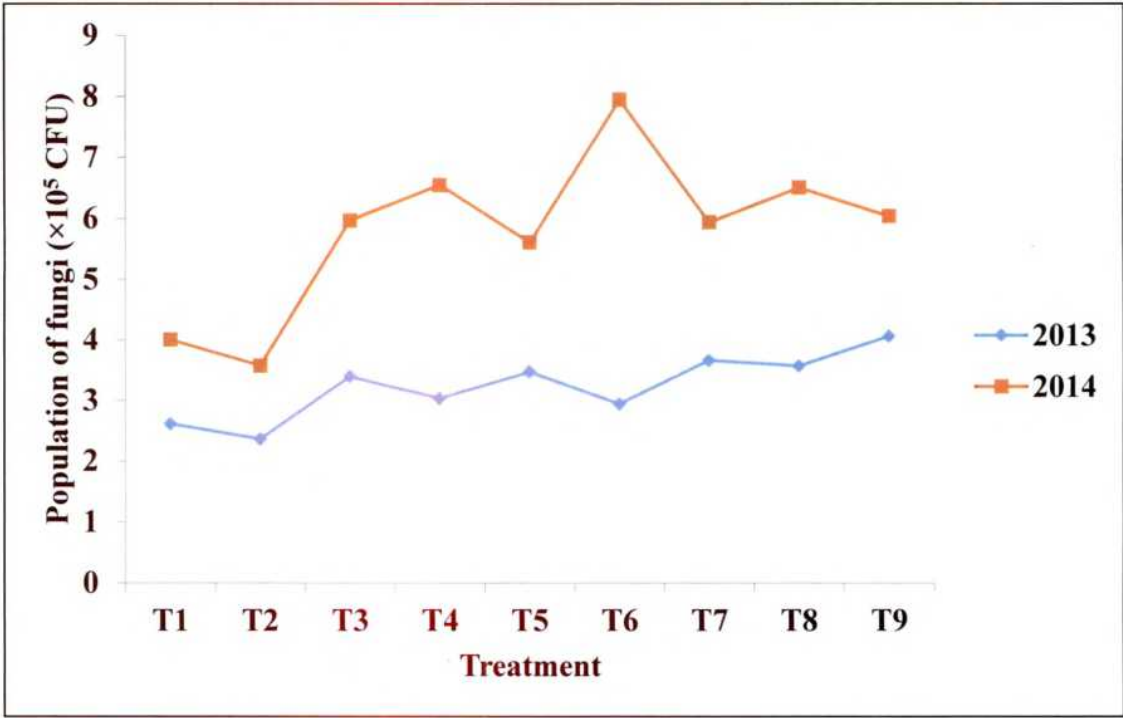


Fig 4.19: Population of fungi per gram of rhizosphere soil

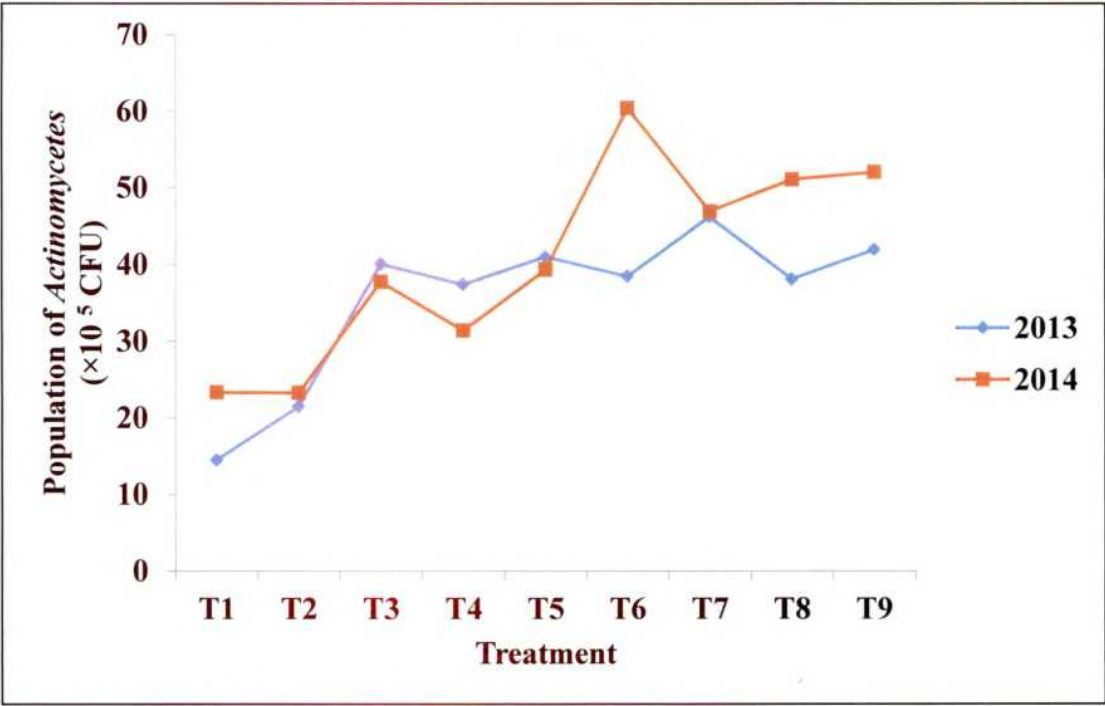


Fig 4.20: Population of *Actinomycetes* per gram of rhizosphere soil



Actinomycetes



Azotobacter



Fungi



Bacteria

Plate 6: Soil micro-flora

4.11 Effect of crop residues and green manuring on N budget under rice-wheat cropping system for the experimental years

It has been found that loss of N was less in those treatments where fertilizer applied along with incorporation of residues with or without green manuring (T₃, T₄, T₅, T₇, T₈ and T₉) and green manuring + fertilizer application (T₆) when compared with fertilizer application alone (T₂) and control (T₁) (Table 4.23). These might be due to improved nutrient balance of the soil as the result of residues incorporation and green manuring and improved soil physical properties due to residue incorporation and green manuring. Similar finding was also reported by Sharma and Prasad (2008) who revealed that the return of rice and wheat residues could recycle up to 20%-30% of the N absorbed by the crops. The continuous application of both the residues along with green manuring (T₉) was associated with the buildup of organic matter, micro-flora, soil available nutrient status as evidenced from the previous results might have contributed the better utilization of input nitrogen (355.02 kg ha⁻¹ N) thus enhancing the yield and yield attributing characters.

4.12 Effect of crop residues and green manuring on net energy return of rice-wheat system

The net energy return have been observed to increase in the second year (2014-15) as compared with the first year (2013-14) in the treatments comprising of crop residue incorporation (rice or wheat or both) along with or without green manuring or green manuring + fertilizers (T₃ to T₉) but reduction in net energy return was observed in case of sole chemical fertilizers (T₂) and control (T₁) (Table 4.24 and Fig. 4.21). This might be due to reduction in both grain and straw yields of rice and wheat crops in these treatments i.e. T₁ and T₂. The highest total energy output was recorded from T₉ (265816.38 and 292447.28 MJ in 2013-14 and 2014-14, respectively) and the lowest was recorded from control T₁ (105411.79 and 101605.79 MJ in 2013-14 and 2014-14, respectively). However, it has been observed that the energy ratio was reduced in all the treatments where crop residue incorporation (rice or wheat or both) was integrated with or without green manuring + fertilizers (T₃, T₄, T₅, T₇, T₈ and T₉) or green manuring + fertilizers (T₆). Higher investment of input energy might have attributed to lower energy ratio in the aforesaid treatments. Lesser energy involvement might have resulted in highest energy ration in the treatments T₂ followed by T₆ and T₁. Similar findings have also been reported by Raju and Reddy (2004).

Table 4.23: Effect of crop residues and green manuring on N budget under rice-wheat cropping system for the experimental years

Treatments	Total N input during experimentation from inorganic & organic source (kg ha ⁻¹)	Total N uptake by rice and wheat (kg ha ⁻¹)	Input N utilization (kg ha ⁻¹)	Input N loss unaccountable (kg ha ⁻¹)	% Input N loss unaccounted
T ₁	0.00	186.00	0.00	0.00	0
T ₂	440.00	364.52	178.52	261.48	59.43
T ₃	510.00	428.47	242.47	267.53	52.46
T ₄	475.00	439.42	253.42	221.58	46.65
T ₅	545.00	467.45	281.45	263.55	48.36
T ₆	481.50	492.29	306.29	175.21	36.39
T ₇	554.70	503.31	317.31	237.39	42.80
T ₈	515.70	490.82	304.82	210.88	40.89
T ₉	580.90	541.02	355.02	225.88	38.88

T₁: Control; T₂: Soil test based fertilizers; T₃: Rice residue incorporation + T₂; T₄: Wheat residue incorporation + T₂; T₅: Rice and Wheat residue incorporation + T₂; T₆: Green manuring + T₂; T₇: Rice residue incorporation + T₆; T₈: Wheat residue incorporation + T₆; T₉: Rice and Wheat residue incorporation + T₆

Table 4.24: Effect of crop residues and green manuring on net energy return of rice-wheat system

Treatment	First year (2013-14)				Second year (2014-15)			
	Total input energy (MJ)	Total output energy (MJ)	Net energy return (MJ)	Energy ratio	Total input energy (MJ)	Total output energy (MJ)	Net energy return (MJ)	Energy ratio
T ₁	9707.42	105411.79	95704.37	9.86	9707.42	101605.79	91898.37	9.47
T ₂	25144.52	250647.09	225502.57	8.97	25144.52	241121.98	215977.46	8.59
T ₃	37644.52	252288.38	214643.86	5.70	37644.52	269011.00	231366.48	6.15
T ₄	25144.52	249307.16	224162.64	8.91	37644.52	264319.45	226674.93	6.02
T ₅	37644.52	255033.37	217388.85	5.77	50144.52	269104.80	218960.28	4.37
T ₆	25144.52	258670.05	233525.53	9.29	26924.32	275987.98	249063.66	9.25
T ₇	37644.52	259606.86	221962.34	5.90	39639.14	283370.17	243731.03	6.15
T ₈	25144.52	255085.31	229940.79	9.14	39424.32	280104.28	240679.96	6.10
T ₉	37644.52	265816.38	228171.86	6.06	51924.32	292447.28	240522.96	4.63

T₁: Control; T₂: Soil test based fertilizers; T₃: Rice residue incorporation + T₂; T₄: Wheat residue incorporation + T₂; T₅: Rice and Wheat residue incorporation + T₂; T₆: Green manuring + T₂; T₇: Rice residue incorporation + T₆; T₈: Wheat residue incorporation + T₆; T₉: Rice and Wheat residue incorporation + T₆

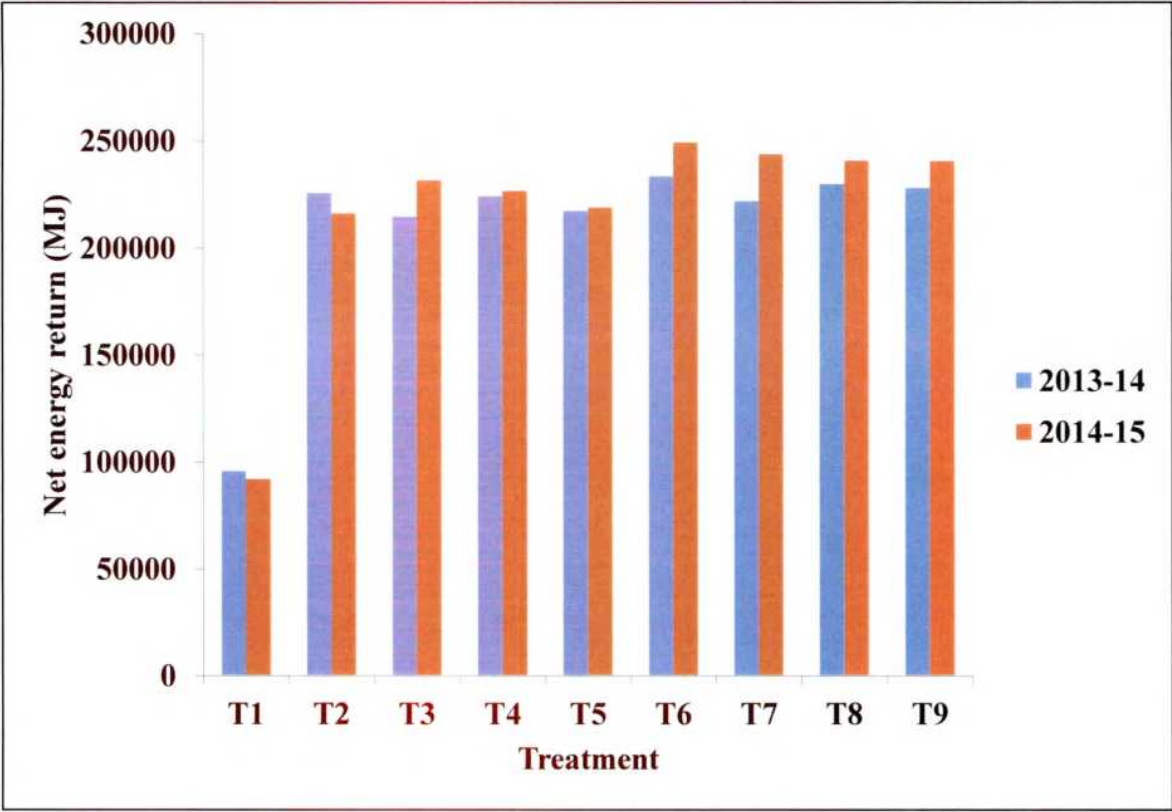


Fig 4.21: Net energy return of the experimental period

4.13 Effect of crop residues and green manuring on benefit: cost ratio of rice-wheat system

It was noted that the treatments having integration of crop residues (rice or wheat or both) with green manuring + fertilizers (T₇, T₈ and T₉) or green manuring + fertilizers (T₆) were recorded with higher B: C ratio than those having only crop residue (rice or wheat or both) incorporation + fertilizers (T₃, T₄ and T₅). Again, these treatments (T₃, T₄ and T₅) have been recorded with better B: C ratio than the treatment having sole chemical fertilizers (T₂) and control (T₁) (Table 4.25). This was attributed to higher gross returns realized because of higher grain yields of rice and wheat which also fetched higher net returns. The results confirm the findings reported by Vinay (2006) who found that the green manure dhaincha applied with 100 % of recommended dose of NPK fertilizers gave the maximum yield of rice as well as wheat crops and gave the highest net return and benefit: cost ratio. In the second year (2014-15), it has been notice that the treatments where crop residues (rice or wheat or both) were incorporated along with or without green manuring + fertilizers (T₃, T₄, T₅, T₇, T₈ and T₉) or green manuring + fertilizers (T₆) were recorded with higher B: C ratio as compared with the first year (2013-14) data. Improved soil environment on account of incorporation of crop residues and green manuring over time might have enhanced crop yields. But, in case of the treatments, T₂ and T₁ the B: C ratio was found be less in second year. Depletion of fertility status in these treatments because of non amendment of organics decreased crop yield and thereby decreased net returns and B: C ratio. The highest B: C ratio was recorded from T₉ (2.43 and 2.56 in the first and second year, respectively) and the lowest from control T₁ (1.07 and 0.94 in the first and second year, respectively). Similar, findings were also reported by Khankhane *et al.* (2009).

Table 4.25: Effect of crop residues and green manuring on benefit: cost ratio of rice-wheat system

Treatment	First year (2013-14)				Second year (2014-15)			
	Total cost of cultivation (rupees)	Gross return (rupees)	Net return (rupees)	Benefit: Cost (B:C)	Total cost of cultivation (rupees)	Gross return (rupees)	Net return (rupees)	Benefit: Cost (B:C)
T ₁	45991.00	49060.31	3069.31	1.07	51009.00	48037.92	-2971.08	0.94
T ₂	58877.40	132666.70	73789.30	2.25	64259.40	134618.20	70358.80	2.09
T ₃	58877.40	133176.80	74299.40	2.26	64259.40	151194.34	86934.94	2.35
T ₄	58877.40	132066.55	73189.15	2.24	64259.40	147733.08	83473.68	2.30
T ₅	58877.40	135592.26	76714.86	2.30	65600.40	151320.29	85719.89	2.31
T ₆	58877.40	138781.50	79904.10	2.36	65600.40	156000.96	90400.56	2.38
T ₇	58877.40	139758.15	80880.75	2.37	65600.40	161270.80	95670.40	2.46
T ₈	58877.40	135973.22	77095.82	2.31	65600.40	158744.84	93144.44	2.42
T ₉	58877.40	143264.03	84386.63	2.43	65600.40	168112.13	102511.73	2.56

*Price of rice is Rs.13 kg⁻¹ and Rs.13.5 kg⁻¹ in first and second year, respectively, Price of wheat is Rs 14kg⁻¹ and Rs 15 kg⁻¹ in first and second year, respectively, Price of straw is Rs. 2.5 kg⁻¹
T₁: Control; T₂: Soil test based fertilizers; T₃: Rice residue incorporation + T₂; T₄: Wheat residue incorporation + T₂; T₅: Rice and Wheat residue incorporation + T₂; T₆: Green manuring + T₂; T₇: Rice residue incorporation + T₆; T₈: Wheat residue incorporation + T₆; T₉: Rice and Wheat residue incorporation + T₆

CHAPTER 5

SUMMARY
AND
CONCLUSION

SUMMARY AND CONCLUSION

Rice-wheat cropping system has emerged as a major cropping system of the Indo-Gangetic Plains (rice bowl and wheat bucket of India). Presently this cropping system has been practiced on nearly 10.3 m ha in India and contributes more than 70% of total cereal production while in West Bengal this system covers about 4.08 lakh hectare and shares about 7.5% of the total cultivated area. However, non judicious use of chemical fertilizers and its potential risks towards soil, environment and plant health are some rising constraints behind the declining productivity of this zone. For this reason nutrient recycling in the soil-plant ecosystem through crop residue incorporation and green manuring may play a great role towards sustainable productive agricultural enterprise.

Keeping this in view the present investigation on **“Effect of crop residue management and green manuring on productivity and soil fertility in rice-wheat system”** was conducted at District Seed Farm, Kalyani, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal during the *kharif* and *rabi* seasons of 2013-14 and 2014-15. The texture of the soil was sandy loam soil with good drainage capacity. The soil has almost neutral pH. The objectives were to find out the effect of crop residue (wheat and rice) management and green manuring (GM) with *Sesbania* on growth and yield of rice (variety: IET-4786) and wheat (variety: K-0307) crop grown in sequence as well as change in soil health status (physical, chemical and biological). The experiment was carried out by incorporating rice, wheat residues and green manuring with *Sesbania* alone or in combination followed by application of soil test based recommended NPK fertilizer dose and the data so obtained were compared with the sole fertilizer source.

Computation of the energy requirements and economics of different crop residue management practices in rice-wheat system were also under the purview of this experimentation.

Nine treatments were used in RBD design with three replication, namely T₁: rice residue removal (var. IET-4786)-wheat residue removal (var. K-0307), T₂: soil test based fertilizers (NPK) application, T₃: rice residue incorporation-wheat residue removal+T₂, T₄: rice residue removal-wheat residue incorporation+T₂, T₅: rice residue incorporation-wheat residue incorporation+T₂, T₆: green manure +T₂, T₇: rice residue

incorporation-wheat residue removal+T₆, T₈: rice residue removal-wheat residue incorporation +T₆,T₉: rice residue incorporation-wheat residue incorporation +T₆.

The important findings emerging out of this experiment are summarized briefly here under:

Growth attributing characters of both rice and wheat were greatly influenced by the treatments in both the years. However, the influences were more pronounced in the second year as compared with that of first year except in case of control (T₁) and sole chemical source of fertilizers treatment (T₂). Significantly higher growth attributing characters namely plant height, number of tillers, LAI and CGR were observed in both rice and wheat crops for the treatments consisting of integration of crop residue incorporation (rice or wheat or both) along with chemical fertilizers followed by green manuring (T₇, T₈ and T₉) as compared to control (T₁) and sole NPK source (T₂). Again, treatments comprising chemical fertilizers + crop residue incorporation and fertilizers + green manuring (GM) (T₃, T₄, T₅ and T₆) were recorded with the higher values of growth attributing characters as compared with T₁ and T₂.

Significantly higher grain and straw yield and harvest index were recorded for both rice and wheat crops in case of residue integration along with inorganic fertilizers followed by green manuring (T₇, T₈ and T₉) as compared to sole NPK source (T₂). Green manuring and/or incorporation of crop residues in rice-wheat system increased SOM and SOC (soil organic matter and soil organic carbon) while maintaining high grain yields. Residue integration along with inorganic fertilizers (T₃, T₄ and T₅) had no significant impact on yield increase for both rice and wheat crops in the first year as compared to application of chemical fertilizers alone (T₂). However, the impact was excellent all through the second year. Integration of both the residues along with green manuring (T₉) gave the highest grain yield for both rice (4.65 t ha⁻¹) and wheat (4.47 t ha⁻¹) crops. Rice + wheat residue incorporation in combination with GM enhanced the grain yield of rice and wheat by 15.67 % and 20.16%, respectively. The maximum system wheat equivalent yields were recorded from T₉ in both the years (8.23 and 9.02 t ha⁻¹, respectively which was 9.15 % and 26.90 % more than that of T₂) and the lowest system wheat equivalent yields were obtained from control (2.55 and 2.32 t ha⁻¹, respectively).

Rice or wheat residues alone or in combination (T₃, T₄ and T₅) improved the available soil NPK and Zn status as compared to sole inorganic sources (T₂). It was

found that the incorporation of rice and wheat straw increased plant recovery of nutrient as well as soil retention in both rice and wheat crops. However, the effect was more pronounced when incorporated with green manuring (T₇, T₈ and T₉). Significant positive influence of crop residue incorporation alone (T₃, T₄ and T₅) or in combination with GM (T₇, T₈ and T₉) was also recorded towards elevated population of *Azotobacter*, total bacteria, fungi and *Actinomycetes* compared to the effect of inorganic fertilizer alone (T₂) and control (T₁).

It has been found that the loss of N was less in those treatments where fertilizer applied along with incorporation of residues with or without green manuring (T₃, T₄, T₅, T₇, T₈ and T₉) and green manuring along with chemical fertilizers (T₆) as compared to fertilizer application alone (T₂) and control (T₁). These might be due to improved nutrient balance of the soil as a result of residues incorporation and green manuring and improved soil physical properties due to residue incorporation and green manuring. The return of rice and wheat residues could recycle up to 20%-30% of the N absorbed by the crops.

Bulk density decreased and soil porosity increased with decrease in bulk density in those treatments involving crop residue (rice or wheat or both) incorporation along with or without green manuring + fertilizers (T₃ to T₉) as compared to the initial values. Green manuring (T₆) had less effect on aggregates stability and formation of macro aggregates, however, when combined with either rice (T₇) or wheat residues (T₈) and with both rice and wheat residues (T₉) increased aggregate ratio, MWD and GMD for controlling water and nutrient movement within the soil.

The treatments with crop residues incorporation (rice or wheat residue or both) + green manuring + fertilizer (T₇, T₈ and T₉) or crop residues + fertilizer (rice or wheat residue or both) (T₃, T₄ and T₅) or green manuring +fertilizer (T₆) proved highly efficient in respect of economic return in terms of B: C ratio and total energy output when compared with sole fertilizer application (T₂) and control (T₁), however, integration of both the residues along with green manuring (T₉) recorded the highest values of both these parameters (2.43 and 2.56 in respect of B: C ratio and 265816.38 and 292447.28 MJ during 1st and 2nd year, respectively). Incorporation of residue was the best in terms of improved soil health, increased wheat yield, monetary return and B: C ratio.

Conclusion

It may be concluded, from the results of the experiment conducted for consecutive two years, that incorporation (rice straw incorporation before 27 days before establishment of wheat and wheat straw incorporation before 42 days of rice transplanting) of rice and wheat residues (separately or both) with wide C/N ratio in combination with soil test based fertilizer application along with green manuring (incorporation of 35 days old *Sesbania* before rice transplanting) could be advantageous in increasing rice and wheat yields and nutrient uptake by both rice and wheat crops and in sustaining soil fertility by improving soil organic matter, soil physical properties, soil available N, P and K and boosting up soil microbial population as compared to sole application of chemical fertilizer. Integration of both the residues along with green manuring proved to be better in maximizing soil organic carbon (SOC) which would lead to favourable nutrient balances and improved yields than integration of only rice or wheat residues along with green manuring and sole green manuring and thus promoting better soil environment in sandy loam soil of the Gangetic alluvial zone of West Bengal. The crop yields and soil properties also revealed an increasing trend with time in all the treatments comprising crop residues with or with ^{out} green manuring. The findings will hopefully encourage farmers for residue incorporation as a means of disposal instead of burning or removal.

CHAPTER 6

**FUTURE
SCOPE OF
RESEARCH**

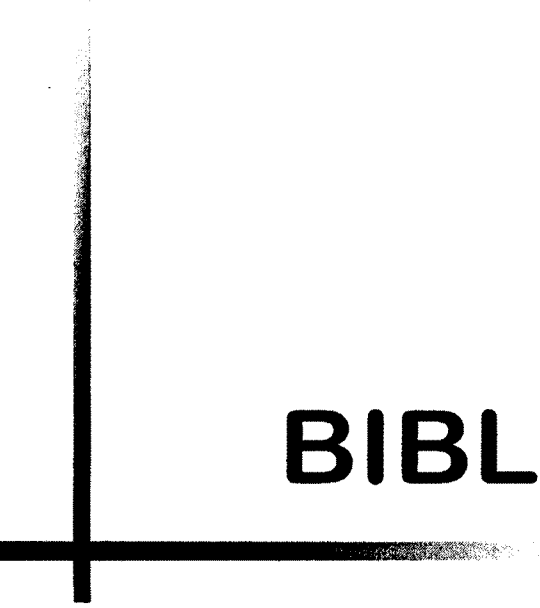
FUTURE SCOPE OF RESEARCH

The present investigation on “Effect of crop residue management and green manuring on productivity and soil fertility in rice-wheat system” was conducted at District Seed farm, Kalyani, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal, during *kharif* and *rabi* seasons of 2013-14 and 2014-15 as carefully as possible. The findings clearly indicated that incorporation of rice and wheat residues (separately or both) with green manuring could be advantageous in increasing rice and wheat yields in rice-wheat cropping system and also for improvement of soil health and sustainability. However, the study was conducted for two consecutive years only. Hence, the experiment should be continued on a long term basis to harness the benefits of residue incorporation. Some more investigations need to be studied in future to come to a definite conclusion of this research work. The research areas for future investigations are given below:

- The experiment should be continued on a long term basis in order to come to a definite conclusion on soil properties and requirement of fertilizers.
- Efficiency of crop residue management practices should be studied on secondary and micro-nutrient composition of soil and their availability to crops grown.
- More detailed research is needed on soil physical and biological properties, soil water movement and availability.
- Detailed studied on soil macro- and micro- fauna under different agro-ecological conditions is needed.
- Effect of tillage practices need to be studied to assess micro-environment and microbial activity under crop residue management programme.
- Efficiency of crop residue on crop quality also needs to be investigated.
- There is a need to fine-tune nutrient management for rice and wheat grown on soils into which crop residues are continuously incorporated. The adoption of this practice by farmers of the region will prove immensely useful because of reduced air pollution and recycling of nutrients.



BIBLIOGRAPHY



- Bodman, G. B., and Colman, E. A. (1944). Moisture and energy conditions during downward entry of water into soils. *Soil Science Society of America Proceedings* 1943. **8**: 116-122.
- Boparai, B. S., Yadvinder Singh and Sharma, B. D. (1992). Effect of green manuring with Sesbania aculeata on physical properties of soil and on growth of wheat in rice-wheat and maize-wheat cropping systems in a semiarid region of India. *Arid Soil Research and Rehabilitation*, **6**(2): 135-143. .
- Boyle, M., Frankenberger, W. T., Jr. and Stolzy, L. H. (1989). The influence of organic matter on soil aggregation and water infiltration. *J. Prod. Agri.*, **2**, 290–299. .
- Dalel Singh and Om, H. (1992). Effect of green manuring, period of decomposition and nitrogen levels on the yield of dwarf rice. *Haryana Journal of Agronomy*, **8**(2): 155-156. .
- Das, K., Medhi, D. N., Guha, B. and Baruah, B. K. (2002). Direct and residual effects of recycling of crop residues along with chemical fertilizers in rice-wheat cropping system. *Annals of Agricultural Research*, **23**(3): 415-418.
- Das, K., Medhi, D. N. and Guha, B. (2003). Application of crop residues in combination with chemical fertilizers for sustainable productivity in rice (*Oryza sativa*) - wheat (*Triticum aestivum*) system. *Indian Journal of Agronomy*, **48**(1): 8-11.
- Dhaliwal, S. S. and Walia, S. S. (2008). Integrated nutrient management for sustaining maximum productivity of rice - wheat system under Punjab conditions. *Journal of Agricultural Research*, **45**(1&2): 12-16. .
- Dhiman, S. D., Nandal, D. P. and Hari Om (2000). Productivity of rice (*Oryza sativa*) - wheat (*Triticum aestivum*) cropping system as affected by its residue management and fertility levels. *Indian Journal of Agronomy*, **45**(1):1-5. .
- Donald, C. M. (1963). Competition among crop and pasture plants. *Advances in Agronomy*, **15**: 1-118. .
- Dotaniya, M. L., Sharma, M. M., Kumar, K. and Singh, P. P. (2013). Impact of Crop Residue Management on nutrient balance in rice-wheat cropping system in an Aquic hapludoll. *The Journal of Rural and Agricultural Research*, **13**(1): 122-123.

- Evans LT. (1993). Crop Evolution, Adaptation and Yield. Cambridge University Press, Cambridge, 500 pp. *Global Journal of Science Frontier Research Agriculture and Veterinary Sciences*, **13**(3):33-38.
- FAO (2004). Food and Agriculture Organisation, Rome, Italy (<http://faostat.fao.org>).
- Fateh Singh, Ravindra Kumar and Samir Pal (2008). Integrated nutrient management in rice-wheat cropping system for sustainable productivity. *Journal of the Indian Society of Soil Science*, **56**(2): 205-208.
- Fischer, R. A. and Yates, F. (1979). *Statistical tables*, Longmans, U.K.
- Gangwar, K.S., Singh, K.K., Sharma, S.K. and Tomar, O.K. (2006). Alternative tillage and crop residue management in wheat after rice in sandy loam soils of Indo-Gangetic plains. *Soil and Tillage Research*, **88**(1-2): 242-252.
- Gomez, K. A. and Gomez, A. A. (1984). *Statistical procedures for agricultural research* (2nd ed). IRRI, Manila, Philippines, John Wiley and Sons, New York, U.S.A.
- Government of India (2015). *Agricultural Statistics at a Glance 2014*. p. 72-77. Ministry of Agriculture, Dept. of Agri. and Cooperation, Directorate of Economics and Statistics.
- Gupta, R. K., Naresh, R. K., Hobbs, P. R., Jheng Jiagua and Ladha, J.K. (2003). Sustainability of Post- Green Revolution Agriculture: The Rice-Wheat Cropping Systems of the Indo-Gangetic Plains and China. In Ladha J K, Hill J, Gupta R K, Duxbury J and Buresh R J. (eds) Improving the productivity and sustainability of rice-wheat systems: issues and impact. ASA, Spec. Publ. 65. Chapter 1:1-25, ASA Madison, WI USA.
- Gupta, R. K., Yadvinder Singh, Ladha, J. K., Bijay Singh, Jagmohan Singh, Gurpreet Singh and Pathak, H. (2007). Yield and phosphorus transformations in a rice-wheat system with crop residue and phosphorus management. *Soil Science Society of America Journal*, **71**(5): 1500-1507.
- Gurpreet Singh, Jalota, S.K. and Yadvinder Singh (2007). Manuring and residue management effects on physical properties of a soil under the rice-wheat system in Punjab, India. *Soil and Tillage Research*, **94**(1): 229-238.

Jackson, M. L. (1973). Soil Chemical analysis. Prentice Hall of India. Pvt. Ltd., New Delhi. ✓

Jai Paul, Choudhary, A. K., Sur, V. K., Sharma, A. K., Vinod Kumar and Shobhna (2014). Bioresource nutrient recycling and its relationship with biofertility indicators of soil health and nutrient dynamics in rice-wheat cropping system. *Communications in Soil Science and Plant Analysis*, **45**(7): 912-924. ✓

Jai Paul, Dixit, A. K., Sharma, A. K. and Vinod Kumar (2014). Nutrient recycling and its relationship with biofertility indicators of soil health and nutrient uptake in rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L. emend. Fiori & Paol) cropping sequence. *Agroecology and Sustainable Food Systems*, **38**(4): 445-459. ✓

Jamshidi, A. R. and Mahmoodzadeh, M. (2011). Effects of wheat stubble management on corn performance in north of Khozestan province, Iran. *Australian Journal of Basic and Applied Sciences*, **5**(9): 1671-1674. ✓

Jat, M. L., Pal, S. S., Livleen Shukla, Mathur, J. M. S. and Mohan Singh (2004). Rice(*Oryza sativa*) residue management using cellulolytic fungi and its effect on wheat (*Triticum aestivum*) yield and soil health in rice-wheat cropping system. *Indian Journal of Agricultural Sciences*, **74**(3): 117-120. ✓

Kachroo Dileep and Dixit, A. K. (2005). Residue-management practices using fly ash and various crop residues for productivity of rice (*Oryza sativa*)–wheat (*Triticum aestivum*) cropping system under limited moisture conditions. *Indian Journal of Agronomy*, **50**(4): 249-252. ✓

Katyal, V., Gangwar, B., Gangwar, K. S. and Singh, K. P. (2002). Changes in productivity and soil fertility under rice (*Oryza sativa*)–wheat (*Triticum aestivum*) system as influenced by long- term integrated nutrient supply. *Indian Journal of Agronomy*, **47**(4): 465-472. ✓

Khankhane, P. J., Barman, K. K. and Jay, G. Varshney (2009). Effect of rice residue management practices on weed density, wheat productivity and soil fertility in a swell-shrink soil. *Indian Journal of Weed Science*, **41**(1&2): 41-45. ✓

Kharub, A. S., Chauhan, D. S., Sharma, R. K., Chhokar, R. S. and Tripathi, S. C. (2003). Diversification of rice (*Oryza sativa*) - wheat (*Triticum aestivum*) system for improving soil fertility and productivity. *Indian Journal of Agronomy*, **48**(3): 149-152. ✓

- Kharub, A. S., Sharma, R. K., Mangia, A. D., Chhokar, R. S., Tripathi, S. C. and Sharma, N. K. (2004). Effect of rice (*Oryza sativa*) straw removal, burning and incorporation on soil properties and crop productivity under rice-wheat (*Triticum aestivum*) system. *Indian Journal of Agronomy*, **74**(6): 295-299.
- Krishna G. Mandal, Arun K. Misra, Kuntal M. Hati, Kali K. Bandyopadhyay, Prabir K. Ghosh and Manoranjan Mohanty (2004). Rice residue management options and effects on soil properties and crop productivity. *Food, Agriculture and Environment*, **2**(1): 224-231.
- Kumar Sandeep, Pandey, D. S. and Rana, N. S. (2004). Effect of tillage, rice residue and nitrogen-management practice on yield of wheat (*Triticum aestivum*) and chemical properties of soil under rice (*Oryza sativa*)-wheat system. *Indian Journal of Agronomy*, **49**(4): 223-225.
- Kumar Sandeep, Pandey, D. S. and Rana, N. S. (2005). Economics and yield potential of wheat (*Triticum aestivum*) as affected by tillage, rice (*Oryza sativa*) residue and nitrogen management options under rice-wheat system. *Indian Journal of Agronomy*, **50**(2): 102-105.
- Kumar, Balwinder, Gupta, R. K. and Bhandari, A. L. (2008). Soil fertility changes after long- term application of organic manures and crop residues under rice-wheat system. *Journal of the Indian Society of Soil Science*, **56**(1): 80-85.
- LiJin Guo, ZhiSheng Zhang, DanDan Wang, ChengFang Li and CouGui Cao (2015). Effects of short-term conservation management practices on soil organic carbon fractions and microbial community composition under a rice-wheat rotation system. *Biology and Fertility of Soils*, **50**(1): 65-75.
- Mandal, A. and Pal, A. K. (2009). Growth of roots and yield as influenced by green manuring in rice-wheat cropping system. *Agricultural Science Digest*, **29**(1): 32-35.
- Mandal, K. G., Misra, A. K., Hati, K. M., Bandyopadhyay, K. K., Ghosh, P. K. and Manoranjan Mohanty (2004). Rice residue - management options and effects on soil properties and crop productivity. *Journal of Food, Agriculture and Environment*, **2**(1): 224-231.

- Martin, J. P. (1950). Use of acid, rose Bengal and streptomycin in the plate method for estimating soil fungi. *Soil Science*, **69**: 332-349.
- Milah, M. G., Bari, M. N., Islam, M. R. and Hirota, O. (2001). Green manuring with *Sesbania* spp. for maintaining rice productivity and soil environment. *Bulletin of the Institute of Tropical Agriculture, Kyushu University*, **24**: 29-42.
- Misra, R. D., Gupta, V. K. and Pandey, D. S. (1996). Managing crop residue in rice. *International Rice Research Note*, **21**(2/3): 71-72.
- Mukherjee, A. and Singh, Y. (2001). Influence of crop residue management and green manuring on growth attributes of transplanted rice (*Oryza sativa* L.). *Environment and Ecology*, **19**(4): 833-835.
- Neeraj Kumar Verma and Binod Kumar Pandey (2013). Effect of varying rice residue management practices on growth and yield of wheat and soil organic carbon in rice-wheat sequence. *Global Journal of Science Frontier Research Agriculture and Veterinary Sciences*, **13**(3): 33-38.
- Olsen, S.R., Cole, C.L., Watanabe F.S. and D.A. Dean. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. *U.S.D.A. Circ.* No. 939.
- Pangali, P. L. and Shah, M. (1999). Rice-wheat cropping systems in the Indo-Gangetic plains: policy re- directions for sustainable resource use. P.1 12. In P. Pangli (ed.) Sustaining rice-wheat production systems: socio- economic and policy issues. Rice Wheat Consortium Paper Series 5. New Delhi, India.
- Panigrahy, S. (2010). Mapping of cropping system for the Indo- Gangetic Plain using multivariate SPOT- NDVI- VGT data. *Journal of Indian Society of Remote Sensing*, **38**(4): 627-632.
- Piper, C.S. 1966. Soil and plant analysis. Inter Science Publication Inc. New York.
- Pramer D. and Schmidt E. L. (1965). Experimental soil microbiology. Burgess Publ. Co., Minneapolis.

- Prasad, R., Gangaiah, B. and Aipe, K. C. (1999). Effect of crop residue management in a rice-wheat cropping system on growth and yield of crops and on soil fertility. *Experimental Agriculture*, **35**(4): 427-435.
- Radford, P. J. (1967). Growth analysis formulae- their use and abuse. *Crop Sci.*, 7: 171-175.
- Raju, R.A. and Reddy, M.N. (2000). Integrate management of green leaf, compost, crop-residues and inorganic fertilizers in rice (*Oryza sativa*)-rice system. *Indian Journal of Agronomy*, **45**(4): 629-635.
- Ramesh Chandra (2011). Effect of summer crops and their residue management on yield of succeeding wheat and soil properties. *Journal of the Indian Society of Soil Science*, **59**(1): 37-42.
- Reshmi Sarkar and Sandipta Kar (2011). Optimum N rate for sustainable rice-wheat system under tillage and crop residue management. *Journal of Crop Improvement*, **25**(4): 337-355.
- Roy, M. de., Chhonkar, P. K. and Patra, A. K. (2006). Effect of crop residue and fertilizer nitrogen on dehydrogenase and urease activity in soil under rice-wheat cropping sequence. *Environment and Ecology*, **24**(1): 51-56.
- Roy, M. de., Chhonkar, P. K. and Patra, A. K. (2006). Effect of crop residue incorporation on N-uptake and dry matter yield of rice and wheat grown in sequence. *Research on Crops*, **7**(3): 647-652.
- Samra, J. S., Bijay Singh and Kumar, K. (2003). Managing crop residues in the rice-wheat system of the Indo-Gangetic Plain. Improving the productivity and sustainability of rice-wheat systems:-issues and impacts- *Proc. Intl. Symp.*, held at the 2001 Annual Meetings of the American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Charlotte, NC, USA, 22-October-2001. 73-195.
- Sandeep Kumar, Pandey, D. S. and Rana, N. S. (2004). Wheat yield and soil bulk density response to tillage, residue and nitrogen management under rice-wheat system. *Annals of Agricultural Research*, **25**(1): 113-117.

- Saraiya, A. B., Tomar, S. S. and Sharma, S. K. (2005). Effect of crop residue and tillage practices on physico-chemical properties and yield of wheat grown after rice in Vertisols. *JNKVV Research Journal*, **39**(1): 57-63.
- Sarkar, R. and Sandipta Kar (2011). Temporal changes in fertility and physical properties of soil under contrasting tillage-crop residue management for sustainable rice-wheat system on sandy-loam soil. *Journal of Crop Improvement*, **25**(3): 262-290.
- Shah, Z., Shah, S. H., Peoples, M. B., Schwenke, G. D. and Herridge, D. F. (2003). Crop residue and fertilizer N effects on nitrogen fixation and yields of legume- cereal rotations and soil organic fertility. *Field Crops Research*, **83**: 1-11.
- Sharma, M. P., Bali, S. V. and Gupta, D. K. (2000). Crop yield and properties of Inceptisol as influenced by residue management under rice-wheat cropping sequence. *Journal of the Indian Society of Soil Science*, **48**(3): 506-509.
- Sharma, S. K. and Sharma, S. N. (2005). Effect of crop diversification of rice-wheat cropping system on productivity and profitability. *Journal of Sustainable Agriculture*, **26**(1): 39-48.
- Sharma, S. N. and Prasad, R. (2001). Effect of wheat, legume and legume-enriched wheat residues on the productivity and nitrogen uptake of rice-wheat cropping system and soil fertility. *Acta Agronomica Hungarica*, **49**(4): 369-378.
- Sharma, S. N. and Rajendra Prasad (2008). Effect of crop-residue management on the production and agronomic nitrogen efficiency in a rice-wheat cropping system. *Journal of Plant Nutrition and Soil Science*, **171**(2): 295-302.
- Sharma, S. N., Singh, S. and Prasad, R. (2001). Effect of crop residues incorporation on the relative efficiency of diammonium phosphate and mussoorie rock phosphate in rice (*Oryza sativa*) - wheat (*Triticum aestivum*) cropping system. *Indian Journal of Agricultural Sciences*, **71**(2): 77-81.
- Shreyasi Gupta Chodhury, Sonal Srivastava, Ranbir Singha, Chodharia, S. K., Sharma, D. K., Singh, S. K. and Dipak Sarkar (2014). Tillage and residue management effects on soil aggregation, organic carbon dynamics and yield attribute in rice-wheat cropping system under reclaimed sodic soil. *Soil and Tillage Research*, **136**: 76-83.

Singh Fateh, Kumar Ravindra and Pal Samir (2008). Integrated Nutrient Management in Rice-Wheat Cropping System for Sustainable Productivity. *Journal of the Indian Society of Soil Science*, **56**(2): 205-208.

6 Singh Rajeev and Yadav, D. S. (2006). Effect of rice (*Oryza sativa*) residue and nitrogen on performance of wheat (*Triticum aestivum*) under rice-wheat cropping system. *Indian Journal of Agronomy*, **51**(4): 247-250.

Singh, B., Gajri, P. R., Timsina, J., Singh, Y. and Dhillon, S. S. (2002). Some issues on water and nitrogen dynamics in rice- wheat sequences on flats and beds in the Indo- Gangetic plains. In: Modeling irrigated cropping systems with special attention to rice- wheat sequences and raised bed planting. Humphreys, E., and Timsina, J. (Eds.) *Processings of a workshop*, CSIRO Land and Water, Griffith, NSW, Australia, 25-28 February 2002. CSIRO Land and Water Technical Report 25/02.

Singh, K.K., Jat,A.S. and Sharma,S.K.(2005). Improving productivity and profitability of rice (*Oryza sativa*)-wheat (*Triticum aestivum*) cropping system through tillage and planting management. *Indian Journal of Agricultural Sciences*, **75**: 396-399.

Singh, Mahender and Sharma, S. N. (2000). Effect of wheat residue management practices and nitrogen rates on productivity and nutrient uptake of rice (*Oryza sativa*)-wheat (*Triticum Aestivum*) cropping system. *Indian Journal of Agricultural Sciences*, **70**(12): 835-839.

Singh, R. D. (2000). Feasibility of vermifarming in Peanut (*Arachis hypogoea*) – Vegetable Pea (*Pisum sativum*) cropping system. *Indian Journal of Agronomy*, **45**(2): 257-262.

Singh,V. K. and Sharma, B. B. (2001). Productivity of rice (*Oryza sativa*) as influenced by crop diversification in wheat (*Triticum aestivum*)-rice cropping system on Mollisols of foothills of Himalayas. *Indian Journal of Agricultural Sciences*, **71**(1): 5-8.

Stewart, B. A. and Robinson, C. A. (1997). Are agroecosystems sustainable in semi-arid regions? *Advances in Agronomy*, **60**, 191–228.

Thornton, H. G. (1922). On the development of standardized agar medium for counting soil bacteria with special reference to the repression of spreading colonies. *Annual Applied Biology*, **9**: 241.

- Tilak, K. V. B. R. (2004). Response of Sesbania green manuring and mungbean residue incorporation on microbial activities for sustainability of a rice-wheat cropping system. *Journal of Agriculture and Rural Development in the Tropics and Subtropics*, **105**(2): 189-196. ✓
- Tomar, R. K.; Garg, R. N.; Gupta, V. K.; Dwivedi, B. S.; Sahoo, R. N; Chakraborty, D. and Kalra, N. (2006). Influence of tillage, nitrogen and residue management on performance of wheat in rice-based cropping system, *Annals of Plant Protection Sciences*, **14**(1): 272-273. .
- Vikas Gupta, Sharma, R. S. and Vishwakarma, S. K. (2006). Long- term effect of integrated nutrient management on yield sustainability and soil fertility of rice (*Oryza sativa*)-wheat (*Triticum aestivum*) cropping system. *Indian Journal of Agronomy*, **51**(3): 160-164. .
- Vinay Singh (2006). Productivity and economics of rice (*Oryza sativa*)-wheat (*Triticum aestivum*) cropping system under integrated nutrient- supply system in recently reclaimed sodic soil. *Indian Journal of Agronomy*, **51**(2): 81-84. .
- Walia, S. S., Brar, S. S. and Kher, D. S. (1995). Effect of management of crop residues on soil properties in rice-wheat cropping system. *Environment and ecology*, **13**: 3, 503; 16 ref. .
- Walia, S. S., Brar, S. S. and Kher, D. S. (1998). Management of crop residues in rice-wheat system. *Environment and Ecology*, **16**: 3, 730-731; 1 ref. .
- Walkely, A. J. and Black, I. A. (1934). Estimation of soil organic carbon by the chronic acid titration method. *Soil Science*, **37**: 29-38. ✓
- Wang Yong Sheng, Huang Jian and Yang ShiQi (2011). Influence of rice straw returning to paddy field on leaching losses of nitrate nitrogen in Ningxia Irrigation District of China. *Journal of Agro Environment Science*, **30**(4): 697-703. .
- Watson, D. J. (1947). Comparative Physiological studies on the growth of field crops II. The effect of varying nutrient supply on the net assimilation rate. *Annals of Botany*, **11**: 375- 407. .

- Yaduvanshi, N. P. S. and Sharma, D. R. (2007). Use of wheat residue and manures to enhance nutrient availability and rice-wheat yields in sodic soil under sodic water irrigation. *Journal of the Indian Society of Soil Science*, **55**(3): 330-334.
- Yadvinder Singh, Bijay Singh, 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 of America Journal*, **68**: 854–864.
- Yadvinder Singh, Gupta, R. K., Gurpeet Singh, Jogmohan Singh, Sidhu, H. S. and Bijya Singh (2009). Nitrogen and residue management effects on agronomic productivity and nitrogen use efficiency in rice-wheat system in Indian Punjab. *Nutrient Cycling in Agro-ecosystem*, **84**(2): 141-154.
- Yuan HongZhao, Qin HongLing, Liu ShouLong, Tong ChengLi, Wei WenXue and Wu JinShui (2011). Response of abundance and composition of the bacterial community to long-term fertilization in paddy soils. *Scientia Agricultura Sinica*, **44**(22): 4610-4617.

An abstract graphic consisting of several thick black lines. A vertical line runs down the right side of the page. A horizontal line runs across the top, starting from the left edge and ending near the vertical line. Another horizontal line runs across the bottom, starting from the left edge and ending near the vertical line. A short horizontal line is positioned above the top horizontal line, and another short horizontal line is positioned to the left of the vertical line, intersecting it.

ANNEXURE

Annexure

Table 1: Energy equivalent for direct and indirect sources of energy

Particulars	Units	Energy equivalent (MJ)
Inputs		
Human labour		
Adult man	hour	1.96
Adult woman	hour	1.57
Bullock	Pair-hour	10.10
Diesel	litre	56.31
Electric motor	kg	64.80
Chemical fertilizers		
N	kg	60.60
P ₂ O ₅	kg	11.10
K ₂ O	kg	6.70
Seed (Rice, Wheat, Dhaincha)	kg(dry matter)	14.70
Dhaincha plant	t	239.71
Outputs		
Grain (rice and wheat)	kg(dry matter)	14.70
Straw (rice and wheat)	kg(dry matter)	12.50

Table 2: Energy calculation for rice grown in one hectare of land

Sl. No.	Particulars	Energy source	Amount	Calculation	Energy input
Raising of seedling in nursery bed					
1.	Land preparation	Land preparation by tractor with disc harrow	1 time × 2 hrs = 2 hrs	[Wt. of the tractor (kg)/Life span (hrs)] × E. E.(MJ) × hrs of operation = [2500/12000] × 64.80 × 2 = 27.00 MJ	27.00 MJ
				[Wt. of disc harrow (kg)/Life span (hrs)] × E. E. (MJ) × hrs of operation = [400/6000] × 64.80 × 2 = 8.64 MJ	8.64 MJ
		Diesel consumption (3.5 litres hr ⁻¹)	For 2 hrs = 2 × 3.5 = 7 litres	7 × E.E. (MJ) = 7 × 56.31 MJ = 394.17 MJ	394.17 MJ
		Driver (Human)	1 M.U. (man)	1 × hrs of operation × E.E. (MJ) = 1 × 2 × 1.96 = 3.92 MJ	3.92 MJ
		Laddering with bullock drawn ladder	2 hrs	2 × E.E. (MJ) = 2 × 10.10 MJ = 20.20 MJ	20.20 MJ
		Human	1 M.U.(Man)	2 × E.E (MJ) = 2 × 1.96 MJ = 3.92 MJ	3.92 MJ
2.	Sowing	Cleaning the stubbles and raise the seed bed	3 M.U. (2 man and 1 woman)	Man = 2 × hrs of operation × E.E (MJ) = 2 × 8 × 1.96 MJ = 31.36 MJ Woman = 2 × 8 × 1.57 MJ = 12.56 MJ	43.92 MJ
		Seed	40 kg ha ⁻¹	40 × E.E.(MJ) = 40 × 14.7 MJ = 588.00 MJ	588.00 MJ
		Sowing	2 M.U. (Man)	2 × hrs of operation × E.E	31.36 MJ

				(MJ) = $2 \times 8 \times 1.96 \text{ MJ} = 31.36 \text{ MJ}$	
3.	Irrigation	Water lifting pump (diesel motor 5 HP)	3 times $\times$ 2 hrs = 6 hrs	[Wt. of engine/ Life span (hrs)] $\times$ E.E. (MJ) $\times$ hrs of operation = $[150/10500] \times 64.80 \text{ MJ} \times 6 = 5.55 \text{ MJ}$	5.55 MJ
		Diesel consumption (0.5 litres hr ⁻¹)	For 6 hrs = $6 \times 0.5 = 3$ litres	$3 \times \text{E.E. (MJ)} = 3 \times 56.31 \text{ MJ} = 168.93 \text{ MJ}$	168.93 MJ
		Application	1 M.U. (1Man)	$1 \times \text{hrs of operation} \times \text{E.E. (MJ)} = 1 \times 8 \times 1.96 \text{ MJ} = 15.68 \text{ MJ}$	15.68 MJ
4.	Intercultural operation	Weeding	2 M.U.(2Woman)	$2 \times \text{hrs of operation} \times \text{E.E. (MJ)} = 2 \times 8 \times 1.57 \text{ MJ} = 25.12 \text{ MJ}$	25.12 MJ
Main field preparation					
5.	Land preparation	Land preparation by tractor along with cultivator	2 times $\times$ 2.5 hrs = 5 hrs	[Wt. of the tractor (kg)/ Life span (hrs)] $\times$ E.E. (MJ) $\times$ hrs of operation = $[2500/12000] \times 64.80 \text{ MJ} \times \text{E.E. (MJ)} \times \text{hrs of operation} = [400/6000] \times 64.80 \text{ MJ} \times 5.0 = 21.60 \text{ MJ}$	67.50 MJ 21.60 MJ
		Diesel consumption (3.5 litres hr ⁻¹)	For 5 hrs = $3.5 \times 5 = 17.5$ litres	$17.5 \times \text{E.E. (MJ)} = 17.5 \times 56.31 \text{ MJ} = 985.42 \text{ MJ}$	985.42 MJ
		Driver (Human)	1 M.U. (Man)	$1 \times \text{hrs of operation} \times \text{E.E. (MJ)} = 1 \times 5 \times 1.96 \text{ MJ} = 9.80 \text{ MJ}$	9.80 MJ
		Puddling with power tiller	1 time $\times$ 2.5 hrs = 2.5 hrs	[Wt. of the power tiller (kg)/ Life span (hrs)] $\times$ E.E. (MJ) $\times$ hrs of operation = $[800/3000] \times 64.80 \text{ MJ} \times 2.5 = 43.20 \text{ MJ}$	43.20 MJ
		Diesel consumption (3.5 litres hr ⁻¹)	For 2.5 hrs = $3.5 \times 2.5 = 8.75$ litres	$8.75 \times \text{E.E. (MJ)} = 8.75 \times 56.31 \text{ MJ} = 492.71 \text{ MJ}$	492.71 MJ
		Driver (Human)	1 M.U. (Man)	$1 \times \text{hrs of operation} \times \text{E.E. (MJ)} = 1 \times 2.5 \times 1.96 \text{ MJ} = 4.90 \text{ MJ}$	4.90 MJ
		Preparation of bund, irrigation channel	7 M.U. (Man)	$7 \times \text{hrs of operation} \times \text{E.E. (MJ)} = 7 \times 8 \times 1.96 \text{ MJ} = 109.76 \text{ MJ}$	109.76 MJ
6.	Fertilizers	N	80 kg	$80 \times 60.60 \text{ MJ} = 4848 \text{ MJ}$	4848.00 MJ
		P ₂ O ₅	35 kg	$35 \times 11.10 \text{ MJ} = 388.5 \text{ MJ}$	388.50 MJ
		K ₂ O	40 kg	$40 \times 6.7 \text{ MJ} = 268 \text{ MJ}$	268.00 MJ
		Application	10 M.U. (Man)	$10 \times 8 \times 1.96 \text{ MJ} = 156.8 \text{ MJ}$	156.80 MJ
				Sub total	5661.30 MJ
7.	Transplanting	Uprooting and transplanting of seedling	25 M.U. (10 Man and 15 Woman)	$10 \times 8 \times 1.96 \text{ MJ} = 156.80 \text{ MJ}$ $15 \times 8 \times 1.57 \text{ MJ} = 188.40 \text{ MJ}$	345.20 MJ
8.	Irrigation	Water lifting pump (diesel motor 5 HP)	3 times $\times$ 5 hrs = 15 hrs	[Wt. of engine/ Life span (hrs)] $\times$ E.E. (MJ) $\times$ hrs of operation = $[150/10500] \times 64.80 \text{ MJ} \times 15 = 13.88 \text{ MJ}$	13.88 MJ
		Diesel consumption (0.5 litres hr ⁻¹)	$0.5 \times 15 = 7.5$ litres	$7.5 \times \text{E.E. (MJ)} = 7.5 \times 56.31 \text{ MJ} = 422.32 \text{ MJ}$	422.32 MJ
		Application	3 M.U.(Man)	$3 \times \text{hrs of operation} \times \text{E.E. (MJ)} = 3 \times 5 \times 1.96 \text{ MJ} = 29.40 \text{ MJ}$	29.40 MJ

9.	Harvesting, bundling and carrying	20 M.U. (10 Man and 10 Woman)	$10 \times 8 \times 1.96 \text{ MJ} = 156.80 \text{ MJ}$ $10 \times 8 \times 1.57 \text{ MJ} = 125.60 \text{ MJ}$	282.40 MJ
10.	Threshing, winnowing, bagging and storing	20 M.U. (5 Man and 15 Woman)	$5 \times 8 \times 1.96 \text{ MJ} = 78.40 \text{ MJ}$ $15 \times 8 \times 1.57 \text{ MJ} = 188.40 \text{ MJ}$	266.80 MJ
	Total			10092.60 MJ

E.E = Energy equivalent, Wt. = Weight, hrs = Hours, M.U. = Man unit, HP = Horse power, MJ = Mega joule

Table 3: Energy calculation for wheat grown in one hectare of land

Sl. No.	Particulars	Energy source	Amount	Calculation	Energy input
1.	Land preparation	Land preparation by tractor with cultivator	3 times $\times$ 2.5 hrs = 7.5 hrs	[Wt. of the tractor (kg)/ Life span (hrs)] $\times$ E.E. (MJ) $\times$ hrs of operation = $[2500/12000] \times 64.80 \text{ MJ} \times 7.5 = 101.25 \text{ MJ}$ [Wt. of the cultivator (kg)/ Life span (hrs)] $\times$ E.E. (MJ) $\times$ hrs of operation = $[400/6000] \times 64.80 \text{ MJ} \times 7.5 = 32.40 \text{ MJ}$	101.25 MJ 32.40 MJ
		Diesel consumption (3.5 liters hr ⁻¹)	$3.5 \times 7.5 = 26.25$ litres	$26.25 \times \text{E.E. (MJ)} = 26.25 \times 56.31 \text{ MJ} = 1478.14 \text{ MJ}$	1478.14 MJ
		Driver (Human)	1 M.U. (Man)	$1 \times 8 \times 1.96 \text{ MJ} = 15.68 \text{ MJ}$	15.68 MJ
		Preparation of bund, irrigation channel	7 M.U. (Man)	$7 \times \text{hrs of operation} \times \text{E.E. (MJ)} = 7 \times 8 \times 1.96 \text{ MJ} = 109.76 \text{ MJ}$	109.76 MJ
				Sub-total	9775.80 MJ
2.	Fertilizers	N	140 kg	$140 \times 60 .60 \text{ MJ} = 8484.00 \text{ MJ}$	8484.00 MJ
		P ₂ O ₅	60 kg	$60 \times 11.10 \text{ MJ} = 666.00 \text{ MJ}$	666.00 MJ
		K ₂ O	70 kg	$70 \times 6.7 \text{ MJ} = 469.00 \text{ MJ}$	469.00 MJ
		Application	10 M.U.(Man)	$10 \times 8 \times 1.96 \text{ MJ} = 156.80 \text{ MJ}$	156.80 MJ
				Sub-total	9775.80 MJ
3.	Sowing		100 kg	$100 \times 14.70 \text{ MJ} = 1470 \text{ MJ}$	1470 MJ
		Sowing	55 M.U. (25 Man and 28 Woman)	Man = $25 \times 8 \times 1.96 \text{ MJ} = 392.00 \text{ MJ}$ Woman = $28 \times 8 \times 1.57 \text{ MJ} = 351.68 \text{ MJ}$	743.68 MJ
4.	Irrigation	Water lifting pump (diesel motor 5 HP)	5 times $\times$ 5 hrs = 25 hrs	[Wt. of engine/ Life span (hrs)] $\times$ E.E. (MJ) $\times$ hrs of operation = $[150/10500] \times 64.80 \text{ MJ} \times 25 = 23.14 \text{ MJ}$	23.14 MJ
		Diesel consumption (0.5 litres hr ⁻¹)	$0.5 \times 25 = 12.5$ litres	$12.5 \times \text{E.E. (MJ)} = 12.5 \times 56.31 \text{ MJ} = 703.87 \text{ MJ}$	703.87 MJ
		Application	5 M.U.(Man)	$5 \times \text{hrs of operation} \times \text{E.E. (MJ)} = 5 \times 5 \times 1.96 \text{ MJ} = 49.00 \text{ MJ}$	49.00 MJ
5.	Harvesting, bundling and carrying		20 M.U. (10 Man and 10 Woman)	$10 \times 8 \times 1.96 \text{ MJ} = 156.80 \text{ MJ}$ $10 \times 8 \times 1.57 \text{ MJ} = 125.60 \text{ MJ}$	282.40 MJ
6.	Threshing, winnowing, bagging and storing		20 M.U. (5 Man and 15 Woman)	$5 \times 8 \times 1.96 \text{ MJ} = 78.40 \text{ MJ}$ $15 \times 8 \times 1.57 \text{ MJ} = 188.40 \text{ MJ}$	266.80 MJ
	Total				15051.92 MJ

E.E = Energy equivalent, Wt. = Weight, hrs = Hours, M.U. = Man unit, HP = Horse power, MJ = Mega joule

Table 4: Input energy through green manuring and straw incorporation in one hectare of land

Sl. No.	Particulars	Energy source	Amount	Calculation	Energy input
Raising of Dhaincha					
1.	Sowing	Seed	30 kg	$30 \times 14.70 \text{ MJ} = 441.00 \text{ MJ}$	441.00 MJ
		Sowing	3 M.U. (Man)	$3 \times 8 \times 1.96 \text{ MJ} = 47.04 \text{ MJ}$	47.04 MJ
2.	Irrigation	Water lifting pump (diesel motor 5 HP)	1 time $\times$ 3 hrs = 3 hrs	[Wt. of engine/ Life span (hrs)] $\times$ E.E. (MJ) $\times$ hrs of operation = $[150/10500] \times 64.80 \text{ MJ} \times 3 = 2.78 \text{ MJ}$	2.78 MJ
		Diesel consumption (0.5 litres hr ⁻¹)	$0.5 \times 3 = 1.5$ litres	$1.5 \times \text{E.E. (MJ)} = 1.5 \times 56.31 \text{ MJ} = 84.46 \text{ MJ}$	84.46 MJ
		Application	1 M.U. (Man)	$1 \times \text{hrs of operation} \times \text{E.E. (MJ)} = 1 \times 3 \times 1.96 \text{ MJ} = 5.88 \text{ MJ}$	5.88 MJ
3.	Incorporation of Dhaincha plant		5 t	$5 \times 239.71 \text{ MJ} = 1198.55 \text{ MJ}$	1198.55 MJ
			Sub-total		1288.89 MJ
4.	Incorporation of straw		1 t (dry matter)	$1 \times 1000 \times 12.5 \text{ MJ} = 12500 \text{ MJ}$	12500 MJ
	Total				13788.89 MJ

E.E = Energy equivalent, Wt. = Weight, hrs = Hours, M.U. = Man unit, HP = Horse power, MJ = Mega joule

Table 5: Cost of cultivation of rice grown in one hectare land area

Sl. No.	Particulars		Quantity	Rupees unit ⁻¹	Total (rupees)
1.	Land preparation		3 times	1000	3000
2.	Puddling		4 hrs	120	480
3.	Irrigation		21 hrs	80	1680
4.	Seed		40 kg	15	600
5.	Fertilizers (80:35:40 kg N:P ₂ O ₅ :K ₂ O ha ⁻¹)	Urea	174 kg	5.6	974.40
		SSP	219 kg	7.8	1708.20
		MOP	67 kg	17.6	1179.20
				Sub- total	3861.8
6.	Mandays		97 mandays	167 (first year)	16199
				193 (second year)	18721
	Total cost of cultivation			First year	25820.80
				Second year	28342.80

Selling price of rice grain in first and second year is Rs 13 kg⁻¹ and Rs. 13.5 kg⁻¹, respectively. Selling price of straw in both the years is Rs. 2.5 kg⁻¹

Table 6: Cost of cultivation of wheat grown in one hectare land area

Sl. No.	Particulars		Quantity	Rupees unit ⁻¹	Total (rupees)
1.	Land preparation		3 times	1000	3000
2.	Irrigation		25 hrs	80	2000
3.	Seed		100 kg	30	3000
4.	Fertilizers (140:60:70 kg N:P ₂ O ₅ :K ₂ O ha ⁻¹)	Urea	304 kg	5.6	1702.40
		SSP	375 kg	7.8	2925.00
		MOP	117 kg	17.6	2059.20
				Sub- total	6686.60
5.	Mandays	110 mandays	167 (first year)	18370.00	
			193 (second year)	21230.00	
	Total cost of cultivation			First year	33056.60
				Second year	35916.60

Selling price of wheat grain in first and second year is Rs 14 kg⁻¹ and Rs. 15 kg⁻¹, respectively. Selling price of straw in both the years is Rs. 2.5 kg⁻¹

Table 7: Cost of cultivation of dhaincha in one hectare land area

Sl. No.	Particulars	Quantity	Rupees unit ⁻¹	Total (rupees)
1.	Seed	30 kg	20	600
2.	Irrigation	3 hrs	80	240
3.	Mandays	3 mandays	167	501
	Total cost of cultivation			1341

