CONSERVATION AGRICULTURE BASED RESOURCE MANAGEMENT IN RICE – MAIZE CROPPING SYSTEM

Ph. D. Thesis

by

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Submitted to the

Indira Gandhi Krishi Vishwavidyalaya, Raipur

by

DINESH KUMAR MARAPI

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CERTIFICATE - I

This is to certify that the thesis entitled **"Conservation agriculture based resource management in rice – maize cropping system"** submitted in partial fulfillment of the requirements for the degree of **Doctor of Philosophy in Agriculture** of the Indira Gandhi Krishi Vishwavidyalaya, Raipur, is a record of the bonafide research work carried out by **Dinesh Kumar Marapi** under my guidance and supervision. The subject of the thesis has been approved by Student's Advisory Committee and the Director of Instructions.

No part of the thesis has been submitted for any other degree or diploma or certificate course. All the assistance and help received during the course of the investigation have been duly acknowledged by him.

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CERTIFICATE - II

This is to certify that the thesis entitled **"Conservation agriculture based resource management in rice – maize cropping system"** submitted by **Dinesh Kumar Marapi** to the Indira Gandhi Krishi Vishwavidyalaya, Raipur, in partial fulfillment of the requirements for the degree of **Doctor of Philosophy in Agriculture** in the Department of **Agronomy** has been approved by the external examiner and Student's Advisory Committee after oral examination.

29-11-19

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Dean Faculty ______________________

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LIST OF ABBREVIATIONS

Abbreviation	Description	Abbreviation	Description
^{O}C	Degree Celsius	P_2O_5	Phosphorus
%	Per cent	CGR	Crop growth rate
@	At the rate	RGR	Relative growth rate
B:C	Benefit: Cost ratio	MJ	Mega joule
CD	Critical Difference	a.i.	Active ingredient
cm	Centimetre	K_2O	Potassium
cm^2	Centimetre square	REY	Rice equivalent yield
d.f.	Degree of freedom	$KMnO_4$	Potassium permanganate
E	East	m^{-2}	Meter per square
et al.	co – worker	day^{-1}	Per day
Fig.	Figure	kg ha^{-1}	Kilogram per hectare
g	Gram	$Leaf^{-1}$	Per leaf
hr	Hours	$Plant^{-1}$	Per plant
i.e.	That is	t ha^{-1}	Ton per hectare
kg	Kilogram	$Panicle^{-1}$	Per panicle
LA	Leaf area	Mg ha^{-1}	Mega gram ha^{-1}
LAI	Leaf area index	Cob^{-1}	Per cob
LCC	Leaf colour chart	CA	Conservation agriculture
m	Metre	ZT	Zero tillage
mg	Milligram	CT	Conventional tillage
mm	Milimetre	NT	No tillage
N	North	RDN	Recommended dose of nitrogen
No.	Number	DAS	Days after sowing
NS	Non-significant	RM	Residue mulching
ha^{-1}	Per hectare	NR	No residue
₹	Rupees	SOC	Soil organic carbon
S	Significant	SEm±	Standard error of mean
N	Nitrogen	K	Potassium
P	Phosphorus	Ca	Calcium
S	Sulphur	C:N	Carbon:Nitrogen
CO_2	Carbon dioxide	RMS	Rice - Maize System
DSR	Direct seeded rice	REN	Nitrogen recovery efficiency

THESIS ABSTRACT

(a)	Title of the Thesis	:	"Conservation agriculture based resource management in rice – maize cropping system"
(b)	Full Name of the Student	:	Dinesh Kumar Marapi
(c)	Major Subject	:	Agronomy
(d)	Name and Address of the Major Advisor	:	Dr. (Major) G. K. Shrivastava Dean Students' Welfare, IGKV, (C.G.)
(e)	Degree to be awarded	:	Doctor of Philosophy in Agriculture (Agronomy)

Signature of the Student

Signature of Major Advisor

Date: 12/7/19

Signature of Head of the Department

ABSTRACT

The field experiments were conducted during *kharif* and *rabi* seasons of 2016-17 and 2017-18 at Institute Research Farm of ICAR- National Rice Research Institute, Cuttack (Odisha). In *kharif* season, the field experiment was laid out in split-split plot design with three replications. The treatment consisted of two tillage practices in rice *viz.*, KT_1 – conventional tillage (CT) and KT_2 – zero tillage (ZT) in main – plot, three residual of residues in maize *viz.*, KR_1 – RDF + no residue, KR_2 – RDF + residue mulching (3 t ha^{-1}) and KR_3 – RDF + residue mulching (6 t ha^{-1}) in sub - plot and two nitrogen management in rice *viz.*, KN_1 – LCC based (100 % RDN) and KN_2 – LCC based (75 % RDN) in sub – sub plot.

In *rabi* season, maize crop was grown in the same set of layout following the above design and replications. The treatment consisted of two tillage practices in maize viz., RT_1 – conventional tillage (CT) and RT_2 – zero tillage (ZT) in main

– plot, three residue management in maize *viz.*, RR_1 – RDF + no residue, RR_2 – RDF + residue mulching (3 t ha^{-1}) and RR_3 – RDF + residue mulching (6 t ha^{-1}) in sub - plot and two residual of nitrogen management in rice *viz.*, RN_1 – LCC based (100 % RDN) and RN_2 – LCC based (75 % RDN) in sub – sub plot. This experiment is on – going since past three years at Division of Crop Production, ICAR – National Rice Research Institute, Cuttack (Odisha).

The results revealed that the KT_1 – conventional tillage (CT) gave significantly higher plant height, dry matter accumulation, leaf area index and crop growth rate, yield attributes of rice *viz.* effective tillers m^{-2}, panicle weight, total and filled grains $panicle^{-1}$ as well as grain and straw yields as compared to KT_2 – zero tillage (ZT). Lowest total and species wise density and dry weight of weeds were also registered in this treatment. Significantly highest nutrient N, P and K uptake by rice as well as production efficiency were also recorded under KT_1 - conventional tillage (CT). However, carbon pools (total and soil organic carbon, water soluble carbon, $KMnO_4$ extractable carbon, microbial biomass carbon and readily mineralizable carbon) and nitrogen pools (total nitrogen, available nitrogen, microbial biomass nitrogen, ammonical and nitrate nitrogen), available P and K in soil were noted under KT_2 – zero tillage (ZT) as compared to KT_1 – conventional tillage (CT).

Among the residual of residues in maize, plant height, dry matter accumulation, leaf area index and crop growth rate, yield attributes (*i.e.* effective tillers, panicle weight, total and filled grains $panicle^{-1}$), grain and straw yields were registered significantly highest under KR_3 - RDF + residue mulching (6 t ha^{-1}), but it was at par to KR_2 - RDF + residue mulching (3 t ha^{-1}). Nutrient uptake by rice (N, P and K) and partial factor productivity (nitrogen, phosphorus and potassium) as well as production efficiency of rice, carbon pools (total and soil organic carbon, water soluble carbon, acid hydrolysable carbon, $KMnO_4$ extractable carbon, microbial biomass carbon and readily mineralizable carbon) and nitrogen pools (total nitrogen, available nitrogen, microbial biomass nitrogen, ammonical and nitrate nitrogen), available P and K in soil also followed the above pattern.

As regards to nitrogen management, KN_1 - LCC based (100 % RDN) registered significantly higher growth parameters (plant height, dry matter accumulation, leaf area index and crop growth rate), yield attributes (effective tillers, panicle weight, total and filled grains panicle^{-1}), grain and straw yields as compared to KN_2 - LCC based (75 % RDN). Nutrient uptake by rice (N, P and K), partial factor productivity (phosphorus and potassium), production efficiency of rice, microbial biomass carbon, total nitrogen, available nitrogen, microbial biomass nitrogen, ammonical nitrogen and nitrate nitrogen, available phosphorus and potassium in soil also followed the same pattern.

The interaction between KR_3 – RDF + residue mulching (6 t ha^{-1}) with KN_1 – LCC based (100 % RDN) noted significantly higher number of effective tillers m^{-2}, number of filled grains panicle^{-1}, grain and straw yields, available nitrogen and net return as compared to other interactions, but it was at par to interactions of KR_2 – RDF + residue mulching (3 t ha^{-1}) with KN_1 – LCC based (100 % RDN), KR_3 – RDF + residue mulching (6 t ha^{-1}) with KN_2 – LCC based (75 % RDN) and KR_2 – RDF + residue mulching (3 t ha^{-1}) with KN_2 – LCC based (75 % RDN).

As regards to economics and energetics of rice, KT_1 - conventional tillage (CT), KR_3 – RDF + residue mulching (6 t ha^{-1}) and KN_1 – LCC based (100 % RDN) obtained significantly highest net return, benefit cost ratio and net energy as compared to their respective treatments.

During *rabi* season in maize, significantly higher growth parameters (plant height, dry matter accumulation, leaf area index and crop growth rate), yield attributes (length and girth of cob, weight and number of grains cob^{-1}), grain and stover yields, nutrient uptake (N, P and K), partial factor productivity (N, P and K), protein yield and productivity, carbon pools (total and soil organic carbon, water soluble carbon, acid hydrolysable carbon, $KMnO_4$ extractable carbon, microbial biomass carbon and readily mineralizable carbon) and nitrogen pools (total nitrogen, available nitrogen, microbial biomass nitrogen, ammonical and nitrate nitrogen), available P and K, net return, B:C ratio and energetics (specific energy, energy intensity in economic and physical term) were recorded under RR_3 - RDF + residue mulching (6 t ha^{-1}) in comparison to other treatments of residue management. Significantly lowest total and species wise density and dry weight of weeds were also obtained in this treatment. Treatment RR_2 - RDF + residue mulching (3 t ha^{-1}) also showed comparable values of growth parameters, total organic carbon, water soluble carbon, acid hydrolysable carbon, total nitrogen, available nitrogen and phosphorus in soil. However, RT_2 - zero tillage (ZT) proved better in terms of carbon and nitrogen pools, available phosphorus and potassium in soil than RT_1 - conventional tillage (CT). Interaction between RT_2 – zero tillage (ZT) with RR_3 – RDF + residue mulching (6 t ha^{-1}) recorded significantly higher weight and number of grains cob^{-1}, grains and straw yields and net return as compared to other interactions, but it was statistically similar to interactions of RT_1 – conventional tillage (CT) with RR_3 – RDF + residue mulching (6 t ha^{-1}), RT_1 – conventional tillage (CT) with RR_2 – RDF + residue mulching (3 t ha^{-1}) and RT_2 – zero tillage (ZT) with RR_2 – RDF + residue mulching (3 t ha^{-1}).

In system analysis of rice – maize cropping system, maximum system productivity was recorded under the treatment combination of KR_5 [{CT + residual of RM (6 t ha^{-1}) + LCC 100 %} – {CT + RM (6 t ha^{-1}) + Residual of LCC 100 %}] followed by KR_6 [{CT + residual of RM (6 t ha^{-1})+ LCC 75 %} – {CT + RM (6 t ha^{-1}) + residual of LCC 75 %}], KR_3 [{CT + residual of RM (3 t ha^{-1})+ LCC 100 %} – {CT + RM (3 t ha^{-1}) + residual of LCC 100 %}] and KR_{11} [{ZT + residual of RM (6 t ha^{-1}) + LCC 100 %} – {ZT + RM (6 t ha^{-1}) + residual of LCC 100 %). However, highest rice equivalent yield and net return were noted under the treatment combination of KR_{11} [{ZT + residual of RM (6 t ha^{-1}) + LCC 100 %} – {ZT + RM (6 t ha^{-1}) + residual of LCC 100 %) followed by KR_{12} [{ZT + residual of RM (6 t ha^{-1}) + LCC 75 %} – {ZT + RM (6 t ha^{-1}) + residual of LCC 75 %), KR_5 [{CT + residual of RM (6 t ha^{-1})+ LCC 100 %} – {CT + RM (6 t ha^{-1}) + Residual of LCC 100 %}] and KR_6 [{CT + residual of RM (6 t ha^{-1}) + LCC 75 %} – {CT + RM (6 t ha^{-1}) + residual of LCC 75 %}].

शोधग्रंथ सारांश

अ)	शोध शीर्षक –	"धान–मक्का फसल प्रणाली में संसाधन प्रबंधन आधारित संरक्षण कृषि"
ब)	विद्यार्थी का पूरा नाम –	दिनेश कुमार मरापी
	प्रमुख विषय	सस्य विज्ञान
द)	प्रमुख सलाहकार का नाम व पता	डॉ. (मेजर) जी. के. श्रीवास्तव अधिष्ठाता छात्र कल्याण इंदिरा गांधी कृषि विश्वविद्यालय रायपुर (छ.ग.)
इ)	सम्मानित की जाने वाली उपाधि	कृषि में डॉक्टर ऑफ फिलॉसाफी (सस्य विज्ञान)

विद्यार्थी का हस्ताक्षर

प्रमुख सलाहकार का हस्ताक्षर

दिनाँक : 12/7/19

विभागाध्यक्ष के हस्ताक्षर

शोध सारांश

भारतीय कृषि अनुसंधान संस्थान – राष्ट्रीय चावल अनुसंधान संस्थान, कटक (उड़ीसा) के अनुसंधान प्रक्षेत्र में वर्ष 2016–17 एवं 2017–18 के खरीफ और रबी ऋतु के दौरान प्रक्षेत्र परिक्षणों का आयोजन किया गया था। खरीफ ऋतु में, प्रक्षेत्र परीक्षण को तीन प्रतिकृतियों के साथ विभक्त – विभक्त भूखण्ड अभिकल्पना में लगया गया था। उपचार मुख्य भूखण्ड में धान के दो भू परिष्करण यथा केटी$_1$ – पारंपरिक जुताई (सीटी) और केटी$_2$ – शून्य जुताई (जेडटी), उप भूखण्ड मक्का के तीन पूर्व फसल अवशेषों के अवशिष्ट प्रभाव यथा केआर$_1$ – आरडीएफ + कोई अवशेष नहीं, केआर$_2$ – आरडीएफ + अवशेष पलवार (3 टन प्रति

हेक्टेयर) एवं केआर$_3$ – आरडीएफ + अवशेष पलवार (6 टन प्रति हेक्टेयर) और उप – उप भूखण्ड में धाने के दो नत्रजन प्रबंधन यथा केएन$_1$ – एलसीसी आधारित (100 प्रतिशत आरडीएन) एवं केएन$_2$ – एलसीसी आधारित (75 प्रतिशत आरडीएन) था।

रबी ऋतु में, मक्का की फसल को उपरोक्त अभिकल्पना एवं प्रतिकृतियों को अपनाते हुए उसी अभिन्यास में उगाया गया था। उपचार मुख्य भूखण्ड में मक्का के दो भू परिष्करण यथा आरटी$_1$ – पारंपरिक जुताई (सीटी) और आरटी$_2$ – शून्य जुताई (जेडटी), उप भूखण्ड मक्का में तीन अवशेष प्रबंधन यथा आरआर$_1$ – आरडीएफ + कोई अवशेष नहीं, आरआर$_2$ – आरडीएफ + अवशेष पलवार (3 टन प्रति हेक्टेयर) एवं आरआर$_3$ – आरडीएफ + अवशेष पलवार (6 टन प्रति हेक्टेयर) और उप – उप भूखण्ड में धाने के दो नत्रजन प्रबंधन के अवशिष्ट प्रभाव यथा केएन$_1$ – एलसीसी आधारित (100 प्रतिशत आरडीएन) एवं केएन$_2$ – एलसीसी आधारित (75 प्रतिशत आरडीएन) था।

परिणामों से पता चला कि केटी$_1$ – पारंपरिक जुताई (केटी) ने पौधे की उॅचाई, शुष्क पदार्थ संचय, पर्ण क्षेत्र सूचकांक और फसल की वृद्धि दर, उपज गुण जैसे प्रभावी कल्ले प्रति वर्ग मीटर, बाली की भार, कुल एवं भरे हुए अनाज की संख्या प्रति बाली के साथ –साथ अनाज एवं पुवाल की उपज केटी$_2$ – शून्य जुताई (जेडटी) की तुलना में सार्थक रूप से आधिक दिया। इसी उपचार में कुल एवं प्रजातियों के अनुसार सबसे कम घनत्व और शुष्क भार भी प्राप्त किया गया। धान के द्वारा पोषक तत्वो की अंतर्ग्रहण (नत्रजन, स्फूर और पोटाश) एवं उत्पादन क्षमता भी केटी$_1$ – पारंपरिक जुताई (केटी) में सार्थक रूप से अधिक पाया गया। हालॉकि, केटी$_2$ – शून्य जुताई (जेडटी) में कार्बन पूल (कुल मृदा कार्बन, पानी में घुलनशील कार्बन, पोटेशियम परमैंगनेट निष्कर्षण कार्बन, सूक्ष्मजीवीय कार्बन, तत्परता खनिजकरण कार्बन), नत्रजन पूल (कुल नत्रजन, उपलब्ध नत्रजन, सूक्ष्मजीवीय नत्रजन, अमोनिकल और नाइट्रेट नत्रजन), उपलब्ध स्फूर एवं पोटेशियम केटी$_1$ – पारंपरिक जुताई (केटी) के तुलना में सार्थक रूप से अधिक नोट किया गया था।

फसल अवशेषों के अवशिष्ट के बीच में, केआर$_3$ – आरडीएफ + अवशेष पलवार (6 टन प्रति हेक्टेयर) ने पौधे की उॅचाई, शुष्क पदार्थ संचय, पर्ण क्षेत्र सूचकांक और फसल की वृद्धि दर, उपज गुण (जैसे प्रभावी कल्ले प्रति वर्ग मीटर, बाली की भार, कुल एवं भरे हुए अनाज की संख्या प्रति बाली), अनाज एवं पुवाल की उपज में सार्थक रूप से अधिक दर्ज की गई थी, लेकिन यह केआर$_2$ – आरडीएफ + अवशेष पलवार (3 टन प्रति हेक्टेयर) के बराबर थी। पोषक तत्वो की अंतर्ग्रहण (नत्रजन, स्फूर और पोटाश) एवं आंशिक कारक

उत्पादकता (नत्रजन, स्फूर और पोटाश) के साथ – साथ धान की उत्पादन क्षमता, कार्बन पूल्स (कुल मृदा कार्बन, पानी में घुलनशील कार्बन, अम्ल हाइड्रोलाइजेबल कार्बन, पोटेशियम परमैंगनेट निष्कर्षण कार्बन, सूक्ष्मजीवीय कार्बन, तत्परता खनिजकरण कार्बन), नत्रजन पूल्स (कुल नत्रजन, उपलब्ध नत्रजन, सूक्ष्मजीवीय नत्रजन, अमोनिकल और नाइट्रेट नत्रजन), मृदा में उपलब्ध स्फूर और पोटाश मे भी उपरोक्त पैटर्न का पालन किया।

जैसा कि नत्रजन प्रबंधन के संबंध में, केएन$_1$ – एलसीसी आधारित (100 प्रतिशत आरडीएन) ने वृद्धि मापदण्ड (पौधे की उँचाई, शुष्क पदार्थ संचय, पर्ण क्षेत्र सूचकांक और फसल की वृद्धि दर), उपज गुण (जैसे प्रभावी कल्ले प्रति वर्ग मीटर, बाली की भार, कुल एवं भरे हुए अनाज की संख्या प्रति बाली), अनाज एवं पुवाल की उपज केएन$_2$ – एलसीसी आधारित (75 प्रतिशत आरडीएन) के तुलना में सार्थक रूप से अधिक दर्ज किया गया। पोषक तत्वो की अंतर्ग्रहण (नत्रजन, स्फूर और पोटाश) एवं आंशिक कारक उत्पादकता (स्फूर और पोटाश), धान की उत्पादन क्षमता, सूक्ष्मजीवीय कार्बन, कुल नत्रजन, उपलब्ध नत्रजन, सूक्ष्मजीवीय नत्रजन, अमोनिकल और नाइट्रेट नत्रजन, मृदा में उपलब्ध स्फूर और पोटाश इसमें भी उपरोक्त पैटर्न का पालन किया।

केआर$_3$ – आरडीएफ + अवशेष पलवार (6 टन प्रति हेक्टेयर) एवं केएन$_1$ – एलसीसी आधारित (100 प्रतिशत आरडीएन) के साथ में प्रभावी कल्ले प्रति वर्ग मीटर, भरे हुए अनाज की संख्या प्रति बाली, अनाज एवं पुवाल उपज, उपलब्ध नत्रजन और शुद्ध लाभ पर दुसरो के प्रति पारस्परिक प्रभाव सार्थक रूप अधिक नोट कि गया, लेकिन यह केआर$_2$ – आरडीएफ + अवशेष पलवार (3 टन प्रति हेक्टेयर) एवं केएन$_1$ – एलसीसी आधारित (100 प्रतिशत आरडीएन) के साथ, केआर$_3$ – आरडीएफ + अवशेष पलवार (6 टन प्रति हेक्टेयर) एवं केएन$_2$ – एलसीसी आधारित (75 प्रतिशत आरडीएन) के साथ और केआर$_2$ – आरडीएफ + अवशेष पलवार (3 टन प्रति हेक्टेयर) एवं केएन$_1$ – एलसीसी आधारित (75 प्रतिशत आरडीएन) के साथ परस्पर संबंधो के बराबर था।

जैसा कि धान के अर्थशास्त्र और उर्जावान के संबंध में, केटी$_1$ – पारंपरिक जुताई (केटी), केआर$_3$ – आरडीएफ + अवशेष पलवार (6 टन प्रति हेक्टेयर) और केएन$_1$ – एलसीसी आधारित (100 प्रतिशत आरडीएन) ने शुद्ध लाभ, लाभ लागत अनुपात और शुद्ध उर्जा उनके संबंधिक उपचारों की तुलना में सार्थक रूप से अधिक पाया गया।

मक्का रबी ऋतु के दौरान, आरआर$_3$ – आरडीएफ + अवशेष पलवार (6 टन प्रति हेक्टेयर) में वृद्धि मानक (पौधे की उँचाई, शुष्क पदार्थ की संचय, पर्ण क्षेत्र सूचकांक और फसल की वृद्धि दर), उपज के गुण (भुट्टा की लंबाई और परिधि, वजन और अनाज की संख्या प्रति भुट्टा), अनाज और पुवाल उपज, पोषक तत्वो की अंतर्ग्रहण (नत्रजन, स्फूर और पोटाश), आंशिक कारक उत्पादकता (नत्रजन, स्फूर और पोटाश) एवं उत्पादन क्षमता, प्रोटीन उपज एवं उत्पादकता, कार्बन पूल्स (कुल मृदा कार्बन, पानी में घुलनशील कार्बन, अम्ल हाइड्रोलाइजेबल कार्बन, पोटेशियम परमैंगनेट निष्कर्षण कार्बन, सूक्ष्मजीवीय कार्बन, तत्परता खनिजकरण कार्बन), नत्रजन पूल्स (कुल नत्रजन, उपलब्ध नत्रजन, सूक्ष्मजीवीय नत्रजन, अमोनिकल और नाइट्रेट नत्रजन), मृदा में उपलब्ध स्फूर और पोटाश, शुद्ध लाभ, लाभःलागत अनुपात ंऔर उर्जावान (विशिष्ट उर्जा, आर्थिक और भौतिक रूप में उर्जा की तीव्रता) अन्य फसल प्रबंधन के उपचारों की तुलना में सार्थक रूप से अधिक पंजीकृत की गई। इसी उपचार में कुल एवं प्रजातियों के अनुसार सबसे कम घनत्व और शुष्क भार भी प्राप्त किया गया। आरआर$_2$ – आरडीएफ + अवशेष पलवार (3 टन प्रति हेक्टेयर) ने सभी वृद्धि मानकों में ही तुलनीय दिखाया गया। हालाकि आरटी$_1$ – पारंपरिक जुताई (सीटी) की तुलना में मिट्टी में कार्बन और नत्रजन पूल, उपलब्ध स्फूर एवं पोटेशियम के संदर्भ में आरटी$_2$ – शून्य जुताई (जेडटी) बेहतर साबित हुई। आरटी$_2$ – शून्य जुताई (जेडटी) एवं आरआर$_3$ – आरडीएफ + अवशेष पलवार (6 टन प्रति हेक्टेयर) के साथ में वजन और अनाज की संख्या प्रति भुट्टा, अनाज एवं पुवाल उपज और शुद्ध लाभ परं दुसरो के प्रति पारस्परिक प्रभाव सार्थक रूप अधिक नोट कि गया, लेकिन यह आरटी$_1$ – पारंपरिक जुताई (सीटी) एवं आरआर$_2$ – आरडीएफ + अवशेष पलवार (6 टन प्रति हेक्टेयर) के साथ, आरटी$_1$ – पारंपरिक जुताई (सीटी) एवं आरआर$_2$ – आरडीएफ + अवशेष पलवार (3 टन प्रति हेक्टेयर) के साथ और आरटी$_2$ – शून्य जुताई (जेडटी) एवं केआर$_2$ – आरडीएफ + अवशेष पलवार (3 टन प्रति हेक्टेयर) के साथ परस्पर संबंधो के साख्यिकीय रूप से बराबर था।

धान – मक्का फसल प्रणाली के प्रणाली विश्वेषण, प्रणाली उत्पादकता केआर$_5$ {(सीटी + आरएम (6 टन प्रति हेक्टेयर) का अवशिष्ट + एलसीसी 100 प्रतिशत) – (सीटी + आरएम (6 टन प्रति हेक्टेयर) +एलसीसी 100 प्रतिशत का अवशिष्ट)} के उपचार संयोजन में अधिकतम था इसके बाद केआर$_6$ {(सीटी + आरएम (6 टन प्रति हेक्टेयर) का अवशिष्ट + एलसीसी 75 प्रतिशत) – (सीटी + आरएम (6 टन प्रति हेक्टेयर) +एलसीसी 75 प्रतिशत का अवशिष्ट)}, केआर$_3$ {(सीटी + आरएम (3 टन प्रति हेक्टेयर) का अवशिष्ट + एलसीसी 100 प्रतिशत) – (सीटी + आरएम (3 टन प्रति हेक्टेयर) +एलसीसी 100 प्रतिशत

का अवशिष्ट)} और केआर$_{11}$ {(जेडटी + आरएम (6 टन प्रति हेक्टेयर) का अवशिष्ट + एलसीसी 100 प्रतिशत) – (जेडटी + आरएम (6 टन प्रति हेक्टेयर) +एलसीसी 100 प्रतिशत का अवशिष्ट)} के उपचार संयोजन थे। हालांकि, धान सपतुल्य उपज और शुद्ध लाभ, केआर$_{11}$ {(जेडटी + आरएम (6 टन प्रति हेक्टेयर) का अवशिष्ट + एलसीसी 100 प्रतिशत) – (जेडटी + आरएम (6 टन प्रति हेक्टेयर) +एलसीसी 100 प्रतिशत का अवशिष्ट)} के उपचार संयोजन में अधिकतम था इसके बाद केआर$_{12}$ {(जेडटी + आरएम (6 टन प्रति हेक्टेयर) का अवशिष्ट + एलसीसी 75 प्रतिशत) – (जेडटी + आरएम (6 टन प्रति हेक्टेयर) +एलसीसी 75 प्रतिशत का अवशिष्ट)}, केआर$_{5}$ {(सीटी + आरएम (6 टन प्रति हेक्टेयर) का अवशिष्ट + एलसीसी 100 प्रतिशत) – (सीटी + आरएम (6 टन प्रति हेक्टेयर) +एलसीसी 100 प्रतिशत का अवशिष्ट)} एवं केआर$_{6}$ {(सीटी + आरएम (6 टन प्रति हेक्टेयर) का अवशिष्ट + एलसीसी 75 प्रतिशत) – (सीटी + आरएम (6 टन प्रति हेक्टेयर) +एलसीसी 75 प्रतिशत का अवशिष्ट)}.

CHAPTER - I

INTRODUCTION

Rice (*Oryza sativa* L.) and maize (*Zea mays* L.) are important cereal crops which contribute to food security and income generation in South Asia. Rice is a staple food crop for around fifty per cent of the world's population and provides more than fifty per cent of total calorie consumption in many South Asian countries (Bronson *et al*., 1997). Maize is an important cereal crop with various uses and known as 'Queen of Cereals Crop' being C_4 plant, high productive and requires less water can be grown successfully under limited water resources conditions. Rice and maize are cultivated either as mono – cropping or in crop rotations under tropical and sub – tropical environments. In spite of the concerted research efforts to increase the yield of these crops, there is a still significant gap between biologically and achievable potential yield of crop under research station and farmland (Timisina *et al*., 2010). Rice – maize cropping system has become very dominant alternative for diversification under prevailing rice based cropping system in Asia. Rice – maize cropping system have a highly production potential and profitable in Eastern and Peninsular India due to the rice – rice cropping system deteriorates the physical condition of soil, encourages physiological disorders and create problems of multi – nutrient deficiencies thus causing a decline in factor productivity of rice. The drivers for substituting *Rabi* rice in rice based cropping system by maize comprise better suitability after harvest of long duration rice varieties with higher productive and profitable compared to the other *Rabi* season crops (Ali *et al*., 2009).

Conventional rice and maize cultivation methods results in extreme use of energy, which may constitute 25 – 30 per cent of total energy use (Sidhu *et al*., 2004). Further, achieving proper tilth for sowing maize after rice takes longer time and labour lack is lead to complexity of challenges in conventional production systems. However, information regarding to management approaches on soil organic carbon accumulation in soil is very limited under rice based cropping system in India. Hence, conservation tillage practices such as zero and minimum tillage are gaining more attention in recent years. Adoption of no tillage helps in timelines of sowing each in rotation and hence, leads to increase in productivity (Mohammad, 2009). Conservation tillage technologies include minimum soil disturbance, providing a soil cover through crop residues and dynamic crop rotations for achieving higher productivity and sustainability. The main features of these technologies comprise: adopting no tillage/direct sowing and minimum traffic for agricultural operations, retain and management of the crop residues on the soil surface, and adopt spatial and temporal crop sequences to obtain maximum benefits from inputs and minimize adverse impacts on environment. The zero tillage for *rabi* maize may also help in advanced sowing, earlier crop emergence, less weed growth and use of residual soil moisture. Maize is having wider adaptability in varied agro ecologies and versatile uses and requires much less water than dry season rice due to its higher water productivity with less detrimental effect to the environment. During dry season in the coastal region temperature during the growth period does not go below 10 ^{0}C. Radiation is excellent and maize being a photo – insensitive crop has better option for adaption in the changing climatic scenario. However, to acquire the full benefits from zero tillage, both rice and maize need to be grown with a 'double zero tillage' system (Jat *et al*., 2006, Bhushan *et al*., 2007). Zero tillage system provide more carbon sequestration and add sufficient soil organic matter in upper layer of soil. Zero tillage also minimize soil erosion, reduces production costs and improves soil organic carbon accumulation resulting in a improve physico-chemical and biological properties of soil such as soil aggregation, pH, soil temperature regulation, nutrient supply and balance microbial population which get the proper root growth and development with increased the potential of productivity (Lal *et al*., 2007).

Resource degradation problems are exhibiting in several methods in the present day modern agriculture. Deteriorating soil carbon, fertility and water table are reflecting on loss of soil biodiversity, multiple nutrients deficiencies and increasing inputs use to achieve maximum yield. In India, rice residue is produced huge quantities but farmers have no alternate uses of residue and usually disposed by burning because rice residue is reduce yield of succeeding crop due to poor plant population establishment and increase attack of pest and diseases (Singh *et al*., 2002). Crop residue is main input source of organic carbon under rice based cropping system and contributed to the increase in soil organic matter concentration, improvement hydrothermal regime and physical condition of soil (Jat *et al*., 2009). Rice residues supply essential plant nutrients by mineralization and improve biophysical condition and soil organic matter accumulation in soil as well as maintain soil fertility (Nyborg *et al*., 1995). Rice residue contains 5-8 kg nitrogen, 0.7-1.2 kg phosphorus, 12-17 kg potassium, 0.5-1 kg sulphur, 3-4 kg calcium and 1-3 kg magnesium per ton of rice residue on dry weight basis (Dobermann and Witt, 2000). The incorporation of crop residues as an essential practice for maintaining productivity of soil (Singh *et al*., 2007) and enhancing the ability of farmlands to sequestration of soil organic matter (Xu *et al*., 2011).

The aim of nutrient management to provide an adequate supply of all essential plant nutrients for a crop growth during the growing season and the amount of any nutrient is limiting at any time which is a potential for loss in crop yield. In many areas, crop yield started declining because a reduction in factor productivity and farmers have resorted to using higher dose of fertilizers than recommended doses of fertiliser (RDF) to maintain previously achieved yield levels. RDF play an important role for enhancing the production of crop, but continuous and inappropriate use of chemical fertilizers which adversely affect the production potential and soil health (Sharma *et al*., 2003). Cereal crops like rice and maize demand sound and effective nutrient management for obtaining productivity targets and fertility sustainability of soil, about 67 per cent of rice growing soils are assessed to be unavailability of sufficient nitrogen, therefore rice has become a major consumer of nitrogen fertilizer. Furthermore, the use efficiency of applied nitrogen fertilizer in lowland rice is extremely low which the different challenges to the rice farmers. The RDF is a challenge to scientists as it should meet both nutrient demand of the crop and sustain the crop yield (Shankar and Umesh, 2008). Therefore, one of the most promising means for increasing productivity is to develop alternative nutrient management practices in the rice - maize system, which may be increase factor productivity and system productivity. Nitrogen is the most challenging to manage due to several transformation and loss mechanism in soil. Loss of nitrogen through denitrification and volatilization are probable to be higher in dry direct seeded rice than the transplanted rice (Davidson, 1991). Field to field huge variability of soil nitrogen supply, agro – climatic and varietal conditions restrict efficient use of nitrogenous fertilizer when broad based blanket recommendation is used (Singh *et al*., 2010). Recently, it has become possible to rapidly and non – destructively measure spectral characteristics of leaves which can be used to diagnose nitrogen deficiency and indirectly to correct nitrogen fertilization and improve nitrogen use efficiency in cereal crops. Hence, a 'real time' approach to nitrogen management is critical for achieving higher yield of crop and enhancing nitrogen use efficiency. Real time nitrogen management approach such as leaf colour chart (LCC) have an inexpensive and simple tool which easy to use for monitoring the greenness of leaves and thereafter providing a quick estimate of the leaf nitrogen status and farmers take LCC readings at 7-10 day intervals and apply fertilizer nitrogen whenever the LCC reading fall below a critical level. The LCC is an ideal and inexpensive tool to enhance nitrogen use in rice (Singh and Singh, 2003). Nitrogen fertilizer management through using LCC shade 3 as a threshold level resulted higher grain yield and enhance nitrogen use efficiency in direct seeded rice in North Western India (Singh *et al*., 2006).

Keeping the above fact in view, the present investigation entitled " **Conservation agriculture based resource management in rice – maize cropping system"** was carried out during *khari*f – *rabi* seasons of 2016-17 and 2017-18 at the Institute Research Farm, ICAR – National Rice Research Institute, Cuttack (Odisha) with the following **objectives:**

1. To assess the effect of conservation agriculture on morpho – physiological parameters, weed dynamics and physico - chemical properties of soil in rice – maize cropping system
2. To study the production potential, economics and energetics of rice – maize cropping system under conservation agriculture

CHAPTER – II

REVIEW OF LITERATURE

The soil system should be manipulated appropriately for confirming a good plant population and increase resource use efficiency, where tillage operation has an important role. Conventional tillage can be lead to deterioration of the soil structure, rapid erosion, depletion of organic matter and fertility. The traditional rice based cropping system is time, money and energy consumption, which varies according to the soil and the agro climatic condition. Inadequate use of input and management methods causes resource degradation and contamination of groundwater which connected to human health threats. Hence, there is an urgent need to develop and promote technologies that can reverse the processes leading to the degradation of resources.

Sustaining production and productivity of any system is most importance for improvement of the physico-chemical and biological properties of soil. Resource conservation system have drawn the attention of agronomists and other crop production scientist to develop innovative tillage techniques for efficient resource management and sustained productivity of system. Tillage residue management especially adoption of conservation agriculture (CA) practices which involve zero tillage (ZT), residue retention and crop rotation may have a significant effect on supply and transformation of nutrient in soil. Nitrogen is the paramount important nutrient for plant growth and development, high yield and improves quality parameters. It needs to be managed carefully to escape nitrogen deficiency due to slow mineralization, immobilization and volatilization, and to avoid excess nitrogen fertilization. A challenge has been made in this chapter to review the published literature relating to the present investigation entitled "Conservation agriculture based resource management in rice – maize cropping system". The review of literature has been presented under the following headings:

2.1 Rice based cropping system

2.2 *Kharif* season rice

2.2.1 Effect of tillage practices

2.2.1.1 Growth, yield attributes and yield

2.2.1.2 Weed density and weed dry weight

2.2.1.3 Physico-chemical properties of soil

2.2.1.4 Nutrient content and its uptake by rice

2.2.2 Effect of nitrogen management

2.2.2.1 Growth, yield attributes and yield

2.2.2.2 Weed density and weed dry weight

2.2.2.3 Physico-chemical properties of soil

2.2.2.4 Nutrient content and its uptake by rice

2.3 *Rabi* season maize

2.3.1 Effect of tillage practices

2.3.1.1 Growth, yield attributes and yield

2.3.1.2 Weed density and weed dry weight

2.3.1.3 Physico-chemical properties of soil

2.3.1.4 Nutrient content and its uptake by maize

2.3.2 Effect of residue management

2.3.2.1 Growth, yield attributes and yield

2.3.2.2 Weed density and weed dry weight

2.3.2.3 Physico-chemical properties of soil

2.3.2.4 Nutrient content and its uptake by maize

2.4 System productivity

2.5 Economics

2.6 Energetics

2.1 Rice based cropping system

Neogi *et al*. (2014) revealed that the microbial biomass carbon, readily mineralizable carbon, water soluble carbon and permanganate oxidizable carbon were 19.4, 20.4, 39.5 and 15.1 per cent, respectively as well as carbon content in soil aggregate fraction significantly higher under minimum tillage over conventional tillage in rice based cropping system.

Singh *et al*. (2016a) found that soil physical properties such as water stable aggregates, bulk density, penetrometer resistance and infiltration rate showed significant improvement under zero tillage direct seeded rice/ zero tillage maize with residue as compared to transplanted rice and conventional maize without residue along with the soil organic carbon increased by 2.86 Mg ha^{-1} at 0.30 cm of soil depth in zero tillage direct seeded rice/ zero tillage maize with residue than conventional practice.

Huang *et al*. (2016a) reported that stocks of soil organic carbon and total soil nitrogen were recorded significantly higher under no tillage compared to conventional tillage at 0-5 cm depth in rice based cropping systems.

Sorokhaibam *et al*. (2017) revealed that no - tillage was superior as compared to conventional tillage with respect to water use efficiency and partial factor productivity for nutrient use as it recorded significantly higher values of water use efficiency and partial factor productivity over conventional tillage under rice based cropping system.

Nandan *et al*. (2018) found that total grassy weed density and total broad leaved weed density were significantly increased in zero tillage direct seeded rice – zero tillage by 29.1 per cent and 34.6 per cent during 2013 and 2014, respectively, compared to conventional transplanted rice – conventional tillage under rice based cropping system.

2.2 *Kharif* season rice

2.2.1 Effect of tillage practices

2.2.1.1 Growth, yield attributes and yield

Yadav *et al*. (2005) observed that yield and number of effective tillers m^{-2} of rice were recorded higher with zero tillage over conventional tillage. The yield of rice was decreased under zero tillage direct seeded rice compared to puddle transplanted rice (Singh *et al*., 2006b).

Song *et al*. (2007) concluded that a leaf net photosynthetic rate was observed significantly higher under no tillage compared to conventional tillage, but non-significantly in yield between conventional tillage and zero tillage practices during four years period by reported that by Bhattacharyya *et al*. (2008).

Aslam *et al*. (2008) reported that number of effective tillers m^{-2} was recorded significantly highest under direct seeding (231.7) followed by double zero tillage (219.0), bed planting (206.7) and conventional planting (200.2), respectively.

Singh *et al*. (2008) stated that significant increase in grain yield was found associated with residue incorporation with conventional tillage. Initially conventional tillage recorded 23.3 and 18.6 per cent higher yield of rice compared to zero tillage but later zero tillage was found 25.1 per cent more yield than conventional tillage (Mishra and Singh, 2012).

Bazaya *et al*. (2009) noted that grain and straw yield of rice were obtained higher under conventional tillage than conservation tillage. Jat *et al*. (2009) also found that yield of rice was found higher under conventional tillage direct seeded rice (7.5 t ha^{-1}) which was at par with puddled transplanted rice (7.5 t ha^{-1}) but it was higher compared to zero tillage direct seeded rice (7.19 t ha^{-1}).

Surin *et al*. (2013) revealed that effective tillers (14.6 %), panicle length (3.0 %), filled grains (9.3 %), grain yield (25.5 %) and straw yield (27.9 %) were produced significantly higher with rice sown under conventionally tilled compared to rice sown under zero tilled. Jadhav *et al*. (2014) also reported that plant height, leaf area, number of tillers m^{-2}, panicle weight, number of panicles m^{-2}, test weight (1000 grain weight), grain yield and straw yield of rice were significantly higher with rice sown under conventional tillage than rice sown under zero tillage.

Das *et al*. (2014) found that plant height, dry matter accumulation, number of tillers $hill^{-1}$, panicle weight, grains $panicle^{-1}$ and yield of rice were recorded significantly higher under conventional tillage which was at par with options of two spading + one trampling + two weeding at 25 and 45 DAT, two spading + one trampling + one weeding 30 DAT and one spading + one trampling + one weeding 30 DAT.

Devi *et al*. (2015) reported that the grain yield of rice was found to increase only slightly in zero tillage treatment compared to conventional tillage treatment during the two years of cropping season.

Gupta *et al*. (2016) stated that in 2012, the grain and straw yield, harvest index and yield attributes were recorded no significant differences among the tillage treatments but floret fertility was significantly higher with zero tillage direct seeded rice compared to conventional tillage direct seeded rice. However, in 2013, zero tillage direct seeded rice had significantly lower grain and straw yield and harvest index compared to conventional tillage direct seeded rice.

Singh *et al*. (2016b) revealed that higher productive tillers $hill^{-1}$, panicle length (cm), panicle weight (g), number of grain $panicle^{-1}$, test weight (g) and grain yield of rice were recorded with reduced tillage followed by conventional tillage and no - tillage.

Singh *et al*. (2017) concluded that aerobic direct seeded rice sown after conventional tillage gave significantly higher grain yield compared to no tillage with 15.4 per cent higher water expense efficiency.

Singh *et al*. (2018) showed that the rice yield under transplanted rice was significantly higher compared to conventional tillage direct seeded rice and zero tillage direct seeded rice treatments during the investigation period.

Choudhary *et al*. (2018) noticed that grain yield of rice was recorded significantly lower under zero tillage compared to conventional tillage in the first year, which was at par with among different treatments in the second and third year.

Nandan *et al*. (2018a) found that significantly higher grain yield were registered in zero tillage direct seeded rice – zero tillage (5.21 and 5.39 t ha^{-1}, respectively) followed by zero tillage transplanted rice – zero tillage (4.75 and 4.94 t ha^{-1}, respectively) and lowest under transplanted rice – conventional tillage (4.06 and 4.47 t ha^{-1}, respectively).

2.2.1.2 Weed density and weed dry weight

Prasad *et al*. (2002) revealed that the zero tillage system was recorded significantly higher dry weight of grasses weeds compared to conventional tillage system, whereas dry weight of broad leaved weeds recorded under conventional tillage sytem.

Brar and Walia (2007) noted that relative density of grassy weeds was recorded significantly lower under zero tillage compared to conventional tillage while relative density of broad leaved weeds recorded higher under zero tillage.

Chauhan and Johnson (2009) found that the seedling emergence of *Digitaria ciliaris, Echinochloa colona, Eleusine indica, Ageratum conyzoides, Eclipta prostrate* and *Portulaca oleracea* were higher in zero tillage compared with either conventional or minimum tillage but emergence of *Rottboellia cochinchinensis* was not influenced by the tillage system.

Chauhan (2013) reported that in both seasons, weed density and biomass were greater in the zero tillage system than in the conventional tillage system.

Vijaymhantesh *et al*. (2013) revealed that conventional tillage practices considerably reduced the population of weeds compared to reduced and minimum tillage.

Jadhav *et al*. (2014) stated that significantly more number of weeds m^{-2} and weed dry matter m^{-2} were recorded in conservation tillage compared to conventional tillage during experiment period.

Upasani *et al*. (2014) noted that grassy weeds, viz. *Digitaria sanguinalis* (L.) Scop. (33.56 %), *Dactyloctenium aegyptium* (L.) (4.60 %), *Echinochloa crusgalli* (L.) P. Beauv. (2.76 %), *Commelina nudifolia* (L.) (6.90 %), broad leaf weeds, viz. *Eclipta alba* (L.) Hassk (6.44 %), *Ludwigia parviflora* (Jacq.) Raven (4.00 %), while among sedges *Cyperus iria* (L.) (1.84 %) and *Fimbristylis milliaceae* (L.) (3.91 %) were dominant in rice and conventional tillage recorded reduced density and dry matter of weed which was on par with zero tillage.

Singh *et al*. (2015a) reported that the maximum emergence of *Cyperus rotundus* and *Echinochloa colona* was 33 - 42 per cent and 20 - 26 per cent higher in zero tillage compared to conventional tillage in direct seeded rice and in second season, *Cyperus compressus* emergence in zero tillage exceeded conventional tillage by 65 per cent, whereas *Echinochloa crusgalli* and *Dactyloctenium aegyptium* emerged 22 per cent and 52 per cent more in the conventional tillage system than zero tillage.

Matloob *et al*. (2015) indicated that population of grassy weeds were recorded significantly higher under zero tillage, while conventional tillage had higher population of broad leaved weeds under the direct seeded rice.

2.2.1.3 Physico-chemical properties of soil

Tillage practice can also influence the distribution of soil organic carbon in the profile with higher soil organic matter content in surface layers with zero tillage compared to conventional tillage but a higher content of soil organic carbon at deeper layers under conventional tillage, whereas residue was incorporated through tillage (Donal *et al*., 2006 and Jantalia *et al*., 2007).

Xu *et al*. (2007) found that soil organic carbon, nitrogen and microbial biomass carbon and microbial biomass nitrogen were higher at the top 5 cm layer after 18 years under no - tillage than conventional tillage, whereas the reverse trend was observed at 5-10 cm and 20 cm layers. No- tillage treatment was recorded higher phosphorus, potassium and organic carbon concentration at 0 - 2.5 cm soil layer compared to conventional tillage (Betrol *et al*., 2007).

Bhattacharya *et al*. (2008) revealed that the soil organic carbon after the harvest of the crop at 0 - 15 cm soil depth was estimated significantly higher under zero tillage compared to conventional tillage.

Gupta *et al*. (2011a) evaluated that available nitrogen, phosphorus and potassium content of the soil was not significantly influenced between zero tillage and conventional tillage practices.

Bhattacharyya *et al*. (2011) noted that conventional tillage practice had significantly less labile soil organic carbon content compared to zero tillage practice in the surface soil layer during the investigation.

Ghimire *et al*. (2012) noticed that the soil organic carbon sequestration (28 %) was recorded higher with rice sown under no - tillage compared to rice sown under conventional tillage at 15 cm soil depth.

Das *et al*. (2014) reported that the soil organic carbon (11.5%), microbial biomass carbon (17 %) and dehydrogenase activity (10.7%) were recorded higher under no - tillage compared to conventional tillage but the bulk density was significantly higher with conventional tillage compared to other tillage treatments.

Jadhav *et al*. (2014) reported that conservation tillage showed significantly higher values of nitrogen, phosphorus, potassium, iron and bulk density than conventional tillage.

Xue *et al*. (2015) revealed that no - tillage recorded increased bulk density, soil organic carbon and total nitrogen at 0 - 20 cm soil depth compared to conventional tillage practices.

Kumar *et al*. (2015a) observed that the soil health in terms of bulk density, soil organic carbon, available nitrogen, phosphorus and potassium were recorded superior in zero tillage than in other tillage practice treatments.

Huang *et al*. (2016b) found that concentration of soil organic carbon, soil total nitrogen and soil organic nitrogen were recorded higher under no - tillage at 0 - 5 cm soil depth but lower under no - tillage than conventional tillage at 5 - 10 cm soil depth, while at 10 - 20 cm soil depth, the difference was not significantly. Consequently, stocks of soil organic carbon, soil total nitrogen and soil organic nitrogen were estimated higher under no - tillage compared to conventional tillage at 0 - 5 cm soil depth with lower at 5 - 10 soil depth. However, no significant difference was observed on stocks of soil organic carbon soil total nitrogen and soil organic nitrogen at 10-20 cm soil depth in between no - tillage and conventional tillage.

Bera *et al*. (2018) observed that the microbial biomass carbon content at flowering stage was significantly higher by 29 and 37 per cent at 0 - 7.5 cm soil depth and 31 and 57 per cent at 15 - 30 cm soil depth under conventional tillage direct seeded rice and zero tillage direct seeded rice, respectively compared with conventional transplanted rice but the soil organic carbon content at flowering stage was recorded significantly higher under zero tillage direct seeded rice compared to other treatments.

Das *et al*. (2018) stated that the soil organic carbon concentration, available nitrogen, available phosphorus, available potassium, microbial biomass carbon and dehydrogenase activity were recorded significantly higher under no-tillage compared to conventional tillage.

2.2.1.4 Nutrient content and its uptake by rice

Lupwayi *et al*. (2006) observed significantly higher nitrogen, phosphorus and potassium uptake under zero tillage over conventional tillage.

Das *et al*. (2014) found that no - tillage had contributed 2-4, 0.8-2 and 0.78-1.9 times more uptakes of nitrogen, phosphorus and potassium, respectively.

Seema (2014) observed that significantly higher nitrogen uptake of grain was noted under zero tillage compared to minimum tillage and conventional tillage while the treatment effect on phosphorus and potassium were recorded non – significantly in between treatments.

Kumar *et al*. (2015b) reported that nitrogen, phosphorus and potassium uptake of grain was noted significantly higher under zero tillage compared to conventional tillage. However, the highest nitrogen, phosphorus and potassium uptake of straw was recorded in conventional tillage.

Huang *et al*. (2016c) revealed that no - tillage had 17 - 43 per cent less nitrogen, phosphorus and potash uptake compared to conventional tillage. Singh *et al*. (2018) found that conventional tillage noted significantly higher of potassium uptake over zero tillage.

2.2.2 Effect of nitrogen management

2.2.2.1 Growth, yield attributes and yield

The leaf colour chart (LCC) and chlorophyll meter have emerged as diagnostic tools which can indirectly estimate nitrogen status of the rice and help describe time and quantity of nitrogen fertilizer given through top dressing in rice. Optimum nitrogen management for zero tillage with residue retention may differ from that of conventional practice. However, there are potential issues with switching establishment system that especially concerning agronomic productivity and nitrogen fertilizer management practices to optimize yield.

Pandu (2002) observed that nitrogen management at LCC 3 did not differ significantly on grain yield of upland rice from recommended dose of nitrogen (RDN). However, nitrogen management at LCC 3 threshold value required less nitrogen (70-90 kg ha^{-1}) compared to RDN (100 kg ha^{-1}).

Porpavai *et al*. (2002) indicated that the grain yield of rice was obtained highest under SPAD based nitrogen applied treatment compared to blanket recommendation and LCC 4 threshold based nitrogen management during *rabi* season, but *kharif* season, LCC 5 threshold based nitrogen management recorded highest grain yield of rice compared to SPAD optimum treatments.

Budhar and Tamilselvan (2003) concluded that LCC threshold score 4 based nitrogen application (30, 45 and 30 kg ha^{-1} at the early, rapid and late growth stages, respectively) recorded higher grain yield of rice than the blanket recommendation during experiment period.

Budhar (2005) revealed that grain yield of rice was recorded significantly higher under LCC value 4 (135 kg ha^{-1}) which was at par with LCC value 5 (165 kg ha^{-1}) and lowest under the recommended nitrogen dose (120 kg ha^{-1}).

Reddy *et al*. (2005) reported that significantly higher grain yield of rice was noted under LCC threshold level 6 based nitrogen management (40, 60 and 40 kg ha^{-1} at early, rapid and late vegetative growth stages, respectively) compared to other recommended dose of nitrogen treatments.

Manjappa *et al*. (2006) noted that application of nitrogen as per LCC 5 has recorded maximum panicles m^{-2}, filled grains, grain filling percentage, test weight, grain weight $panicle^{-1}$ and grain yield during all the three years. However, it was on par with application of nitrogen as per LCC Index 4.

Alam *et al*. (2007) stated that application of nitrogen fertilizer through LCC 4 produced higher grain yield of rice which was at par with blanket recommendation dose (120 kg ha^{-1}) in three equal splits during experiment years.

Nachimuthu *et al*. (2007a) showed that the grain yield of rice was recorded significantly highest under application of nitrogen (135 kg ha^{-1}) in four splits at seeding (30 kg ha^{-1}), active tillering (45 kg ha^{-1}), panicle initiation (30 kg ha^{-1}) and flowering (30 kg ha^{-1}) through LCC threshold value 4 which was at par with application of nitrogen (165 kg ha^{-1}) using LCC threshold value 5.

Nachimuthu *et al*. (2007b) reported that biomass production was recorded highest under LCC based nitrogen management at panicle initiation to first flowering stages have effectively saved the nitrogen fertilizer compared to application of nitrogen fertilizer through conventional blanket application.

Balaji and Jawahar (2007) revealed that the LCC 4 treatment had recorded significantly highest 1000 grains weight, grain and straw yield of rice followed by LCC threshold value 5.

Sharma and Masand (2008) noted that the LCC threshold value 3 produced significantly higher grain yield of rice compared to LCC threshold value 2 and recommended dose of fertilizer.

Singh *et al*. (2009) stated that application of nitrogen through LCC <5 with 20 kg or 30 kg ha^{-1} as a basal and without basal N (100-180 kg ha^{-1}) was recorded significantly higher grain yield of rice compared to nitrogen application through LCC <3 with 30 kg ha^{-1} as a basal and without basal (60-90 kg ha^{-1}) and recommended dose of nitrogen (120 kg ha^{-1}) in three splits during both the years.

Sathiya and Ramesh (2009) concluded that nitrogen management by LCC value 4 (150 kg ha^{-1}) produced significantly higher tillers (369.3 m^{-2}), plant height

(81.7 cm), dry matter (5710 kg ha^{-1}) and grain yield (2915 kg ha^{-1}) of rice compared to nitrogen management by LCC value 3 during experiment season period.

Gupta *et al*. (2011b) reported that real time nitrogen management using LCC threshold value 4 with a basal dose of 20 kg ha^{-1} produced higher grain yield of rice which was statistically similar to with application 120 kg ha^{-1} in 3 splits doses.

Yogendra *et al*. (2014) reported that the LCC based nitrogen application of 75 kg ha^{-1} (basal 30 kg ha^{-1} + LCC) recorded higher grain and straw yield of rice which was on par with recommended dose of fertilizer, while significantly higher effective number of tillers m^{-2}, number of grains $panicle^{-1}$ and 1000 grain weight of rice in aerobic and wetland situation.

Thirunavukkarasu and Vinoth (2014) noted that the nitrogen application based on LCC critical value less than 4 noted highest dry matter production (4597 and 7182 kg ha^{-1} at active tillerig and panicle initiation, respectively), grain yield (6207 kg ha^{-1}) and straw yield (7815 kg ha^{-1}) followed by recommended dose of nitrogen.

Duttarganvi *et al*. (2014) revealed that nitrogen application through LCC value 5 (120 kg ha^{-1}) and SPAD 37.5 (120 kg ha^{-1}) observed significantly higher grain yield of rice compared to other treatments under low land system.

Bhat *et al*. (2015) reported that nitrogen application @ 30 and 20 kg ha^{-1} based on LCC <5 gave significantly higher number of grains $panicle^{-1}$ compared to nitrogen application @ 30 and 20 kg ha^{-1} based on LCC <4 and LCC <3 while maximum grain yield of rice was registered under nitrogen application @ 30 kg ha^{-1} based LCC <5 which was at par with nitrogen application @ 20 kg ha^{-1} based on LCC <5 during both the years.

Lone *et al*. (2016) observed that highest number of tillers m^{-2} and LAI values were obtained in treatments N_{120}, LCC 4_{20} and LCC 4_{30} compared to other treatments, while highest number of panicles m^{-2}, grain yield and straw yield were recorded under treatments LCC 420 and LCC 430 compared to control treatment.

Moharana *et al.* (2017) revealed that application of nitrogen based on LCC threshold value 4 produced significantly higher grain (52.6 q ha^{-1}) and straw (65.4 q ha^{-1}) yield, number of ear bearing tillers m^{-2} (403.7), panicle length (25.43 cm) and filled grains $panicle^{-1}$ (148.94) compared to other treatments.

Lone and Ganie (2017) reported that growth parameters, yield attributes, grain and straw yield of rice under application of nitrogen @ 20 kg ha^{-1} based on LCC 4 were recorded significantly higher compared to remaining LCC and fixed time nitrogen management treatments.

2.2.2.2 Weed density and weed dry weight

Bayan and Kandasamy (2002) reported that commended dosage of nitrogen applied in four splits at 10 DAS (active tillering, panicle initiation and heading stages) recorded significantly lower dry weight of weeds as compared to others.

Singh *et al.* (2003) found that the split application of nitrogen ½ as basal + active tillering + ½ panicle initiation stage recorded significantly higher weed dry matter production (90.8 g m^2) over the rest of treatments.

Singh *et al.* (2005b) indicated that application of nitrogen (half basal + one fourth at tillering + one fourth at panicle initiation) gave significantly higher weed density and weed dry weight than other 2 splits. Higher dose of nitrogen as basal appeared instrumental in boosting initial weed growth and hence increased the weed biomass per unit area.

Chaudhary *et al.* (2011) noted that N – scheduling under 1/2 at sowing + ¼ tillering + ¼ panicle recorded significantly higher values of weed density and dry weight of weed and minimum weed density were recorded in four split as ¼ each at early tillering, active tillering, panicle initiation and panicle emergence.

Sahu *et al.* (2015) found that initial reduced dose and delayed nitrogen application (1/4 at 10 DAT, ½ at tillering and ¼ at panicle initiation) was recorded significantly reduced weed density and significantly higher weed control efficiency as compared to conventional scheduling of nitrogen application.

Kumar and Singh (2016) revealed that the minimum weed density, total weed dry weight and depletion of nutrient recorded under nitrogen schedule of ¼ 2 WAS (week after sowing) + ¼ 4 WAS + ¼ 6 WAS+ ¼ 8 WAS, which was statistically at par with 1/3 2 WAS + 1/3 4 WAS + 1/3 6 WAS.

Singh *et al*. (2017) concluded that nitrogen application significantly affected weed emergence (represented here by density); number of weed plants m^{-2} increased with nitrogen addition, highest densities were observed for *E. crus-galli*.

Hemalatha and Singh (2018) observed that *Echinochloa colona*, *Echinochloa crussgalli*, *Cyanodon dactylon*, *Cyperus rotundus*, *Cyperus iria*, *Eclipta alba* and *Caesulia auxillaris* were the dominant weeds throughout the crop growth period. Weed density and weed dry weight of grasses, sedges and broad leaved weeds were observed significantly lower under LCC < 5 compared to recommended dose of nitrogen (120 kg ha^{-1}) during both the years of study.

2.2.2.3 Physco-chemical properties of soil

Nachimuthu *et al*. (2007) stated that the significantly higher available nitrogen, available phosphorus and available potassium" were estimated under nitrogen application based LCC compared to conventional blanket nitrogen treatment.

Ghimire *et al*. (2012) found that nitrogen application through LCC recorded significantly higher soil organic matter sequestration compared to nitrogen application through recommended dose during experimental period.

Thirunavukkarasu and Vinoth (2014) concluded that the LCC critical value less than 4 noted the highest available nitrogen of 296.5, 278.1 and 255.3 kg ha^{-1} at active tillering and panicle initiation followed by recommended dose of nitrogen (292.7, 274.4 and 250.9 kg ha^{-1} at active tillering and panicle initiation, respectively).

Das and Sahu (2015) noted that significantly higher available nitrogen, available phosphorus and available potassium were recorded under nitrogen application through LCC + soil test based P and K application compared to farmer's practice during the both the years.

Barad *et al*. (2018) revealed that available nitrogen, available phosphorus, available potassium and heat soluble sulphur were recorded significantly higher under application of nitrogen (40 kg ha^{-1} as basal + 80 kg ha^{-1} in two equal splits based SPAD threshold 40) followed by application of nitrogen (40 kg ha^{-1} as basal + 80 kg ha^{-1} in two equal splits based LCC 4), application of nitrogen (40 kg ha^{-1} as basal + 80 kg ha^{-1} in two equal splits based SPAD threshold 35), application of nitrogen (40 kg ha^{-1} as basal + 60 kg ha^{-1} in two equal splits based LCC 4) and application of nitrogen (40 kg ha^{-1} as basal + 60 kg ha^{-1} in two equal splits based SPAD threshold 40) compared to the fixed time nitrogen application.

2.2.2.4 Nutrient content and its uptake by rice

Pandu (2006) reported that the total nitrogen uptake was recorded significantly higher with nitrogen management through LCC - 3 compared to recommended dose of nitrogen.

Reddy and Pattar (2006) revealed that significantly higher nitrogen uptake was recorded under LCC 6 based nitrogen management compared to other methods of nitrogen management.

Ravi *et al*. (2007) noted that significantly higher nitrogen content of leaf recorded under LCC critical value 5 based nitrogen application compared to other nitrogen application methods.

Nachimuthu *et al*. (2007b) showed that nitrogen, phosphorus and potassium uptake recorded significantly highest under LCC based nitrogen management at panicle initiation to first flowering stages compared to conventional blanket based nitrogen management.

Singh *et al*. (2009) found that the LCC <5 (30 kg N ha^{-1} as basal) with without basal nitrogen (150 and 180 kg N ha^{-1}) recorded significantly higher uptake compared to LCC <3 (30 kg N ha^{-1} as basal) without basal nitrogen (60 and 90 kg N ha^{-1}).

Houshmandfar and Kimaro (2011) revealed that the total nitrogen uptake recorded significantly higher under LCC based nitrogen application compared to fixed schedule recommended nitrogen application.

Thirunavukkarsu and Vinoth (2014) noticed that nitrogen, phosphorus and potassium uptake recorded significantly highest under application of nitrogen through LCC <4 compared to recommended dose of nitrogen.

Gupta *et al.* (2011b) reported that total nitrogen uptake recorded significantly lower under LCC 4 compared to LCC 5 and 120 kg N ha^{-1} treatments.

Barad *et al*. (2018) noted that nitrogen, phosphorus and potassium uptake by grain straw were recorded significantly highest with the treatment 40 kg N ha^{-1} as basal + 80 kg N ha^{-1} two equal splits based SPAD threshold 40 which was at par with 40 kg N ha^{-1} as basal + 80 kg N ha^{-1} two equal splits based LCC 4, 40 kg N ha^{-1} as basal + 80 kg N ha^{-1} two equal splits based SPAD threshold 35, 40 kg N ha^{-1} as basal + 60 kg N ha^{-1} two equal splits based LCC 4 and 40 kg N ha^{-1} as basal + 60 kg N ha^{-1} two equal splits based SPAD threshold 40.

2.3 *Rabi* season maize

2.3.1 Effect of tillage practices

2.3.1.1 Growth, yield attributes and yield

Bachmann and Friedrich (2002) reported that no tillage with direct seeding significantly increased the yield of maize (17 % higher) compared to the conventionally tilled treatments.

Jat *et al*. (2005) revealed that productivity of maize was marginally higher with no - tillage compared to conventional tillage practices. Srivastava *et al*. (2005) noted that the yield, water productivity and profitability of quality protein maize hybrid were recorded under no - tillage planting compared to conventional tillage on a sandy loam soil.

Khurshid *et al*. (2006) evaluated that the conventional tillage practice recorded significantly maximum plant height and yield of maize compared to other tillage treatments.

Kumar *et al*. (2006) stated that plant height, leaf area index, dry matter accumulation plant^{-1}, relative leaf water content and grain yield of maize were observed significantly higher under conventional tillage compared to zero tillage.

Singh *et al*. (2007) reported that lower plant height, leaf area index, grain and stover yield of maize were obtained under maize sown under no tillage compared to maize sown under conventional tillage practices.

Khurshid and Iqbal (2008) observed that number of grains cob^{-1} and 1000 grains weight of maize was recorded significantly higher under conventional tillage compared to the no - tillage.

Khan *et al*. (2008) found that plant, number of leaves and grain yield of maize was observed significantly highest under conventional tillage compared to deep tillage and zero tillage.

Sharma *et al*. (2009) revealed that conventional tillage practices was significantly influenced on corn yield compared to no - till system.

Gul *et al*. (2009) noted that biological yield of maize was recorded significantly higher under conventional tillage than no - tillage.

Rashidi *et al*. (2010) stated that significantly higher yield and yield components of maize was recorded with conventional tillage method compared to no - tillage.

Ram *et al*. (2010) revealed that all the growth parameters (plant height, dry matter accumulation and leaf area index), yield attributes (cob plant^{-1}, grains cob^{-1} and 1000 grain weight) and yield of maize were found statistically similar in between conventional tillage and zero tillage practices.

Ahmad *et al*. (2010) noticed the superior yield attributes in term of grains cob^{-1}, grain weight and grain yield of maize under conventional tillage as compared to no - tillage.

Singh *et al*. (2011) observed that grain yield (12.1 %) and stover yield (17.1 %) of maize were decreased under no - tillage compared with conventional tillage.

However, water storage was higher under no tillage treatments compared to conventional tillage plot.

Kutu (2012) noticed that zero tillage as conservation agriculture practice gave the higher grain yield of maize by 2805 and 2776 kg ha^{-1} under supplementary irrigation and dry land conditions, respectively over conventional tillage.

Kumar and Angadi (2014) found that conventional tillage showed significantly higher plant height (182.3 cm), leaf area index (4.18), cob weight (170.60 g cob^{-1}), 100 seed weight (27.92 g), grain yield (5.91 t ha^{-1}) and harvest index (42.3 %) as compared to minimum and zero tillage practice.

Parihar *et al.* (2015) stated that zero tillage flat sowing with residue retention resulted significantly higher plant height, dry matter accumulation, leaf area, leaf area index, grains cob^{-1}, grain and stover yield of maize as compared to conventional tillage flat sowing.

Visalakshi and Sireeha (2015) noted that significantly higher number of plants m^{-2}, number of cob $plant^{-1}$, number of grains cob^{-1}, grains weight cob^{-1} and grain yield of maize were recorded under conventional tillage than zero tillage sowing.

Stanzen *et al.* (2016) recorded significantly maximum number of grains cob^{-1}, 1000 seed weight and grain yield of maize under conventional tillage which was at par with zero tillage.

Khan *et al.* (2017) found that significantly higher leaf area index and harvest index were recorded in conventional tillage followed by minimum tillage, while higher total plant biomass and grain yield of maize were obtained from deep tillage practices followed by conventional tillage practices and minimum tillage.

Khedwal *et al.* (2017) showed that maize sown under zero tillage with residue recorded the highest grain yield of maize (7.32 t ha^{-1}), which was at par with raised bed planting method.

Singh *et al*. (2018) revealed that maize yield was significantly higher under zero tillage by 2 - 6.1 Mg ha^{-1} as compared to conventional tillage.

2.3.1.2 Weed density and weed dry weight

Sinha *et al*. (2000) reported that the *Cynodon dactylon*, *Sorghum halepense*, *Cyperus rotundus*, *Convolvulus arvensis*, *Anagallis arvensis*, *Chenopodium album*, *Melilotus alba*, *Lathyrus aphaca*, *Cichorium intybus* and *Cannabis sativa* were observed during winter maize experiment.

Carter *et al*. (2002) noted that significantly higher number of annuals weeds (18.5 m^{-2}), broad leaved weeds (13.6 m^{-2}) and grasses (5.6 m^{-2}) were recorded with maize sown under no - tillage compared to maize sown other tillage practice.

Sinha *et al*. (2003) concluded that *Cyperus rotundus*, *Cynodon dactylon*, *Sorghum halepense*, *Chenopodium album*, *Convolvulus arvensis*, *Anagallis arvensis*, *Cannabis sativa* and *Melilotus alba* were observed in maize filed during winter season.

Joshua and Benson (2004) reported that the pre – dominant broadleaved weeds (*Tridax procumbens*, *Euphorbia heterophylla*, *Ageratum conyzoides* and *Calapogonium mucunoides*) and grassy weeds (*Panicum maximum*, *Sporobolus pyranidalis* and *Eragrostis tenella*) were observed in maize. The weed density was recorded significantly higher under zero tillage compared to other tillage practices at 6 week after sowing, whereas, at 10 week after sowing, significantly lowest weed biomass was recorded under zero tillage than other tillage practices.

Nakamoto *et al*. (2006) observed that diversity of winter weeds were decreased by conventional tillage compared to other till plots during three years, while summer weeds also decreased by conventional tilled plot during experiment period. *Amaranthus retroflexus* showed significantly lower dry weight under reduced tillage compared to conventional tillage in 2002 and 2003. *Echinochloa crusgalli*, *Commelina communis* and total other annual weeds showed significantly higher dry weight under reduced tillage compared to conventional tillage in 2003.

Tolimir *et al*. (2006) stated that the highest number of weed species like *Cirsitum arvense*, *Rubus caesius*, *Amaranthus retroflexus*, *Datura stramonium* and *Sorghum halepense* were observed under no-tillage followed by minimum tillage and conventional tillage.

Chhokar *et al*. (2007) revealed that total weed infestation was recorded significantly higher under zero tillage compared to conventional tillage. Furthermore, numbers of broad leaved weeds also observed higher under zero tillage system.

Khan and Arif (2007) showed that conventional tillage recorded to suppress weed density viz. *Cyperus rotundus*, *Digitaria sanguinalis* and *Convolvulus arvensis* at 21 and 42 DAS.

Sharma and Gautam (2011) reported that significantly higher weed species like *Cynodon dactylon* (44.4 m^{-2}), *Cyperus rotundus* (34.8 m^{-2}), *Echinochloa crusgalli* (25.0 m^{-2}), *Echinochloa colona* (29.5 m^{-2}) and *Agropyron repens* (23.5 m^{-2}), total weed population (43.9 %) and weed dry weight (42.8 g m^{-2}) were recorded under no – tillage system compared to conventional tillage system.

Bahar (2013) stated that conventional tillage was recorded significantly lowest total weed density and total weed dry weight compared to zero tillage practices. However, it was on par with minimum tillage practice during investigation period.

Kumar and Angadi (2014) noted that total dry weight of weed was recorded significantly higher under zero tillage practice compared to conventional tillage practice.

Stanzen *et al*. (2016) revealed that significantly increased weed population and highest biomass of grassy, broad leaved weeds and sedges were recorded under zero tillage system compared to conventional tillage system during growing season.

2.3.1.3 Physico-chemical properties of soil

Dam *et al*. (2005) found that bulk density was recorded 10 per cent higher under no - tillage compared to conventional tillage particularly at 0 – 0.10 m soil depth.

Fabrizzi *et al*. (2005) showed that significantly higher bulk density and soil penetration resistance was recorded under no - tillage compared to other tillage practice, but the values were quite below threshold that could affect crop growth.

Borie *et al*. (2006) observed that total nitrogen was recorded significantly higher under zero tillage compared to conventional tillage. Astier *et al*. (2006) also revealed that total nitrogen was estimated significantly higher under zero tillage compared to conventional tillage in the highlands of Central Mexico.

Ali *et al*. (2006) reported that the lowest value of soil organic matter, available nitrogen, available phosphorus, available potassium, calcium and magnesium were recorded under conventional tillage compared to other tillage practices.

Li *et al*. (2007) found that bulk density was recorded significantly lower under conventional tillage compared to no - tillage at 20 cm soil depth during the 6 years of the experiment.

Jabro *et al*. (2007) revealed that soil penetration resistance was measured significantly greater in the no - tillage over to other tillage treatments.

Abail *et al*. (2013) reported that no - tillage improved soil physico-chemical properties likes soil aggregation, carbon sequestration, nitrogen conservation and soil organic matter content as well as maintained the pH.

Shokati and Ahangar (2014) showed that no - tillage increased soil organic matter and improves soil fertility and has potential for increasing the nutrient supply to crops through mineralization of nutrients by microbial biomass.

Alam *et al*. (2014) observed that the zero tillage recorded significantly higher total nitrogen content compared to conventional tillage and minimum tillage.

Muchabi *et al*. (2014) stated that total porosity, bulk density, soil pH, soil organic carbon, soil microbial biomass, nodulation and biological nitrogen fixation were recorded significantly higher under no - tillage compared to conventional tillage after 7 years.

Yadav *et al*. (2015) reported that the soil organic carbon, available nitrogen, available phosphorus and available potassium were recorded significantly higher in maize sown under no - tillage compared to maize sown under conventional tillage system. However, soil pH was recorded significantly higher under conventional tillage than all other treatments.

2.3.1.4 Nutrient content and its uptake by maize

Lavado *et al*. (2001) found that tillage practice had no significant difference in macronutrient concentration of maize. However, concentrations of nutrients were found slightly higher under zero tillage compared to conventional tillage system.

Ardell *et al*. (2006) concluded that uptake of nitrogen was recorded more with conventional tillage compared to no - tillage in clay loam soil.

Astier *et al*. (2006) observed that significantly higher nitrogen uptake was observed in maize sown with zero tillage + residue management compared to other treatments.

Hedge *et al*. (2007) revealed that the nitrogen uptake was recorded significantly greater with conventional tillage compared to no - tillage practice.

Chopra and Angiras (2008) reported that conventional tillage recorded significantly higher uptake of nitrogen and potassium by maize compared to zero tillage which was at par with raised bed method. However, significantly higher uptake of phosphorus was recorded under raised bed compared to zero tillage which was at par with conventional tillage practice.

Sarma and Gautam (2010) revealed that the uptake of nitrogen (12 %), phosphorus (17 %) and potassium (11 %) were observed significantly higher under conventional tillage in comparison to no - tillage condition.

Ali *et al*. (2016) reported that conventional tillage – raised bed recorded significantly maximum nitrogen uptake which was at par with zero tillage – raised bed and conventional tillage – flatbed, but potassium uptake was recorded significantly higher under conventional tillage – flatbed followed by zero tillage – raised bed.

Yadav *et al*. (2016) noted significantly maximum total nitrogen, phosphorus and potassium uptake by maize under zero tillage practice compared to conventional tillage practice.

2.3.2 Effect of residue management

2.3.2.1 Growth, yield attributes and yield

Awal and Khan (2000) found that rice straw mulch recorded significantly higher crop growth rate, relative growth rate, net assimilation rate, dry matter partitioning higher biological yield, economic yield and harvest index compared to unmulch treatments.

Khurshid *et al*. (2006) stated that number of cobs plant^{-1}, number of grains cob^{-1} and 1000 grain weight were recorded significantly higher under mulch @ 12 Mg ha^{-1} compared to control.

Yi *et al*. (2007) noted that plant height, dry matter accumulation and grain yield of maize were recorded significantly highest under full straw mulch compared to half straw mulch.

Kar and Kumar (2007) indicated that leaf area index, water use efficiency and intercepted photosynthetically active radiation were recorded significantly higher in the mulched plot compared to non – mulched plot under the irrigation condition.

Manhas and Gill (2010) observed significantly maximum plant height, number of leaves and dry matter accumulation plant^{-1} under mulched @ 9.38 t ha^{-1} compared to other treatments.

Uwah and Iwo (2011) reported that plant height and number of leaves plant^{-1} of maize were measured significantly maximum with mulch @ 8 t ha^{-1}, while grains weight cob^{-1}, dry stover and grain yield of maize were recorded significantly higher with @ 6 t ha^{-1} compared to unmulched control plot.

Zhang *et al*. (2011) found that significantly higher leaf area index, biomass accumulation, grain yield and water use efficiency were recorded under crop residue mulch plot compared to other treatments.

Kumar and Angadi (2014) stated that significantly higher plant height (179.5 cm), leaf area index (4.03) at 60 DAS, cob weight (166.10 g), 1000 seed weight (27.52), grain yield (5.75 t ha^{-1}) and harvest index (42.3 %) of maize were recorded with mulch compared to no mulch treatment.

Zayton *et al*. (2014) reported that crop growth rate and grain yield of maize were observed significantly higher under mulched plot compared to no mulched plot.

Amini *et al*. (2014) showed that plant height, number of leaves plant^{-1}, leaf area and biological yield of maize were recorded significantly higher with application of straw mulch compared to no mulch.

Kaur and Mahal (2016) reported that application of paddy straw mulch @ 6 t ha^{-1} recorded significantly increased plant height, dry matter accumulation, yield attributes, grain yield, water productivity, net return and B:C ratio of maize compared to no mulch.

2.3.2.2 Weed density and weed dry weight

Ramakrishna *et al*. (2006) showed that the unmulched plot had significantly greater weed coverage compared to straw mulched plot at 30 DAS and at harvest.

Mahajan *et al*. (2007) reported that the weed population was found significantly decreased under rice straw mulch over unmulched treatment. However, rice straw mulch gave significant reduction in dry matter accumulation of weeds by 63.8 per cent compared to unmulched.

Uwah and Iwo (2011) revealed that the weed infestation and total weed dry weight were recorded significantly highest under the unmulched plot compared to mulch @ 8 t ha^{-1} and mulch @ 6 t ha^{-1}.

Bahar (2013) reported that straw mulch recorded significantly lower total weed density (13.1 m^{-2}) and total weed dry weight (7.8 g m^{-2}) compared to no mulch treatment.

Kumar and Angadi (2014) also reported that significantly lower total dry weight of weeds was recorded under mulched plot than on mulched plot treatment.

Meena and Singh (2013) stated that rice residue mulch practice significantly reduced the weed density and dry matter of weeds at 60 DAS compared to rice retained which was at par with rice residue incorporated during the years.

Mohtisham *et al*. (2013) observed that total weed density and dry weight of weeds were significantly reduced with application of straw as a mulch compared to unmulched treatment.

Choudhary and Kumar (2014) reported that the density, dry weight, index and persistency index of weed were recorded significantly lower under mulched plot compared to unmulched plot.

2.3.2.3 Physico-chemical properties of soil

Residue management might increase the content of soil mineral nitrogen in the long runs in comparison to mono cropping without residue management systems (Wani *et al*., 1995). Lal (2000) noted the decrease in bulk density from 1.20 to 0.98 g cm^{-3} at the surface 0-5 cm layer by application of straw @ 16 t ha^{-1} of rice straw for consecutive 3 years.

Mishra *et al*. (2001) reported that about 22.5 and 59.4 per cent of the total phosphorus present in rice straw was released within 5 to 23 weeks after incorporation of rice straw into the soil.

Shittu and Fasina (2006) noticed the lowest soil organic carbon content was recorded in non-mulched treatment than mulched treatment in maize. Eighteen years of rice straw incorporation experiment showed that straw incorporation into the soil could improve soil fertility (She *et al*., 2008).

Pervaiz *et al*. (2009) showed that bulk density was significantly decreased under mulch compared to control with improved soil physical properties. Bakht *et al*. (2009) also found significantly increase nitrogen content of soil under crop residue incorporation compared to other treatments.

Saha *et al*. (2010) observed that residue incorporation measured significantly lower bulk density of surface soil layer compared to control treatment.

Balakirshnan and Duraisami (2013) observed that mulches have great agro-ecological potential and they typically conserve the soil, improve the soil ecology, stabilize and improve soil properties.

Kumar and Angadi (2014) noted significantly higher available nitrogen (242.1 kg ha^{-1}) under mulched treatment compared to no mulched treatment.

Liu *et al*. (2014) reported that the mulch probably acted as an insulator, resulting in smaller fluctuations in soil temperature, significantly reduced annual total runoff and increased soil water storage in the top 100 cm of soil profile in the straw mulched than control.

2.3.2.4 Nutrient content and its uptake by maize

Singh *et al*. (1991) showed that significantly higher nutrient uptake of nitrogen, phosphorus and potassium were recorded under mulch compared to unmulch in winter maize. Kachroo and Dixit (2005) also reported that the significantly highest uptake of nitrogen, phosphorus and potassium were recorded under rice straw incorporated plot compared to control.

Rahaman *et al*. (2005) found that nitrogen uptake was significantly higher under mulch treatment compared to no mulch.

Astier *et al*. (2005) found that nitrogen content in stover and grain of maize was not affected by residue management, whereas phosphorus content in stover and grain of maize was recorded significantly higher under residue management treatment compared to other treatments.

` Chakraborty *et al*. (2010) reported that nitrogen uptake was significantly higher with paddy straw and paddy husk mulching as compared to no mulch and improved the nitrogen use efficiency.

Shaheen *et al*. (2010) found significantly higher nitrogen and phosphorus uptakes under mulched compared to no mulch.

2.1 System productivity

Yadav *et al*. (2015) found that the no - tillage recorded the maximum system productivity, whereas the conventional tillage had the lowest system productivity. The average system productivity was 6.1 per cent higher under no - tillage systems than conventional tillage systems.

Prasad *et al*. (2016) observed that minimum tillage with mulching recorded 5.4 per cent higher system productivity than conventional tillage during 2010–11, which increased to 7.4 per cent in 2011–12.

Ramesh *et al*. (2016) noticed that MGEY (maize grain equivalent yield), production efficiency and productivity of the system were significantly higher under conventional tillage as compared to zero tillage.

Kumar *et al*. (2016) stated that the highest system productivity was recorded under raised bed planting (9.92 and 9.80 t ha^{-1}) followed by zero tillage planting (9.08 and 9.04 t ha^{-1}) and the minimum under conventional tillage planting (8.63 and 8.84 t ha^{-1} during 2011-12 and 2012-13 respectively) during both the years in maize wheat cropping system.

Samant and Patra (2016) indicated that maximum system productivity, production efficiency ($kg^{-1}ha^{-1}day^{-1}$) and sustainable yield index were recorded under conventional tillage – zero tillage being higher than zero tillage – zero tillage. However, the minimum system productivity, production efficiency and sustainable yield index were observed under conventional tillage – conventional tillage.

Sorokhaibam *et al*. (2017) reported that no - tillage and conventional tillage treatments had negligible differences on the system productivity in terms of REY but these differences were not significant in rice based cropping system.

Nandan *et al*. (2018b) revealed that the system productivity as expressed by rice-equivalent yield (t ha^{-1}) was increased by 10.3 and 23.2 per cent, respectively, in upland transplanted rice – zero tillage rice and zero tillage – zero tillage treatments over conventional transplanted rice – zero tillage.

2.5 Economics

Dhillon *et al*. (2004) reported that zero tillage system recorded lower cost of cultivation (₹ 412 ha^{-1}) compared to conventional tillage system (₹ 1373 ha^{-1}). Jat *et al*. (2005) also noted that cost of cultivation was recorded lowest under no – tillage (US \$ 241 ha^{-1}) compared to conventional tillage (US \$ 393 ha^{-1}).

Reddy and Pattar (2006) found that the highest net return and benefit cost ratio (₹ 30960 ha^{-1} and 2.38) were calculated with leaf colour chart 6 compared to recommended practice (₹ 27258 ha^{-1} and 2.21) and farmers practice (₹ 28032 ha^{-1} and 2.17).

Manjappa *et al*. (2006) showed that application of nitrogen based LCC 5.0 recorded significantly higher net return (₹ 27878 ha^{-1}) which was at par with application of nitrogen based LCC 4.0 (₹ 24945 ha^{-1}).

Sharma *et al*. (2008) revealed that minimum tillage recorded higher B:C ratio (1.08) followed by no - tillage (1.04) and conventional tillage (0.85) and straw mulch was recorded higher B:C ratio (1.11) followed by soil mulch (1.05), polythene mulch (1.04) and no mulch (0.71).

Singh *et al*. (2009) revealed that application of nitrogen based LCC < 5 with 30 kg N ha^{-1} as a basal application registered the highest net income which was at par under LCC < 5 without basal nitrogen as compared to rest of the treatments.

Jat *et al*. (2009) noted minimum cost of cultivation under zero tillage compared to conventional tillage system in rice based cropping system. Furthermore, net return was recorded higher under double zero tillage system in rice based cropping system.

Sharma and Gautama (2010) revealed that cost of cultivation, net return and benefit cost ratio were recorded higher under conventional tillage system compared to no - tillage system.

Srividya (2010) stated that the gross and net return were calculated higher with maize grown under conventional tillage system compared to zero tillage system. However, the highest B:C ratio was recorded with maize sown under zero tillage system.

Upasani *et al*. (2014) observed that continuous conventional tillage sequence recorded the maximum gross return (₹ 57,607 ha^{-1}), net return (₹ 28,446 ha^{-1}) and benefit:cost ratio in rice based cropping system and was similar to zero tillage – conventional tillage practices in rice based cropping system.

Ramesh *et al*. (2013) noted that the net income (₹ 49600 ha^{-1}) and B:C (1.72) of system were recorded under conservation agriculture system compared to conventional agriculture system.

Laik *et al*. (2014) stated that higher net margins and saving in cost of cultivation under zero tillage in cereal based cropping systems. Kumar and Angadi (2014) reported that minimum tillage recorded significantly higher net return (₹ 34301 ha^{-1}) as compared to zero tillage (₹ 31021 ha^{-1}) and conventional tillage practice (₹ 33335 ha^{-1}). There was no significant difference in net return with respect to mulching practices.

Bhat *et al*. (2015) showed that the application of nitrogen through LCC $\leq$ 5 @ 30 kg ha^{-1} gave higher gross return (₹ 145075.60 ha^{-1}), net return (₹ 103425.80 ha^{-1}) and benefit cost ratio (2.24) compared to other treatments.

Singh *et al*. (2016b) revealed that gross return (₹ 96 × 10^3 ha^{-1}) of rice was recorded higher under reduced tillage (₹ 96 × 10^3 ha^{-1}) followed by no - tillage (₹ 95.8 × 10^3 ha^{-1}) and conventional tillage (₹ 95.5 × 10^3 ha^{-1}), whereas, net return (₹ 67 × 10^3 ha^{-1}) and B:C ratio (2.34) were recorded maximum under no - tillage than reduce tillage and conventional tillage.

Ramesh *et al*. (2016) noted that lower cost of cultivation was recorded under zero tillage with mulch treatment, whereas, gross and net return and benefit:cost ratio system were recorded significantly higher under conventional tillage with mulch treatment compared to other treatments.

Moharana *et al*. (2017) found that application of nitrogen based LCC 4 was registered significantly the highest return per rupee invested (1.94) and cost of cultivation did not differ appreciably due to various treatments when compared with no N treatments.

Sorokhaibam *et al*. (2017) revealed that significantly higher net return (₹ 39.90 × 10^3 ha^{-1}) and B:C ratio (1.21) were recorded under no – tillage practice compared to conventional tillage practice.

Tripathi *et al*. (2017) noted that conventional tillage system exhibited the maximum cost of cultivation (₹ 93.6 × 10^3 ha^{-1}), gross return (₹ 209.9 × 10^3 ha^{-1}), net return (₹ 116.3 × 10^3 ha^{-1}) compared to other systems under rice based cropping.

Choudhary *et al*. (2018) concluded that cost of cultivation was recorded higher under conventional tillage compared to zero tillage, whereas net return was recorded significantly higher under zero - tillage compared to conventional tillage in rice based cropping system.

2.6 Energetics

Energy use efficiency of cropping system depends on factors likes soil type, tillage operation, fertilizers, plant protection measures, harvesting, threshing, grain and biomass yield (Baishya and Sharma, 1990 and Singh *et al*., 1997).

Silvio *et al*. (2005) observed that the conventional tillage system was recorded highest energy consumer (1.8 GJ ha^{-1}) compared to zero tillage system under rice based cropping system.

Gupta *et al*. (2007) revealed that energy use efficiency and energy productivity were recorded significantly higher under zero tillage practice compared to conventional tillage practice in rice based cropping system.

Parihar *et al*. (2011) found that sowing of maize through zero tillage resulted maximum energy output, energy productivity and net energy compared to conventional tillage under diversified maize based cropping system.

Sharma *et al.* (2011) noted that higher total energy was spent under conventional tillage (5965.6 MJ ha^{-1}) compared to minimum tillage (3918.6 MJ ha⁻

^{1}) and no - tillage (4110.4 MJ ha^{-1}), whereas, no - tillage was required less energy and saved 80 per cent than other treatments.

Bhangare and Deshmukh (2013) reported that the conservation tillage recorded lower input energy (8616.24 MJ ha^{-1}), output energy (5527.60 MJ ha^{-1}) and energy balance (4665.80 MJ ha^{-1}) compared to other tillage combinations.

Kumar *et al*. (2013) observed that the lower energy requirement (13 %) with higher energy output (5 %) of zero tillage was recorded compared to conventional tillage.

Choudhary and Behera (2013) revealed that zero tillage saved 15 - 20 per cent input energy compared to conventional tillage practice. Furthermore, significantly higher energy use efficiency was calculated under zero tillage – zero tillage system compared to conventional tillage – conventional tillage, conventional tillage – zero tillage and zero tillage – conventional tillage system.

Singh *et al*. (2016) stated that no - tillage recorded higher gross and net return energy, energy use efficiency, energy productivity and had 33 per cent less energy requirement as compared to CT.

Yadav *et al*. (2016) reported that the maximum gross output energy (210.1×103 MJ ha^{-1}), energy efficiency (16.4) and energy intensity (8.50 MJ) were recorded under zero tillage compared to conventional tillage planting, respectively. However, all these energy and economics indices are statistically similar in both the conservation agriculture based tillage practices (zero tillage and permanent bed).

Sorokhaibam *et al*. (2017) showed that the higher input energy was consumed by conventional tillage (16.82×10^{3} MJ ha^{-1}) than no - tillage practices and gross energy output of conventional tillage was at par with no - tillage but net energy output was higher under no - tillage.

CHAPTER – III

MATERIALS AND METHODS

The present research entitled "**Conservation agriculture based resource management in rice – maize cropping system"** was carried out during *kharif* and *rabi* seasons of 2016-17 and 2017-18. The details of the materials used and methods adopted during the course of study are summarized under following heads**:**

3.1 Location and Experimental site

The location of the experimental site was Institute Research Farm of ICAR – National Rice Research Institute, Cuttack (Odisha) located between 85^0 55' 48" E to 85^0 56' 48" E longitudes and 20^0 26' 35" N to 20^0 27' 35" N latitudes with the altitude of 24 m above mean sea level. It represents the East and South East Coastal Plains agro – climatic zone of Odisha state. According to planning commission classification, it falls under Eastern Coastal Plains and Hills.

3.2 Climate

Cuttack belongs to eleventh agro climatic zone of India i.e. Eastern Coastal Plains and Hills. The annual rainfall is about 1500 mm out of which 80-85 per cent rainfall comes from south – west monsoon with about 74 rainy days. The maximum monthly mean temperature raises upto 39.5 ^{0}C during summer season and minimum monthly mean temperature falls upto 8 ^{0}C during winter season. The mean soil temperature difference between in summer and winter is >5 ^{0}C.

3.3 Weather conditions

Meteorological data on temperature, rainfall, relative humidity, wind velocity, evaporation and sunshine hour during the cropping period were recorded (standard meteorological week wise) from the Meteorological Observatory, ICAR – National Rice Research Institute (NRRI), Cuttack, Odisha and presented in Appendix I, II, III and IV and illustrated graphically in Fig 3.1, 3.2, 3.3 and 3.4.

3.3.1 Rice (*kharif* 2016 and 2017)

The total rainfall received during the crop growth period of rice was 1177 mm in year 2016 and 1041 mm in year 2017. The rainfall distribution was more uniformity during the first year than the second years of crop growing period. The weekly mean temperature ranged from 16.56 to 26.89 ^{0}C and 16.67 to 27.03 ^{0}C in years 2016 and 2017, respectively. Whereas, weekly mean maximum temperature ranged from 28.97 to 33.20 ^{0}C and 24.07 to 33.01 ^{0}C in years 2016 and 2017, respectively. The weekly mean maximum relative humidity varied from 88.29 to 97.43 per cent and 86.57 to 96.29 per cent during the *kharif* season rice in 2016 and 2017 years, respectively. Whereas, weekly mean minimum relative humidity ranged from 42.29 to 86.57 per cent and 52.86 to 86.29 per cent in years 2016 and 2017, respectively. Data indicated that the first year was comparatively higher humid than the second year during *kharif* season rice. The weekly mean variation of wind velocity ranged from 1.60 to 6.39 km hr^{-1} and 0.54 to 5.30 km hr^{-1} in years 2016 and 2017, respectively. The weekly mean evaporation ranged from 2.17 to 6.09 mm and 1.10 to 4.96 mm in years 2016 and 2017, respectively. The weekly mean sunshine duration was varied from 0.77 to 8.44 hrs in year 2016 and 0.14 to 5.87 in year 2017.

3.3.2 Maize (*rabi* 2016-17 and 2017-18)

The total rainfall received during crop growth period of maize was 55 mm in year 2016 - 17 and 47 mm in year 2017 - 18. The weekly mean temperature ranged from 11.64 to 26.40 ^{0}C and 10.64 to 26.83 ^{0}C in years 2016 - 17 and 2017 - 18, respectively. However, weekly mean maximum temperature ranged from 26.43 to 37.61 ^{0}C and 25.50 to 38.77 ^{0}C in years 2016 - 16 and 2017 - 18, respectively. The weekly mean maximum relative humidity varied from 85.86 to 96.86 per cent and 88.14 to 96.30 per cent in years 2016 - 17 and 2017 - 18, respectively. Furthermore, in years 2016 - 17 and 2017 - 18, weekly mean minimum relative humidity ranged from 40.14 to 66.71 per cent and 31.29 to 88.29 per cent, respectively. The weekly mean variation of wind velocity ranged from 1.43 to 9.06 km hr^{-1} and 0.56 to 11.63 km hr^{-1} in years 2016 - 17 and 2017 - 18, respectively. The weekly mean evaporation ranged from 1.91 to 6.39 mm and 0.97 to 5.44 mm in years 2016 - 17 and 2017 - 18, respectively. The weekly mean sunshine duration was varied from 4.77 to 8.97 hrs in year 2016-17 and 2.89 to 8.51 hrs in year 2017 - 18.

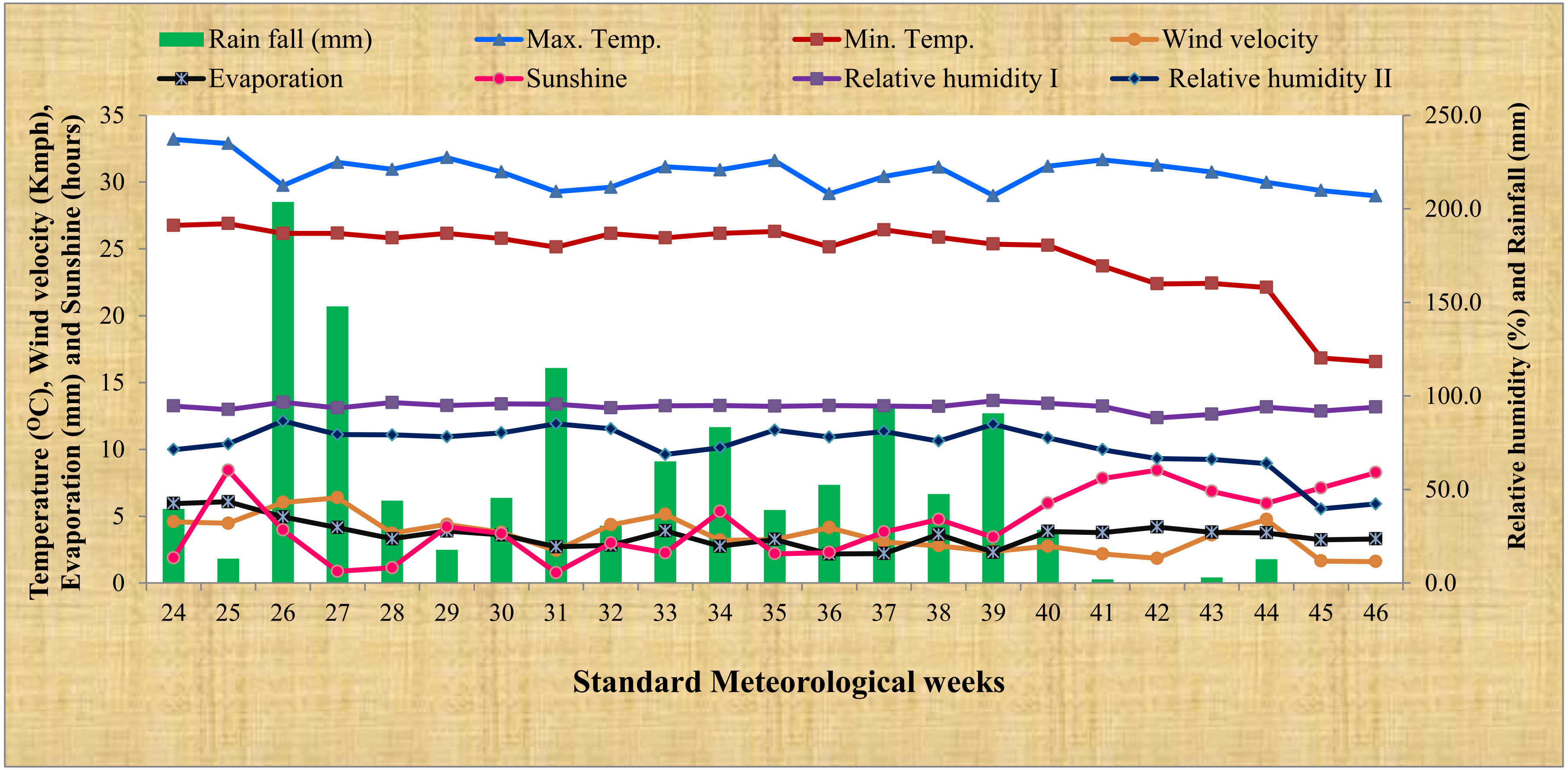


Fig 3.1: Weekly meteorological data recorded during the crop growth period (June 13, 2016 to November 19, 2016)

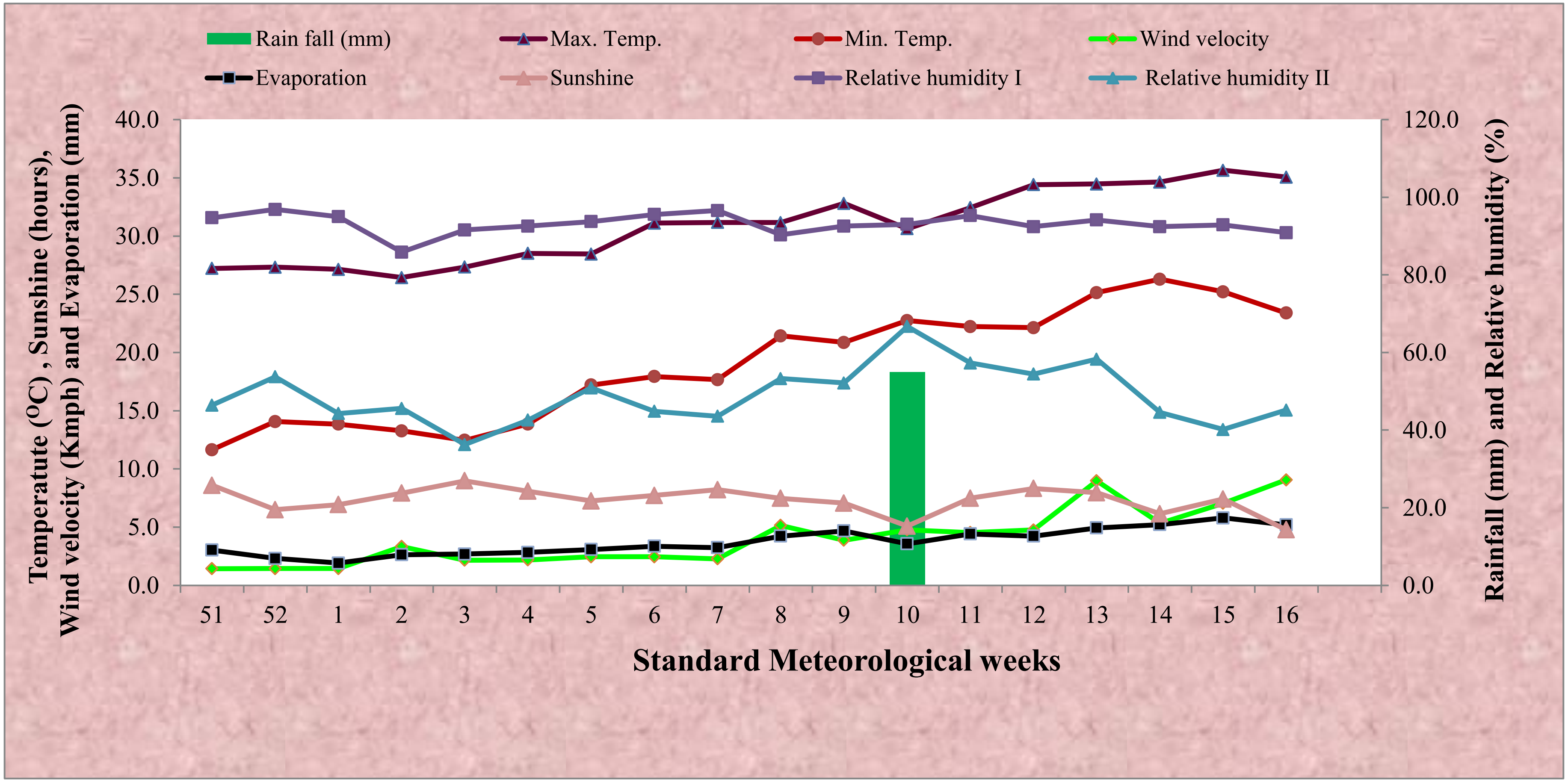


Fig 3.2: Weekly meteorological data recorded during the crop growth period (December 19, 2016 to April 17, 2017)

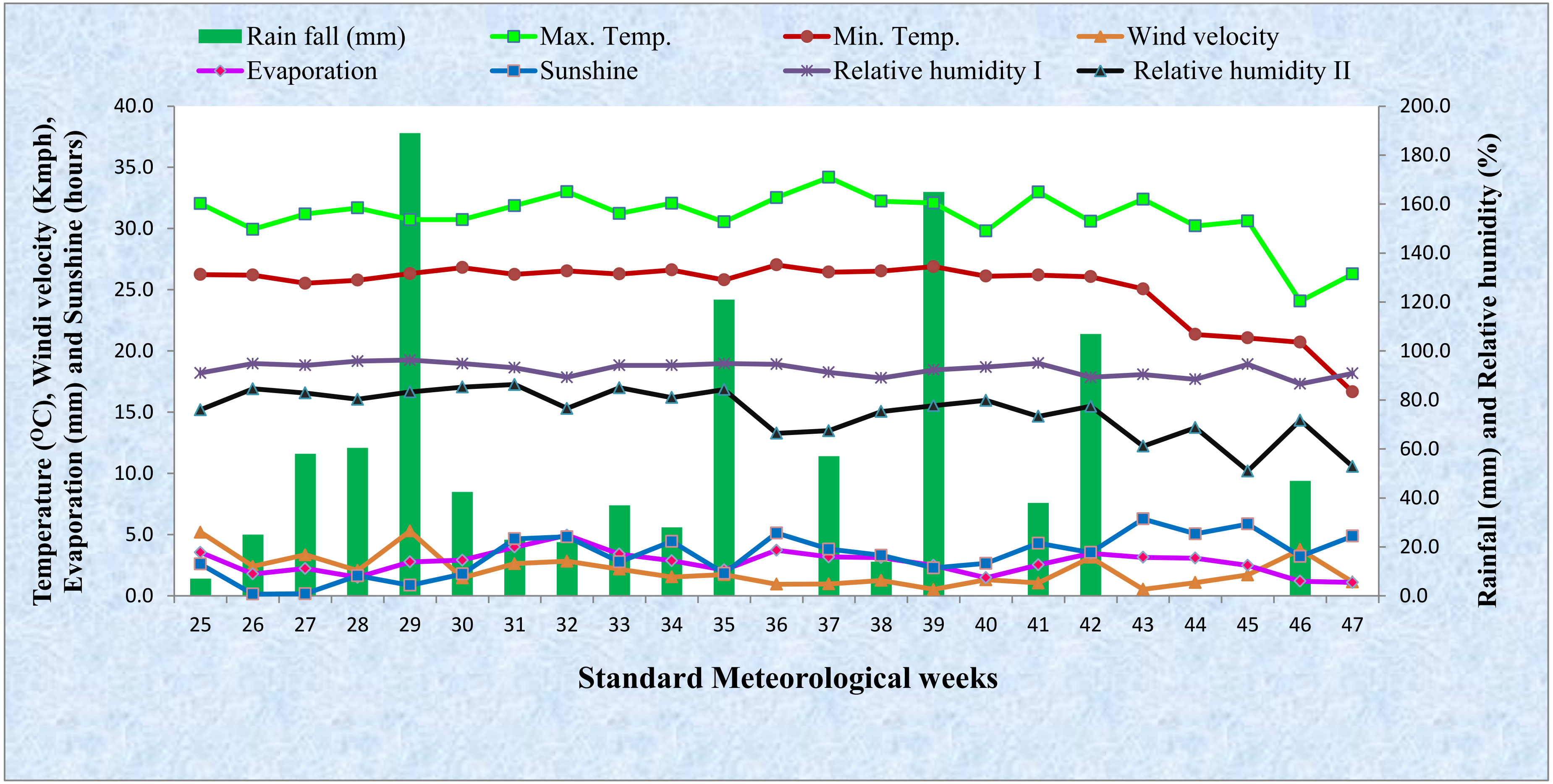


Fig 3.3: Weekly meteorological data recorded during the crop growth period (June 20, 2017 to November 25, 2017)

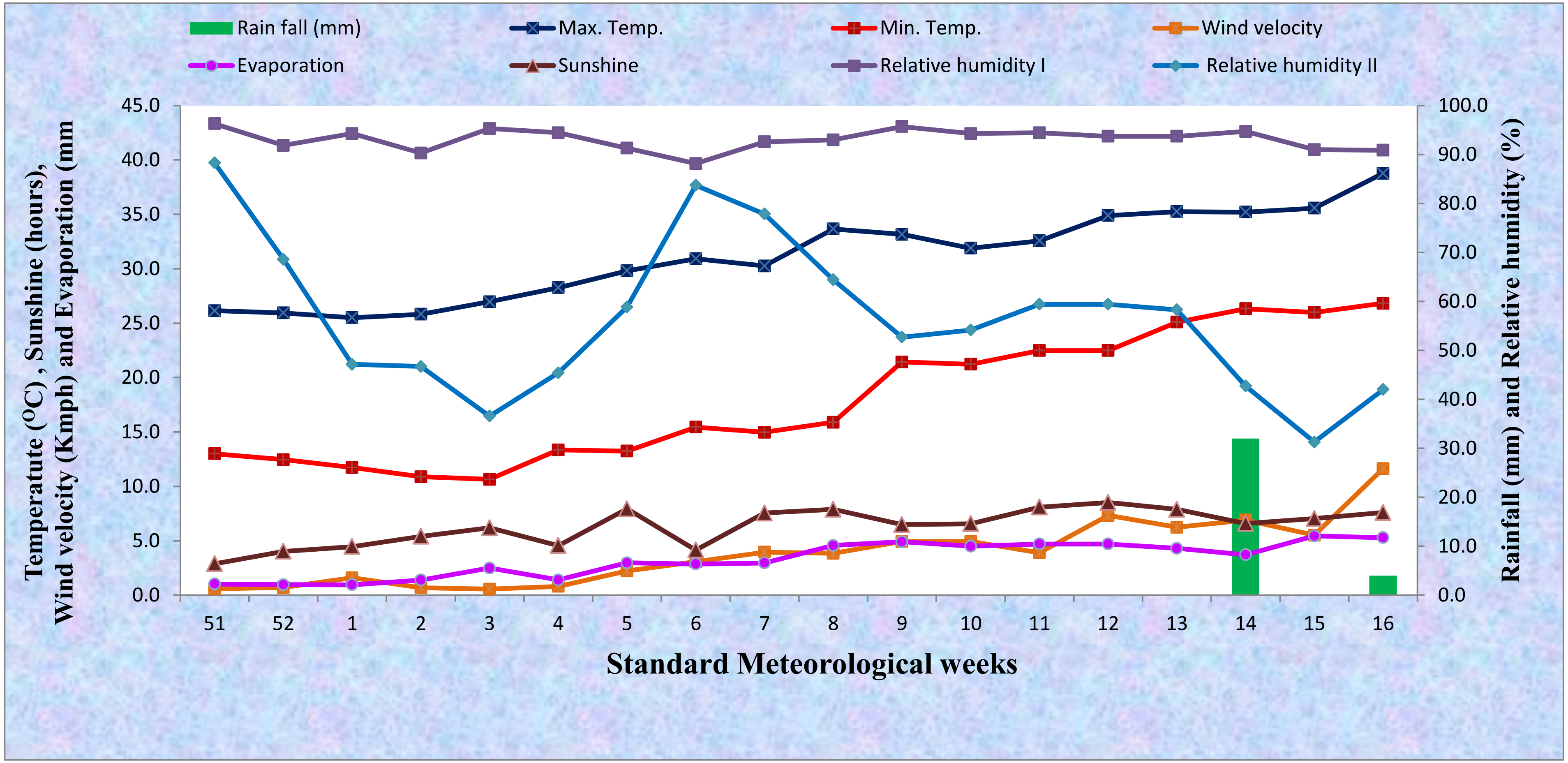


Fig 3.4: Weekly meteorological data recorded during the crop growth period (December 18, 2017 to April 19, 2018)

3.4 Physico – chemical properties of experimental site

Twelve soil samples were taken randomly from experimental plot through with the help of soil auger and composite soil sample was used for analysis of physico – chemical content of soil. The physico – chemical properties of the soil are presented in Table 3.1. The soil was sandy loam with acidic nature (6.31), medium in organic carbon (0.58 %), nitrogen (283 kg ha^{-1}), phosphorus (22.67 kg ha^{-1}) and potassium content (152 kg ha^{-1}).

Table 3.1: Physico – chemical properties of soil of the experimental field

S. No.	Particulars	Values		Class	Method
		2016-17	2017-18		
A.	**Physical properties**				
1.	Mechanical composition				
	Sand (%)	54.87	54.89		International pipette method (Black, 1965)
	Silt (%)	25.08	25.10		
	Clay (%)	20.05	20.01		
2.	Texture class			Sandy loam	
3.	Bulk density (Mg m^{-3})	1.39	1.41		
B.	**Chemical properties**				
1.	Organic Carbon (%)	0.56	0.60	Medium	Walkley Black's rapid titration method (Black, 1965)
2.	Available N (kg ha^{-1})	280	286	Medium	Alkaline permanganate method (Subbiah and Asija, 1965)
3.	Available P_2O_5 (kg ha^{-1})	22.23	23.12	Medium	Olsen's method (Olsen, 1954)
4.	Available K_2O (kg ha^{-1})	150	154	Medium	Flame photometric method (Jackson, 1973)
5.	Soil reaction (pH)	6.30	6.32	Acidic	Glass Electrode pH meter (Piper, 1966)
6.	EC (dsm^{-1})	0.42	0.44	Normal	Solubridge conductivity method (Black, 1965)

3.5 Cropping history

The cropping history of the experimental field of previous five years is given in Table 3.2.

Table 3.2 Cropping history of the field

Years	**Season**	
	***Kharif* season**	***Rabi* season**
2011-12	Rice	Rice
2012-13	Rice	Rice
2013-14	Rice	Maize
2014-15	Rice	Maize
2015-16	Rice	Maize

3.6 Experimental details and Layout

Design	: Split – Split Plot
Replication	: Three
No. of Treatment	: Twelve
Cropping system	: Rice – Maize cropping system
Variety	: Pooja (Rice) and Vijaya-22 (Maize)
Plot size	: 6 m x 4.6 m = 27.60 m2
Spacing	: 20 cm in rice and 60 × 20 cm in maize
Seed rate	: 40 kg ha^{-1} (rice) and 20 kg ha^{-1} (maize)
Date of sowing	: Rice (13.06.2016 and 20.06.2017) and maize (19.12.2016 and 18.12.2017)
Date of harvesting	: Rice (19.11.2016 and 25.11.2017) and maize (17.04.2017 and 19.04.2018)

3.6.1 Treatment details

Main Plot	**: Tillage in Rice and Maize**
T_1	: Conventional Tillage
T_2	: Zero Tillage
Sub plot	**: Residue management in Maize**
R_1	: RDF + No Residue
R_2	: RDF + Residue Mulching (3 t ha^{-1})
R_3	: RDF + Residue Mulching (6 t ha^{-1})
Sub - sub plot	**: Nutrient management in Rice**
$\mathbf{N_1}$	: LCC based (100 % RDN)
$\mathbf{N_2}$	: LCC based (75 % RDN)

Note: This experiment is on – going since past three years at Division of Crop Production, ICAR – National Rice Research Institute, Cuttack (Odisha)

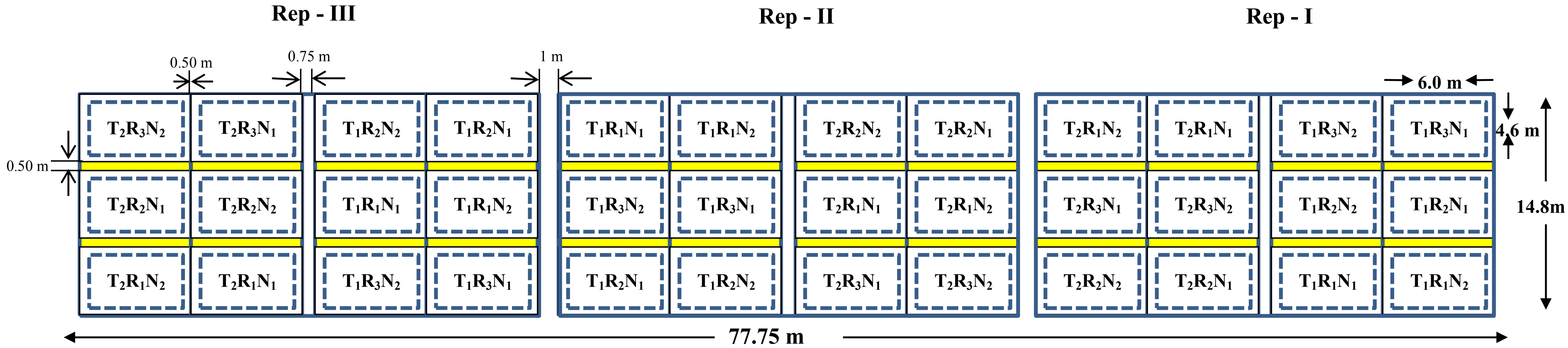
3.6.2 Treatment combinations of the experiment

Rice (*kharif* season, 2016 and 2017)

S. No.	Treatment combination	Treatment details
1	**$KT_1KR_1KN_1$**	Conventional Tillage + (Residual of RDF + No Residue) + LCC based (100 % RDN)
2	**$KT_1KR_1KN_2$**	Conventional Tillage + (Residual of RDF + No Residue) + LCC based (75 % RDN)
3	**$KT_1KR_2KN_1$**	Conventional Tillage + [Residual of RDF + Residue Mulching (3 t ha^{-1})] + LCC based (100 % RDN)
4	**$KT_1KR_2KN_2$**	Conventional Tillage + [Residual of RDF + Residue Mulching (3 t ha^{-1})] + LCC based (75 % RDN)
5	**$KT_1KR_3KN_1$**	Conventional Tillage + [Residual of RDF + Residue Mulching (6 t ha^{-1})] + LCC based (100 % RDN)
6	**$KT_1KR_3KN_2$**	Conventional Tillage + [Residual of RDF + Residue Mulching (6 t ha^{-1})] + LCC based (75 % RDN)
7	**$KT_2KR_1KN_1$**	Zero Tillage + (Residual of RDF + No Residue) + LCC based (100 % RDN)
8	**$KT_2KR_1KN_2$**	Zero Tillage + (Residual of RDF + No Residue) + LCC based (75 % RDN)
9	**$KT_2KR_2KN_1$**	Zero Tillage + [Residual of RDF + Residue Mulching (3 t ha^{-1})] + LCC based (100 % RDN)
10	**$KT_2KR_2KN_2$**	Zero Tillage + [Residual of RDF + Residue Mulching (3 t ha^{-1})] + LCC based (75 % RDN)
11	**$KT_2KR_3KN_1$**	Zero Tillage + [Residual of RDF + Residue Mulching (6 t ha^{-1})] + LCC based (100 % RDN)
12	**$KT_2KR_3KN_2$**	Zero Tillage + [Residual of RDF + Residue Mulching (6 t ha^{-1})] + LCC based (75 % RDN)

Maize (*rabi* season, 2016-17 and 2017-18)

S. No.	Treatment combination	Treatment details
1	**$RT_1RR_1RN_1$**	Conventional Tillage + (RDF + No Residue) + Residual of LCC based (100 % RDN)
2	**$RT_1RR_1RN_2$**	Conventional Tillage + (RDF + No Residue) + Residual of LCC based (75 % RDN)
3	**$RT_1RR_2RN_1$**	Conventional Tillage + [RDF + Residue Mulching (3 t ha^{-1})] + Residual of LCC based (100 % RDN)
4	**$RT_1RR_2RN_2$**	Conventional Tillage + [RDF + Residue Mulching (3 t ha^{-1})] + Residual of LCC based (75 % RDN)
5	**$RT_1RR_3RN_1$**	Conventional Tillage + [RDF + Residue Mulching (6 t ha^{-1})] + Residual of LCC based (100 % RDN)
6	**$RT_1RR_3RN_2$**	Conventional Tillage + RDF + Residue Mulching (6 t ha^{-1})] + Residual of LCC based (75 % RDN)
7	**$RT_2RR_1RN_1$**	Zero Tillage + (RDF + No Residue) + Residual of LCC based (100 % RDN)
8	**$RT_2RR_1RN_2$**	Zero Tillage + (RDF + No Residue) + Residual of LCC based (75 % RDN)
9	**$RT_2RR_2RN_1$**	Zero Tillage + [RDF + Residue Mulching (3 t ha^{-1})] + Residual of LCC based (100 % RDN)
10	**$RT_2RR_2RN_2$**	Zero Tillage + [RDF + Residue Mulching (3 t ha^{-1})] + Residual of LCC based (75 % RDN)
11	**$RT_2RR_3RN_1$**	Zero Tillage + [RDF + Residue Mulching (6 t ha^{-1})] + Residual of LCC based (100 % RDN)
12	**$RT_2RR_3RN_2$**	Zero Tillage + [RDF + Residue Mulching (6 t ha^{-1})] + Residual of LCC based (75 % RDN)



Experimental Detail:

A. **Tillage in rice and maize (Main plot)**
   - KT_1 - Conventional Tillage
   - KT_2 - Zero Tillage

B. **Residual of residues in maize (Sub plot)**
   - KR_1- RDF + No residue
   - KR_2 - RDF + Residue Mulching (3 t ha^{-1})
   - KR_3 - RDF + Residue Mulching (6 t ha^{-1})

C. **Nutrient management in rice (Sub – sub plot)**
   - KN_1 – LCC based (100 % RDN)
   - KN_2 – LCC based (75 % RDN)

Note: This experiment is on – going since past three years at Division of Crop Production, ICAR – National Rice Research Institute, Cuttack (Odisha)

Design	: Split-split Plot
Treatment	: 12
Replication	: 03
Gross Plot	: 6.0 × 4.6 m = 27.60 m^2
Net Plot (rice)	: 5.2 × 4.2 m = 21.84 m^2
Spacing	
Rice	: 20 cm (line)
Rep	: 1 m
Main plot	: 0.75 m
Sub plot	: 0.50 m
Sub – sub plot	: 0.50

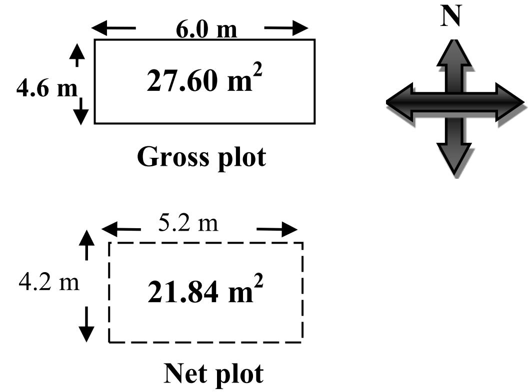
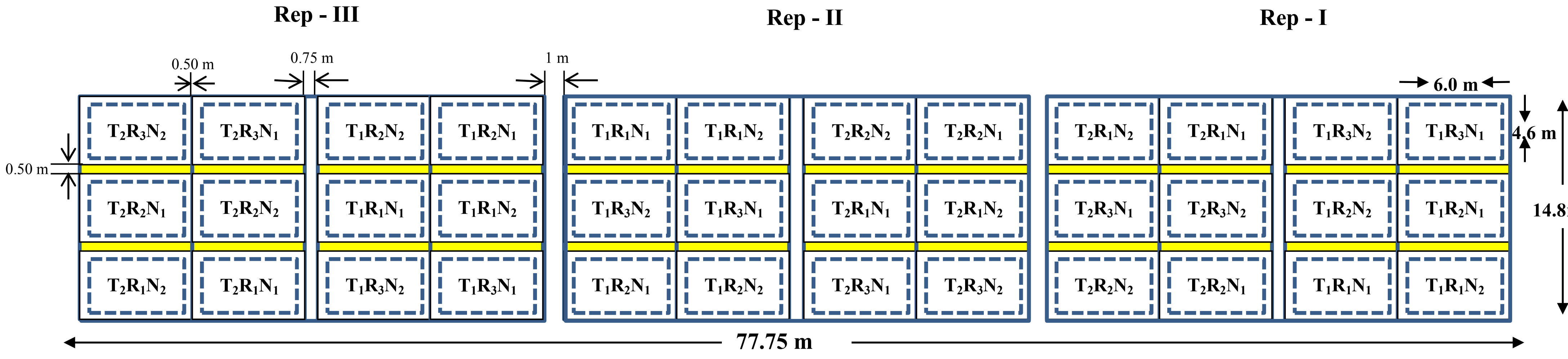


Fig 3.5: The layout plan and other details of *kharif* season of rice (2016 and 2017)



Experimental Detail:

A. Tillage in rice and maize (Main plot)

RT_1 - Conventional Tillage

RT_2 - Zero Tillage

B. Residue management in maize (Sub plot)

RR_1- RDF + No residue

RR_2 - RDF + Residue Mulching (3 t ha^{-1})

RR_3 - RDF + Residue Mulching (6 t ha^{-1})

C. Residual of nutrient management in rice (Sub – sub plot)

RN_1 – LCC based (100 % RDN)

RN_2 – LCC based (75 % RDN)

Note: This experiment is on – going since past three years at Division of Crop Production, ICAR – National Rice Research Institute, Cuttack (Odisha)

Design	**:** Split-split Plot
Treatment	**:** 12
Replication	: 03
Gross Plot	: 6.0 × 4.6 m = 27.60 m^2
Net Plot	**:** 4.2 × 3.6 m = 15.12 m^2
Spacing	
Maize	**:** 60 cm × 20 cm
Rep	: 1 m
Main plot	: 0.75 m
Sub plot	: 0.50 m
Sub – sub plot	: 0.50

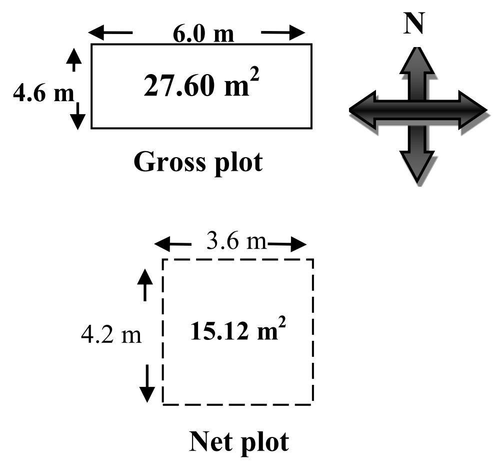


Fig 3.6: The layout plan and other details of *rabi* season of maize (2016-17 and 2017-18)

3.7 Test crop

Rice

A late duration (150 days), 'Pooja (CR – 629 – 256)' variety was taken as a test variety. The cultivar has been short height (90 – 95), having medium slender grains and gives an average of 5.0 t ha^{-1}. It possesses tolerance to all major insects – pests with also tolerates water stagnation (upto 25 cm).

Maize

Maize hybrid 'Vijaya – 22' was used as a test variety. It was developed by Sansar Agropol private limited, Bhubaneswar (Odisha). Vijaya – 22 is suitable for *rabi* season with medium maturity and high stable yield and is responsive to fertilizer application at medium and high levels. Average yield of the hybrid is 70 – 72 q ha^{-1}.

3.8 Field operation

The cultural practice carried out in rice and maize during the course of experimentation period has been given in Table 3.3.

3.8.1 Rice

3.8.1.1 Land preparation

The experiment field was prepared as per the different tillage practice treatments. Under conventional tillage, the field was ploughed twice power tiller followed by planking. No additional tillage practice was implemented in the zero tillage plots.

3.8.1.2 Fertilizer application

A fertilizer dose of 80 kg nitrogen, 40 kg phosphorus and 40 kg potassium ha^{-1} was applied to rice as per the treatments. Full amount of phosphorus and potassium and 25 per cent of nitrogen were applied as basal and remaining nitrogen was applied as top dressing through leaf colour chart at weekly interval.

3.8.1.3 Sowing and seed treatment

Rice seed was treated with carbendazim @ 2.5 g kg^{-1} seed and sown in each plot. Seeds were covered with thin layer of the soil and a seed rate @ 40 kg ha^{-1}.

3.8.1.4 Weed management

The weeds were managed by pre – emergence spray of pendimethalin (1.0 kg a.i. ha^{-1}), post – emergence spray of bispyribac sodium (25 g a.i. ha^{-1}) at 15 DAS and hand weeding at 45 DAS.

3.8.1.5 Water management

After sowing, immediately light irrigation was applied for uniform germination. Total 4 and 6 irrigations were applied to rice during 2016 and 2017, respectively and about 6 cm of water was applied to the rice crop in each of the irrigations.

3.8.1.6 Harvesting, threshing and winnowing

The rice crop was harvested at maturity when more than 80 per cent of the grains had ripened by using sickle. The harvested material of each plot was tied up in bundles, tagged and kept on threshing floor for sun drying. After sun drying, the bundles were weighed separately net plot wise to record biological yield, then threshed manually. The threshed material was kept separately as per the treatments and grain was separated from the chaff and straw by winnowing after this the clean grains were weighed.

3.8.2 Maize

3.8.2.1 Land preparation

The field was prepared equally with the help of power tiller. The individual plot in conventional tillage (CT) was prepared with two passes of power tiller followed by planking, whereas tillage not required in the zero tillage plots.

3.8.2.2 Fertilizer application

The dose of fertilizers i.e. 150:50:50 kg ha^{-1} of nitrogen, phosphorus and potassium were applied in maize, respectively. Urea, single super phosphate and muriate of potash (MOP) were calculated and applied treatment wise. Half dose of nitrogen and full dose of phosphorus and potassium were applied as basal. Remaining half nitrogen was top dressed in two equal splits at knee height and tasseling stages.

Table 3.3 Calendar of operations for *kharif* and *rabi* season crops

S. N.	Operation	Date of operation	
A.	**Wet season crop : Rice (*kharif* 2016 and 2017)**	**2016**	**2017**
1	Layout of the experiment	Fixed	Fixed
2	Site specific application of glyphosate in zero tillage plots	01.06.2016	05.06.2017
3	Field preparation	10.06.2016	19.06.2017
4	Application of basal dose of fertilizers	13.06.2016	20.06.2017
5	Seed treatment and Sowing of the crop	13.06.2016	20.06.2017
6	Pre-emergence herbicide spray (Pendimethalin)	15.06.2016	23.06.2017
7	Post - emergence herbicide spray (Bispyribac sodium)	28.06.2016	05.07.2017
8.	Hand weeding	11.07.2016	25.07.2017
9.	Come-up irrigation	14.06.2016	21.06.2017
	1st irrigation	21.07.2016	16.08.2017
	2nd irrigation	23.08.2016	07.09.2017
	3rd irrigation	14.10.2016	23.09.2017
	4th irrigation	21.10.2016	03.10.2017
	5th irrigation	-	16.10.2017
	6th irrigation	-	28.10.2017
10.	Harvesting	19.11.2016	25.11.2017
11.	Threshing and winnowing	22.11.2016	30.11.2017
A.	**Dry season crop : maize (*rabi* 2016-17 and 2017-18)**	**2016-17**	**2017-18**
1.	Layout of the experiment	Fixed	Fixed
2.	Site specific application of glyphosate in zero tillage plots	09.12.2016	07.12.2017
3.	Field preparation	17.12.2016	16.12.2017
4.	Application of basal dose of fertilizers	19.12.2016	18.12.2017
5.	Seed treatment and Sowing of the crop	19.12.2016	18.12.2017
6.	Pre-emergence herbicide spray (Atrazine)	21.12.2016	20.12.2017
7.	Gap filling	14.01.2017	16.01.2018
8.	Hand weeding on non-mulching plots	20.01.2017	19.01.2018
9.	Residue mulching	27.01.2017	26.01.2018
10.	Come-up irrigation	20.12.2016	19.12.2017
	1st irrigation	11.01.2017	13.01.2018
	2nd irrigation	21.01.2017	25.01.2018
	3rd irrigation	04.02.2017	03.02.2018
	4th irrigation	18.02.2017	13.02.2018
	5th irrigation	04.03.2017	24.02.2018
	6th irrigation	17.03.2017	07.03.2018
	7th irrigation	27.03.2017	15.03.2018
	8th irrigation	-	24.03.2018
	9th irrigation	-	02.04.2018
11.	Application of N		
	Knee height stage	14.01.2017	13.01.2018
	Tasseling stage	20.02.2017	22.02.2018
12.	Harvesting	17.04.2017	19.04.2018
13.	Threshing and winnowing	24.04.2017	27.04.2018

3.8.2.3 Seed rate and spacing

Maize was sown by manual methods in conventional tillage and zero tillage treatments keeping spacing of 60 × 20 cm. The seed rate of maize @ 20 kg ha^{-1} was used for sowing.

3.8.2.4 Gap filling

Gap filling was accomplished during both the years to maintain optimum plant population.

3.8.2.5 Mulching

Rice straw was spread uniformly as mulch based on treatment required. Air dried rice straw covered in the inter row space after one week of sowing.

3.8.2.6 Weed management

Atrazine (50 WP) as a pre – emergence herbicide @ 1.0 kg a.i. ha^{-1} in 500 liters of water was applied at 2 DAS and hand weeding at 30 DAS.

3.8.2.7 Irrigation

Irrigation was given immediately after sowing for ensure proper germination and plant stand. Irrigation was scheduled on basis of crop water requirement and duration of dry spell or period without rainfall and adequate drainage facility was provided by making drainage channel in the field.

3.8.2.8 Harvesting, threshing and winnowing

The harvesting of maize was done by plucking method and grains were separated from cob by hand sheller. Grains were cleaned and weighed from each net plot and yield was expressed in t ha^{-1}. Later the grains were sun dried upto 14 per cent moisture content of grains and the stover yield was recorded after sun drying of stover to a constant weight.

3.9 Observations recorded

3.9.1 Rice

3.9.1.1 Plant population (No. m^2)

Plant population one metre row length at 30 DAS was counted from five randomly spots in each plot and converted into m^{-2}.

3.9.1.2 Plant height (cm)

Plant height was recorded at 30, 60, 90 and 120 DAS from 5th row five plants randomly selected and marked in the plot. Plant height was measured from ground level to tip from the longest leaf and expressed in cm.

3.9.1.3 Dry matter accumulation (g m^{-2})

Dry weight was recorded at 30, 60, 90, 120 DAS and at harvest from 25 cm row length of the second row of plant. After cutting of plants, sun dried for 2 – 3 days and oven dried at 60 ± 2 ^{0}C for 24 hours. Than dry plant was weighed and converted into g m^{-2}.

3.9.1.4 Chlorophyll content (SPAD value)

Chlorophyll content of leaf was measured with the SPAD meter (soil and plant analytical development) at 30, 60, 90 and 120 DAS.

3.9.1.5 Number of effective tillers m^{-2}

The numbers of effective tillers (ear bearing tillers) were counted from the one metre row length randomly selected five spots in every plot, averaged and converted into number of effective tillers m^{-2} area.

3.9.1.6 Number of grains panicle^{-1}

The number of grains panicle^{-1} was counted from the randomly selected ten panicles in each plot and their average was computed.

3.9.1.7 Panicle length (cm)

Panicle length was measured from randomly selected ten panicles in each plot. The length was measured from neck to tip of the apical grains and average length of panicle was determined.

3.9.1.8 Panicle weight (g)

The panicle weight was measured from randomly selected ten panicles in each plot and average panicle weight was computed.

3.9.1.9 Sterility percentage

The number of filled and unfilled grains panicle^{-1} was counted from selected randomly ten panicles and sterility percentage was computed with the following formula:

$$\text{Sterility percentage} = \frac{\text{No. of unfilled granis panicle}^{-1}}{\text{Total number of grains panicle}^{-1}} \times 100$$

3.9.1.10 Test weight (g)

The 1000 filled grains were counted from seed samples taken from grain yield of each plot separately by manual method and same were dried in oven at 60 ^{0}C to constant weight, thereafter, weighed to compute the test weight (g).

3.9.1.11 Grain and straw yield (t ha^{-1})

After harvesting of the rice, the produce of the net plot was tied in bundles and weighed to determine the total biomass yield. The clean grain obtained after threshing and winnowing separately treatment wise, thereafter, grain yield was weighed. Straw yield was achieved by deducting grain yield from the total biomass yield. Yield was expressed in t ha^{-1}.

3.9.1.12 Harvest index (%)

Harvest index was computed by using the following formula.

$$\text{Harvest index (\%)} = \frac{\text{Economical yield (t ha}^{-1}\text{)}}{\text{Biological yield (t ha}^{-1}\text{)}} \times 100$$

3.9.2 Maize

3.9.2.1 Plant height (cm)

The plant height was measured with the help of meter scale at 30, 60, 90 DAS and at harvest stage from five randomly selected plants in each plot. The plant height measured from the ground surface to the tip of the newly emerge leaf.

3.9.2.2 Number of leaves plant^{-1}

The numbers of green leaves were counted at 30, 60, 90 DAS and at harvest in maize from five randomly selected plants in each plot and the average number of green leaves plant^{-1} was worked out by taking mean.

3.9.2.3 Chlorophyll content (SPAD value)

Chlorophyll content of leaf was measured with the SPAD meter (soil and plant analytical development) at 30, 60 and 90 DAS.

3.9.2.4 Dry matter accumulation (g m^{-2})

Randomly selected two plants were taken from the second row in every plot and cut simply over the ground level with the help of sickle. The sampled plants were dried in hot air oven at 60 ^{0}C for 24 hours and the sampled accomplished a consistent weight and weighed at 30, 60, 90 DAS and at harvest at harvest and converted into g m^{-2}.

3.9.2.5 Number of cobs m^{-2}

The number of cobs per metre row length was counted from five randomly spots in each plot and converted into m^{-2}.

3.9.2.6 Cob length (cm)

Five cobs were randomly selected from each plot at time of harvesting and their length was measured from the base of the lower primary rachis to tip of the cob and the average value was recorded as cob length in cm.

3.9.2.7 Cob girth (cm)

The cob girth was measured at the middle portion of the cob from five cobs randomly selected in each plot and the average value was recorded as cob girth/diameter in cm.

3.9.2.8 Number of grains cob^{-1}

The total number of grains from randomly selected five cobs were counted and averaged out to get number of grain cob^{-1}.

3.9.2.9 Weight of grains cob^{-1}

The weight of grains from randomly selected five cobs was recorded and then average was worked out as weight of grains cob^{-1} in gram.

3.9.2.10 Shelling percentage

Cob weight was recorded from previously randomly selected five cobs after removing husks and silks and grain weight was taken after shelling separately. The shelling percentage was computed with the help of following formula:

$$\text{Shelling \%} = \frac{\text{Weight of grains}}{\text{Weight of whole cob}} \times 100$$

3.9.2.11 Test weight (g)

The weight of 100 grains was weighed from the representative samples of each plot yield and expressed in gram. The seeds were weighed on electronic balance.

3.9.2.12 Grain and stover yield (t ha^{-1})

The cobs from each net plot were shelled and grain weight was recorded. It was reported in kg ha^{-1} and then converted into t ha^{-1}. The maize stalks were cut from ground level from the net plot and weighed after sun drying. Final yield was expressed in t ha^{-1}.

3.9.2.13 Harvest index (%)

Harvest index was calculated by dividing the grain yield by the total biological yield and expressed in percentage.

$$\text{Harvest index (\%)} = \frac{\text{Economical yield (t ha}^{-1}\text{)}}{\text{Biological yield (t ha}^{-1}\text{)}} \times 100$$

3.10 Crop growth indices

3.10.1 Leaf area index (LAI)

Leaf area index (LAI) was computed for different durations with the help of the formula as suggested by Evans (1972). Leaf area index is computed by dividing leaf surface by the ground area occupied by the plant.

$$\text{LAI} = \frac{\text{Total leaf area (cm}^2\text{)}}{\text{Ground area (cm}^2\text{)}}$$

3.10.2 Crop growth rate (g m^{-2} day^{-1})

The dry matter accumulation data recorded at different durations were used to calculate the crop growth rate (CGR) with the help of the following formula (Watson *et al*., 1952):

$$\text{CGR (g m}^{-2}\text{ day}^{-1}\text{)} = \frac{w_2 - w_1}{t_2 - t_1}$$

Where, W_1 and W_2 are dry weight (g) of plants. T_1 and T_2 are the time interval in days.

3.10.3 Relative growth rate (mg mg^{-1} m^{-2} day^{-1})

The dry matter accumulation data recorded at different durations were also used to compute the relative growth rate (RGR). The relative growth rate was calculated with the following formula (Watson *et al*., 1952).

$$\text{RGR (mg mg}^{-1}\text{ m}^{-2}\text{ day}^{-1}\text{)} = \frac{\log_e w_2 - \log_e w_1}{t_2 - t_1}$$

Where, W_1 and W_2 are dry weight (g) of plants and T_1 and T_2 are the time interval in days.

3.10.4 System productivity

System productivity of rice – maize cropping system was calculated in term of rice equivalent yield (REY) by using following formula:

$$\text{REY of maize} = \frac{\text{Maize yield} \times \text{Maize price}}{\text{Rice price}}$$

System productivity = Rice yield + REY of maize

3.10.5 Production efficiency

Production efficiency was calculated with the help of following formula given by Tomar and Tiwari (1990):

$$\text{Production efficiency (kg ha}^{-1}\text{day}^{-1}) = \frac{\text{Grain yield (kg ha}^{-1})}{\text{Duration of the crop}}$$

3.10.6 Partial factor productivity (kg kg^{-1})

Partial factor productivity was obtained by dividing grain yield by the applied nutrient and computed following formula:

$$\text{Partial factor productivity} = \frac{\text{Grain yield (kg ha}^{-1})}{\text{Amount of nutrient applied (kg ha}^{-1})}$$

3.11 Plant chemical analysis

Plant samples were collected at harvest and dried in hot air oven at 60 ± 2 ^{0}C for 6 hours. The dried samples of plants and grains were ground to pass through 40 mesh sieve in a Macro Wiley Mill. 0.5 g of grain and straw sample from each plot was taken for chemical analysis to determine the nitrogen, phosphorus and potassium content.

3.11.1 Nitrogen content (%) and uptake (kg ha^{-1})

Nitrogen content in grain and straw/stover was estimated by using Kjeldahl method and nitrogen uptake was computed by using the following formula:

Nitrogen uptake (kg ha^{-1}) in grain/straw = [nitrogen content in grain/straw × grain/straw yield (q ha^{-1})]

Total nitrogen uptake (kg ha^{-1}) = Nitrogen uptake in grain + nitrogen uptake in straw

3.11.2 Phosphorus content (%) and uptake (kg ha^{-1})

Phosphorus content in grain and straw/stover was estimated by vanado molybdate phosphoric acid yellow colour method and phosphorus uptake was calculated by following expression:

Phosphorus uptake (kg ha^{-1}) in grain/straw = [Phosphorus content in grain/straw × grain/straw yield (q ha^{-1})]

Total phosphorus uptake (kg ha^{-1}) = Phosphorus uptake in grain + nitrogen uptake in straw

3.11.3 Potassium content (%) and uptake (kg ha^{-1})

Potassium content in grain and straw/stover was determined by flame photometer and potassium uptake was calculated by using the following formula:

Potassium uptake (kg ha^{-1}) in grain/straw = [potassium content in grain/straw × grain/straw yield (q ha^{-1})

Total potassium uptake (kg ha^{-1}) = Potassium uptake in grain + nitrogen uptake in straw

3.11.4 Protein content (%) and protein yield (kg ha^{-1})

The protein content was computed by multiplying the respective nitrogen content of grain by the constant of 6.25 and then protein yield was worked out using the following formula:

Protein yield (kg ha^{-1}) = Grain yield (q ha^{-1}) × Protein content in grain

3.12 Weed observation and computations

3.12.1 Weed population species wise (No. m^{-2})

Weed associated with rice and maize in the each plot was recorded at different durations. Species wise weed counted with help of quadrate (0.25 m^{2}) four randomly selected spots in each plot. The number of weeds was counted and computed m^{-2} for statistical analysis. Weed population was transformed through square root method i.e. $\sqrt{x}$ +0.5 before statistical analysis.

3.12.2 Weed dry weight species wise (g m^{-2})

Weed dry weight in rice and maize was recorded at different durations. Weeds present in quadrate (0.25 m^{-2}) were uprooted carefully and the root portion detached and their shoot portion of the weeds were oven dried at 60 ^{0}C for 48 hours. After oven drying, the weight was recorded on electronic balance and converted into g m^{-2}. Weed dry matter of weeds was transformed through square root method i.e. $\sqrt{x + 0.5}$ before statistical analysis.

3.13 Soil properties

3.13.1 Physical properties

3.13.1.1 Bulk density (Mg m^{-3})

Bulk density of soil was calculated by the core sampler method from three randomly selected spots in each plot. The method for determining bulk density was followed as described by Chopra and Kanwar (1991).

3.13.1.2 Soil penetration resistance (MPa)

Soil penetrometer resistance (SPR) was measured in different soil layers at the physiological maturity stage of rice and tasseling stage of maize during crop season using penetrologger. The penetration reading from five randomly selected places within each plot was taken by penetrologger. Simultaneously, soil samples were also collected from the same depths for determination of soil moisture.

3.13.2 Chemical properties

3.13.2.1 pH

The pH of the soil was measured by taking soil and water in 1:2 ratio i.e. 10 g soil was taken and 20 ml of water added to it. The solution was mixed properly and left for some times. Then sample measured the soil pH using a pH meter.

3.13.2.2 Soil carbon fractions

A labile carbon fraction like i.e. soil microbial biomass carbon (MBC) was estimated by using modified chloroform fumigation extraction method (Witt *et al.*, 2000). Furthermore, readily mineralizable carbon (RM) content measured by using 0.5 M K_2SO_4 (Inubushi *et al.*, 1991) followed by wet digestion with dichromate (Vance *et al.*, 1987). Acid hydrolysable carbohydrate carbon (AHC) was determined through the procedure of Haynes and Swift (1990). Permanganate oxidizable carbon ($KMnO_4$ C) was determined by using the method given by Blair *et al.* (1995). Soil oxidizable organic carbon was estimated with help of Walkley and Black (1934) method. Total organic carbon (TOC) was determined by using method oxidation with potassium dichromate and titration with ferrous ammonium sulphate (Bao, 2000).

3.13.2.3 Soil nitrogen (N) fractions

The available nitrogen was determined by using alkaline $KMnO_4$ method proposed by Subbiah and Asija (1956) and expressed in kg ha^{-1}. Microbial biomass nitrogen (MBN) was estimated through the fumigation extraction method by Brookes *et al*. (1985). Ammonium nitrogen (NH_4^+ N) in the soil was estimated by nesslerization method (Jackson, 1973) and nitrate nitrogen (NO_3^- N) through 2, 4-phenol disulphonic acid method (Bremner, 1965). Total nitrogen was determined as per standard procedure (Nayak *et al*., 2016). Take 1 g dry soil sample add 2 -3 g digestion mixture and 10 ml of concentration H_2SO_4 set the digestion system attain the temperature 300 ^{0}C and then place the digestion tube to heating unit raise the temp 400 ^{0}C and continue to digestion upto 4 hours. After the 4 hours remove the tube and keep the digestion tube in the digestion unit set the programme with 40 per cent NaOH and 4 per cent boric acid into conical flask kept below the NH_3 outlet then titrate with 0.1 N H_2SO_4 till developed of a light purple colour which is end point.

3.13.2.4 Available P and K (kg ha^{-1})

The soil samples were dried ground and passed through 2 mm mesh sieve and analysed to determination of available P and K. The available P in soil was estimated through Olsen's method (Olsen, 1954) and available K was determined by neutral normal ammonium acetate extraction (Flame photometer) method described by Jackson (1973).

3.14 Economic analysis

The economic analysis in terms of gross return, net return and benfit:cost ratio (B:C ratio) was calculated according to the existing rate of inputs and output. The production of crop was converted into gross return on basis of prevailing market prices and net return computed by subtraction the gross return from the cost of cultivation. Benefit: cost ratio was calculated by dividing net return by the cost of cultivation. The cost of cultivation, gross and net return of cropping system was determined by adding the inputs and outputs respective values under individual crops. Return was calculated with help of following formula:

Gross return = value of the grain + value of straw/stover

Net return = Gross return – Total cost

Benefit: cost ratio = Net return/Total variable cost

3.15 Energetics

Energy inputs were estimated in Mega Joule (MJ) ha^{-1} with reference to the standard values described by Mittal *et al.* (1985). These inputs were taken to each treatment of rice and maize crop. The standard energy coefficient for seed and straw of rice and maize were multiplied with their respective yields and summed upto obtain total energy output. Energy use efficiency and energy productivity were computed as per the following formula:

Net energy (MJ) = Energy output (MJ ha^{-1}) – Energy input (MJ ha^{-1})

$$\text{Energy output – input ratio} = \frac{\text{Energy output (MJ ha}^{-1}\text{)}}{\text{Energy input (MJ ha}^{-1}\text{)}}$$

$$\text{Energy productivity (kg MJ ha}^{-1}\text{)} = \frac{\text{Grain yield (kg ha}^{-1}\text{)}}{\text{Energy input (MJ ha}^{-1}\text{)}}$$

$$\text{Energy intensity in economic term (MJ ₹}^{-1}\text{)} = \frac{\text{Total energy output (MJ ha}^{-1}\text{)}}{\text{Total cost incurred (₹ ha}^{-1}\text{)}}$$

$$\text{Specific Energy (MJ kg}^{-1}\text{)} = \frac{\text{Energy input (MJ ha}^{-1}\text{)}}{\text{Yield of crop (kg ha}^{-1}\text{)}}$$

$$\text{Energy intensity in physical term (MJ kg}^{-1}\text{)} = \frac{\text{Energy input (MJ ha}^{-1}\text{)}}{\text{Total production (kg ha}^{-1}\text{)}}$$

3.16 Statistical analysis

The statistical analysis of data collected on different parameters of rice and maize was conducted in split – split plot design, respectively as described by Gomez and Gomez (1984). The data recorded on weed density and their dry weight was transformed by using square root before analysis to normalize their distribution. Standard error of means (SEm) and critical difference (C.D.) at 5 per cent level were calculated for each character studied to evaluate difference between means. The analysis of variance table (ANOVA) for experiment was drawn as following formula (Table 3.5).

Table 3.5: ANOVA table for split plot design

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	Computed F value	Tabular t-value 5 %
Main plot analysis					
1. Replication	(r-1)	RSS	RMS = RSS/(r-1)	AMS/E(a)MS	
2. Main plot factor (A)	(a-1)	ASS	AMS= ASS/(a-1)		
3. Error (a)	(r-1) (a-1)	E(a)SS	E(a)MS= E(a)SS/(r-1) (a-1)		
Sub plot analysis					
4. Sub plot factor (B)	(b-1)	BSS	BMS= BSS/(b-1)	BMS/E(b)MS	
5. A×B	(a-1) (b-1)	AB SS	AB MS= AB SS/(a-1) (b-1)	AB MS/E(b)MS	
6. Error (b)	a(r-1)(b-1)	E(b)SS	E(b)MS= E(b)SS/a(r-1)(b-1)		
Sub – sub analysis					
7. Sub-sub plot factor (C)	(c-1)	CSS	CMS= CSS/(c-1)	CMS/E(c)MS	
8. A×C	(a-1)(c-1)	ACSS	ACMS= ACSS/(a-1)(c-1)	ACMS/ E(c)MS	
9. B×C	(b-1)(c-1)	BCSS	BCMS= BCSS/(b-1)(c-1)	BCMS/ E(c)MS	
10. A×B×C	(a-1)(b-1)(c-1)	ABCSS	ABCMS= ABCSS/(a-1)(b-1)(c-1)	ABCMS/ E(c)MS	
11. Error(C)	Ab(r-1)(c-1)	E(c)SS	E(c)MS= E(c)SS/ab(r-1)(c-1)		

$$\text{CV (a), \%} = \frac{\sqrt{E(a)MS}}{Grand\ mean} \times 100$$

$$\text{CV (b), \%} = \frac{\sqrt{E(b)MS}}{Grand\ mean} \times 100$$

$$\text{CV (c), \%} = \frac{\sqrt{E(c)MS}}{Grand\ mean} \times 100$$

CHAPTER – IV

RESULTS AND DISCUSSION

The results of the field experiments entitled **"Conservation agriculture based resource management in rice – maize cropping system"** conducted during *kharif* and *rabi* seasons of 2016-17 and 2017-18 at Institute Research Farm of National Rice Research Institute, Cuttack (Odisha) are being presented in this chapter. The observations pertaining to growth parameters, yield attributes, yield, nutrient uptake, economics, energetic and physico – chemical parameters of soil in rice and maize recorded during experimentation was statistically analysed and significance of results verified. The findings of the experiment are presented in tables, graphics and interpretations made of only significant findings on the basis of statistical analysis. Also the findings have been supported with proper reasoning along with research work of others.

4.1 Studies on rice (*kharif* 2016 and 2017)

4.1.1 Pre – harvest observations

4.1.1.1 Plant population (No. m^{-2})

The data on plant population of rice at 30 DAS as influenced by tillage practices in rice, residual of residues in maize and nitrogen management in rice are presented in Table 4.1.

The results revealed that the effect of tillage practices in rice, residual of residues in maize and nitrogen management in rice as well as their interactions did not significantly influence the plant population of rice at 30 DAS during both the years and on mean basis.

4.1.1.2 Plant height (cm)

The data presented in Table 4.2 reveals the periodic changes in plant height due to the effect of tillage practices in rice, residual of residues in maize and nitrogen management in rice. It was noted that in general the plant height increased with an advancement in crop age upto harvest.

The plant height was significantly affected by tillage practices in rice at different durations during both the years and on mean basis, but there was no

Table 4.1: Plant population of rice as influenced by tillage, residual of residues and nitrogen management

Treatment	Plant population at 30 DAS (No. m^{-2})		
	2016	2017	Mean
Tillage			
KT_1: Conventional tillage (CT)	105.58	106.08	105.83
KT_2: Zero tillage (ZT)	99.86	102.36	101.11
SEm±	2.35	2.55	2.45
CD (P=0.05)	NS	NS	NS
Residual of residues			
KR_1: RDF + No residue	100.33	102.58	101.46
KR_2: RDF + Residue mulching (3 t ha^{-1})	101.75	102.67	102.21
KR_3: RDF + Residue mulching (6 t ha^{-1})	106.08	107.42	106.75
SEm±	2.02	2.20	2.10
CD (P=0.05)	NS	NS	NS
Nitrogen management			
KN_1: LCC based (100 % RDN)	103.14	105.53	104.33
KN_2: LCC based (75 % RDN)	102.31	102.92	102.61
SEm±	1.84	1.95	1.89
CD (P=0.05)	NS	NS	NS
Interaction	NS	NS	NS

Table 4.2: Plant height of rice at different durations as influenced by tillage, residual of residues and nitrogen management

Treatment	Plant height (cm)														
	30 DAS			60 DAS			90 DAS			120 DAS			At harvest		
	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean
Tillage															
KT_1: Conventional tillage (CT)	29.60	30.26	29.93	48.56	50.18	49.37	62.92	63.66	63.29	94.47	95.70	95.09	106.21	107.41	106.81
KT_2: Zero tillage (ZT)	24.62	26.65	25.64	42.23	43.07	42.65	51.76	54.01	52.89	82.00	84.90	83.45	93.74	96.61	95.17
SEm±	1.02	0.79	0.81	1.03	1.11	1.07	1.43	1.10	1.26	1.93	1.68	1.80	1.99	1.68	1.82
CD (P=0.05)	NS	NS	NS	6.25	6.77	6.50	8.68	6.72	7.64	11.71	10.23	10.94	12.11	10.23	11.06
Residual of residues															
KR_1: RDF + No residue	25.14	27.47	26.30	43.38	43.93	43.65	53.91	56.55	55.23	82.21	85.90	84.05	93.94	97.61	95.77
KR_2: RDF + Residue mulching (3 t ha^{-1})	28.05	28.51	28.28	45.11	47.44	46.27	57.92	58.28	58.10	89.46	90.86	90.16	101.19	102.56	101.88
KR_3: RDF + Residue mulching (6 t ha^{-1})	28.15	29.40	28.78	47.69	48.51	48.10	60.20	61.68	60.94	93.04	94.15	93.60	104.78	105.86	105.32
SEm±	1.03	0.72	0.40	0.81	0.98	0.63	1.20	1.17	1.16	1.77	1.62	1.59	2.00	1.62	1.59
CD (P=0.05)	NS	NS	NS	2.65	3.21	2.04	3.92	3.81	3.80	5.79	5.27	5.19	6.52	5.27	5.20
Nitrogen management															
KN_1: LCC based (100 % RDN)	27.73	29.12	28.42	47.79	48.78	48.29	59.83	60.89	60.36	90.82	92.99	91.90	102.56	104.92	103.74
KN_2: LCC based (75 % RDN)	26.50	27.80	27.15	43.00	44.47	43.73	54.86	56.79	55.82	85.65	87.62	86.63	97.39	99.10	98.24
SEm±	0.92	0.75	0.65	0.97	1.04	0.90	1.35	1.05	1.20	1.61	1.59	1.51	1.56	1.60	1.47
CD (P=0.05)	NS	NS	NS	2.99	3.20	2.78	4.17	3.24	3.68	4.95	4.91	4.65	4.81	4.93	4.53
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

significant difference at initial stage of growth (at 30 DAS). Significantly taller plants were recorded with KT_1 – conventional tillage (CT) as compared to KT_2 – zero tillage (CT) at 60, 90, 120 DAS and at harvest during both the years and on mean basis.

Among the residual of residues in maize, the plant height was significantly affected at different durations except at 30 DAS during both the years and on mean basis. However, at 60, 90 120 DAS and at harvest, the significantly tallest plants were noted under treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) which was at par to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis. The smallest plants were noted under treatment KR_1 – RDF + no residue at 60, 90, 120 DAS and at harvest during both the years and on mean basis.

As regards to nitrogen management in rice, treatment KN_1 – LCC based (100 % RDN) registered significantly taller plants as compared to treatment KN_2 – LCC based (75 % RDN) at 60, 90, 120 DAS and at harvest except at 30 DAS during both the years and on mean basis.

The interaction effect of tillage practices in rice, residual of residues in maize and nitrogen management in rice on plant height of rice was found non – significant at 30, 60, 90, 120 DAS and at harvest during both the years and on mean basis.

4.1.1.3 Dry matter accumulation (g m^{-2})

The data on dry matter accumulation of rice are presented in Table 4.3. It was noted that there was progressive increase in dry matter accumulation with the advancement of crop age and it reached the highest at harvest.

Tillage practices in rice had significantly influenced the dry matter accumulation at different durations except at 30 DAS during both the years and on mean basis. Significantly higher dry matter accumulation was obtained under KT_1 – conventional tillage (CT) as compared to KT_2 – zero tillage (ZT) at 60, 90, 120 DAS and at harvest during both the years and on mean basis.

Table 4.3: Dry matter accumulation of rice at different durations as influenced by tillage, residual of residues and nitrogen management

Treatment	Dry matter accumulation (g m^{-2})														
	30 DAS			60 DAS			90 DAS			120 DAS			At harvest		
	2016	**2017**	**Mean**	**2016**	**2017**	**Mean**	**2016**	**2017**	**Mean**	**2016**	**2017**	**Mean**	**2016**	**2017**	**Mean**
Tillage															
KT_1: Conventional tillage (CT)	44.67	52.22	48.44	156.38	166.22	161.30	525.56	533.90	529.73	1051.76	1053.60	1052.68	1467.92	1489.51	1478.72
KT_2: Zero tillage (ZT)	40.79	47.01	43.90	138.71	146.43	142.57	467.09	477.52	472.31	905.78	911.18	908.48	1264.24	1268.50	1266.37
SEm±	0.95	1.14	1.04	2.78	3.05	2.92	8.90	8.68	8.79	14.47	21.21	17.82	28.17	31.49	29.82
CD (P=0.05)	NS	NS	NS	16.94	18.57	17.75	54.14	52.84	53.48	88.05	129.07	108.45	171.42	191.62	181.43
Residual of residues															
KR_1: RDF + No residue	42.77	48.32	45.54	141.27	149.06	145.17	477.17	486.32	481.74	949.05	950.73	949.89	1309.87	1323.80	1316.83
KR_2: RDF + Residue mulching (3 t ha^{-1})	42.43	49.82	46.13	147.25	156.39	151.82	494.37	507.07	500.72	974.13	981.06	977.60	1370.37	1374.18	1372.27
KR_3: RDF + Residue mulching (6 t ha^{-1})	42.98	50.70	46.84	154.11	163.53	158.82	517.44	523.74	520.59	1013.12	1015.39	1014.26	1418.01	1439.03	1428.52
SEm±	0.94	1.12	1.03	3.03	3.27	3.15	9.49	8.76	9.10	14.61	11.03	11.55	24.49	24.04	14.68
CD (P=0.05)	NS	NS	NS	9.87	10.65	10.26	30.96	28.55	29.68	47.65	35.98	37.63	79.86	78.40	47.89
Nitrogen management															
KN_1: LCC based (100 % RDN)	43.85	50.96	47.40	153.33	160.92	157.12	516.42	521.69	519.05	1005.41	1015.11	1010.26	1431.24	1430.27	1430.76
KN_2: LCC based (75 % RDN)	41.61	48.26	44.94	141.76	151.73	146.75	476.23	489.73	482.98	952.12	949.68	950.90	1300.92	1327.73	1314.33
SEm±	0.94	1.13	1.04	2.67	2.88	2.77	7.91	7.54	7.71	11.94	14.39	11.26	22.88	25.82	20.11
CD (P=0.05)	NS	NS	NS	8.22	8.87	8.54	24.36	23.25	23.76	36.78	44.34	34.69	70.49	79.55	61.97
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Among the residual of residues in maize, except at 30 DAS, significantly the highest dry matter accumulation was recorded under treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) which was at par to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) at 60, 90, 120 DAS and at harvest during both the years and on mean basis. However, significantly the lowest dry matter accumulation was registered under treatment KR_1 – RDF + no residue at 60, 90, 120 DAS and at harvest during both the years and on mean basis.

With respect to nitrogen management in rice, except at 30 DAS, significantly higher dry matter accumulation was obtained under treatment KN_1 – LCC based (100 % RDN) as compared to treatment KN_2 – LCC based (75 % RDN) at 60, 90, 120 DAS and at harvest during both the years and on mean basis.

The interaction effect of tillage practices in rice, residual of residues in maize and nitrogen management in rice on dry matter accumulation was found non – significant at 30, 60, 90, 120 DAS and at harvest during both the years and on mean basis.

4.1.1.4 Leaf area index

The data on leaf area index recorded at 30, 60, 90 and 120 DAS as influenced by tillage practices in rice, residual of residues in maize and nitrogen management in rice are presented in Table 4.4. The leaf area index was significantly affected by different tillage practices in rice, residual of residues in maize and nitrogen management in rice.

The significantly higher leaf area index was recorded under KT_1 – conventional tillage (CT) as compared to KT_2 – zero tillage (ZT) at 60, 90 and 120 DAS except at 30 DAS during both the years and on mean basis.

Among the residual of residues in maize, treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) gave significantly the maximum leaf area index as compared to treatment KR_1 – RDF + no residue, but it was at par to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) at 60, 90 and 120 DAS except at 30 DAS during both the years and on mean basis.

Table 4.4: Leaf area index of rice at different durations as influenced by tillage, residual of residues and nitrogen management

Treatment	Leaf area index											
	30 DAS			60 DAS			90 DAS			120 DAS		
	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean
Tillage												
KT_1: Conventional tillage (CT)	0.62	0.65	0.64	3.42	3.47	3.44	6.55	6.64	6.60	5.17	5.13	5.15
KT_2: Zero tillage (ZT)	0.60	0.63	0.62	2.78	2.83	2.80	6.11	6.21	6.16	4.84	4.90	4.87
SEm±	0.02	0.02	0.02	0.05	0.04	0.05	0.07	0.07	0.07	0.05	0.04	0.04
CD (P=0.05)	NS	NS	NS	0.30	0.26	0.28	0.40	0.41	0.40	0.33	0.21	0.27
Residual of residues												
KR_1: RDF + No residue	0.61	0.62	0.61	2.98	3.05	3.01	6.09	6.33	6.21	4.91	4.93	4.92
KR_2: RDF + Residue mulching (3 t ha^{-1})	0.60	0.65	0.63	3.15	3.16	3.16	6.36	6.38	6.37	5.01	5.00	5.01
KR_3: RDF + Residue mulching (6 t ha^{-1})	0.63	0.65	0.64	3.17	3.24	3.20	6.54	6.57	6.56	5.10	5.11	5.10
SEm±	0.01	0.01	0.01	0.05	0.04	0.04	0.07	0.06	0.06	0.04	0.04	0.03
CD (P=0.05)	NS	NS	NS	0.15	0.14	0.14	0.22	0.19	0.20	0.13	0.14	0.10
Nitrogen management												
KN_1: LCC based (100 % RDN)	0.62	0.64	0.63	3.19	3.24	3.22	6.53	6.54	6.53	5.19	5.09	5.14
KN_2: LCC based (75 % RDN)	0.61	0.64	0.62	3.00	3.06	3.03	6.14	6.31	6.23	4.82	4.94	4.88
SEm±	0.01	0.01	0.01	0.04	0.04	0.04	0.06	0.06	0.06	0.05	0.04	0.04
CD (P=0.05)	NS	NS	NS	0.13	0.12	0.12	0.19	0.18	0.19	0.15	0.12	0.12
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

With respect to nitrogen management in rice, except at 30 DAS, significantly maximum leaf area index was recorded under treatment KN_1 – LCC based (100 % RDN) as compared to treatment KN_2 – LCC based (75 % RDN) at 60, 90 and 120 DAS during both the years and on mean basis.

The interaction effect of tillage practices in rice, residual of residues in maize and nitrogen management in rice was found non-significant with respect to leaf area index at 30, 60, 90 and 120 during both the years and on mean basis.

4.1.1.5 Crop growth rate (g m^{-2} day^{-1})

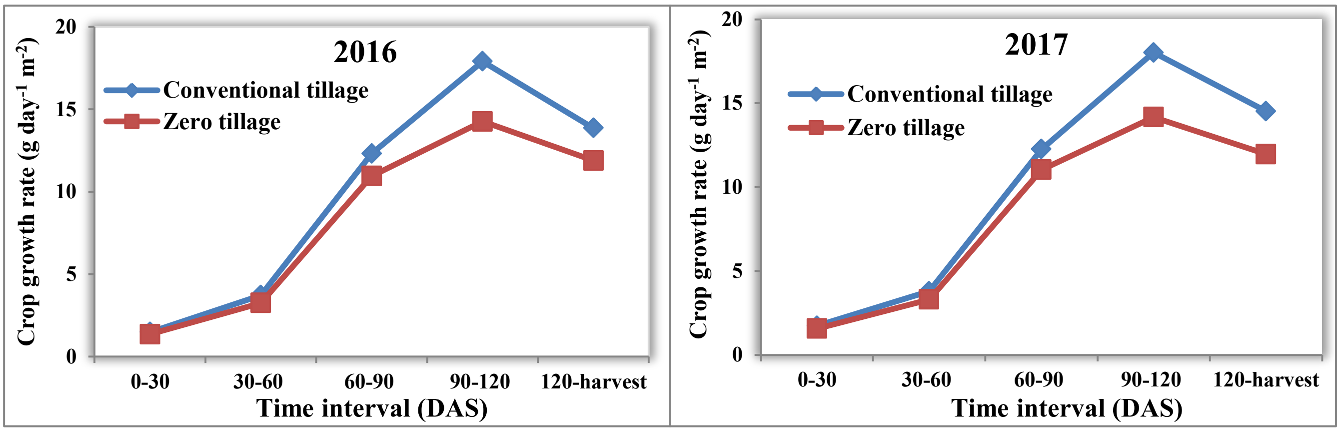
The data on crop growth rate depicted in Fig. 4.1 (2016 and 2017) and Fig 4.2 (mean) reveals that the different treatments did not influence it at early stage (0 - 30 DAS), but it was significantly affected at later durations (30 – 60, 60 – 90, 90 – 120 DAS and 120 DAS – at harvest) during both the years and on mean basis.

Between the tillage practices in rice, except at 0 – 30 DAS, treatment KT_1 – conventional tillage (CT) obtained significantly higher crop growth rate as compared to KT_2 – zero tillage (ZT) at 30 – 60, 60 – 90, 90 – 120 DAS and 120 DAS – at harvest during both the years and on mean basis.

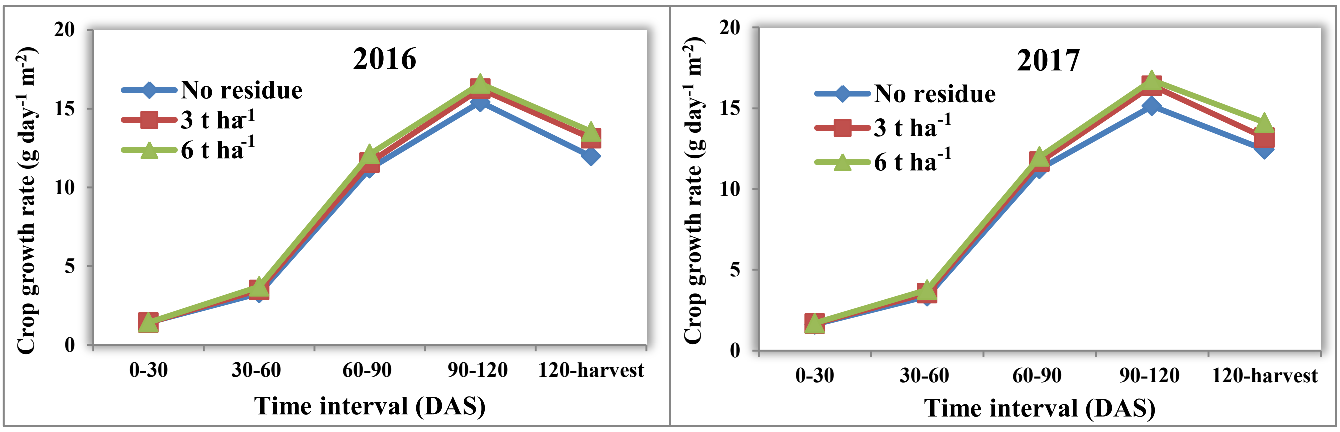
With respect to residual of residues in maize, except at 0 – 30 DAS, significantly highest crop growth rate was recorded under treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) which was at par to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) and significantly lowest crop growth rate was noted under treatment KR_1 – RDF + no residue at 30 – 60, 60 – 90, 90 – 120 DAS and 120 DAS – at harvest during both the years and on mean basis.

As regards to nitrogen management in rice, except at 0 – 30 DAS, the crop growth rate was recorded significantly higher under treatment KN_1 – LCC based (100 % RDN) as compared to treatment KN_2 – LCC based (75 % RDN) at 30 – 60, 60 – 90, 90 – 120 DAS and 120 DAS – at harvest during both the years and on mean basis.

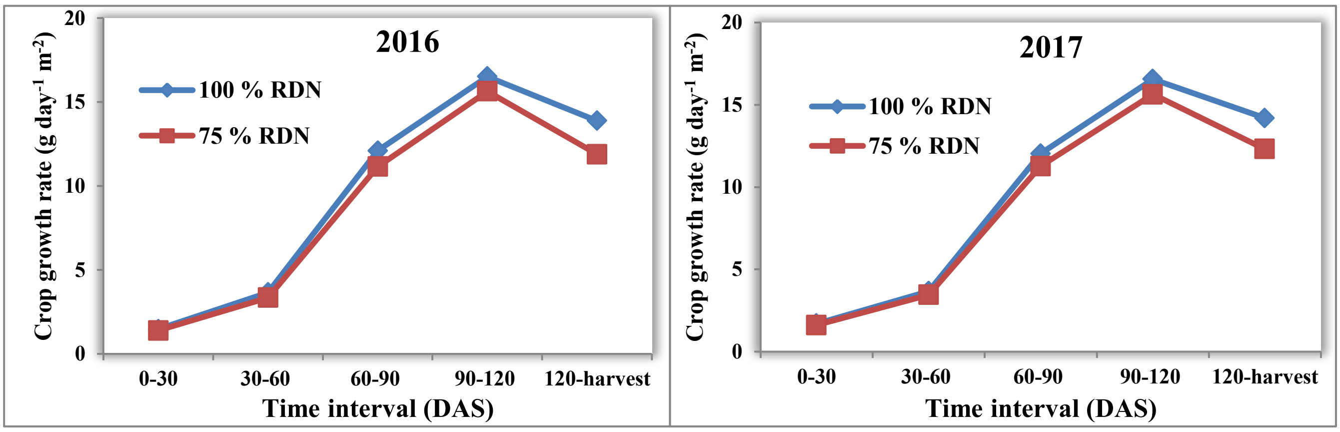
The interaction effect of tillage practices in rice, residual of residues in maize and nitrogen management in rice was found non – significant with respect to



(a) Tillage vs CGR

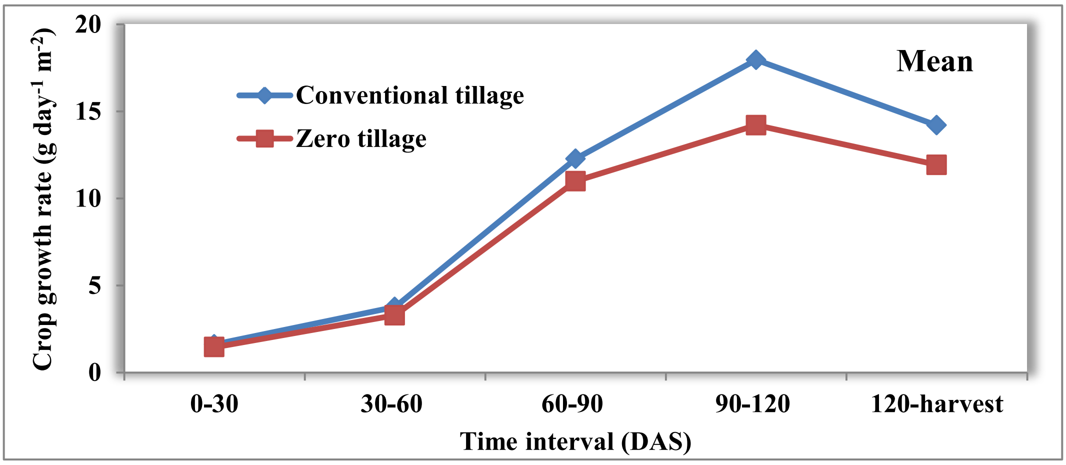


(b) Residual of residues vs CGR

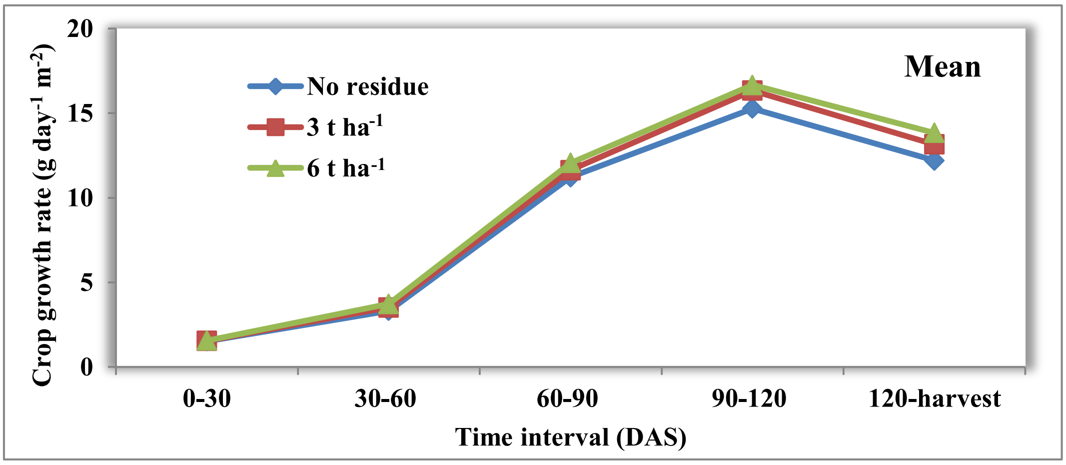


(c) Nitrogen management vs CGR

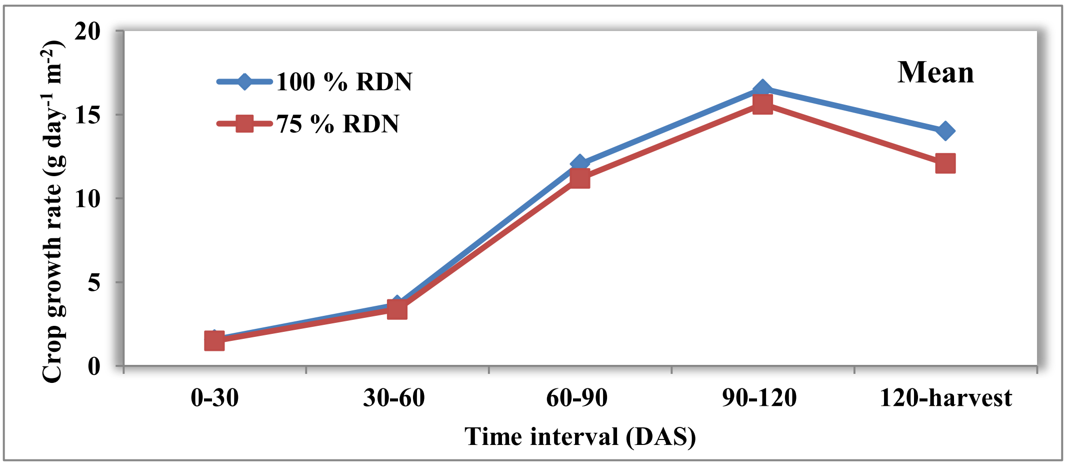
Fig 4.1: Crop growth rate (CGR) of rice at different time intervals as influenced by tillage, residual of residues and nitrogen management (2016 and 2017)



(a) Tillage vs CGR



(b) Residual of residues vs CGR



(c) Nitrogen management vs CGR

Fig 4.2: Crop growth rate (CGR) of rice at different time intervals as influenced by tillage, residual of residues and nitrogen management (mean)

crop growth rate at 0-30, 30 – 60, 60 – 90, 90 – 120 DAS and 120 DAS – at harvest during both the years and on mean basis.

4.1.1.6 Relative growth rate (mg mg^{-1} m^{-2} day^{-1})

The data on relative growth rate of rice as affected by different treatments was computed at 0 – 30, 30 – 60, 60 – 90, 90 – 120 DAS and 120 DAS – at harvest and presented in Fig. 4.3 (2016 and 2017) and Fig 4.4 (mean). Relative growth rate of rice was increased initially and declined there after till harvest.

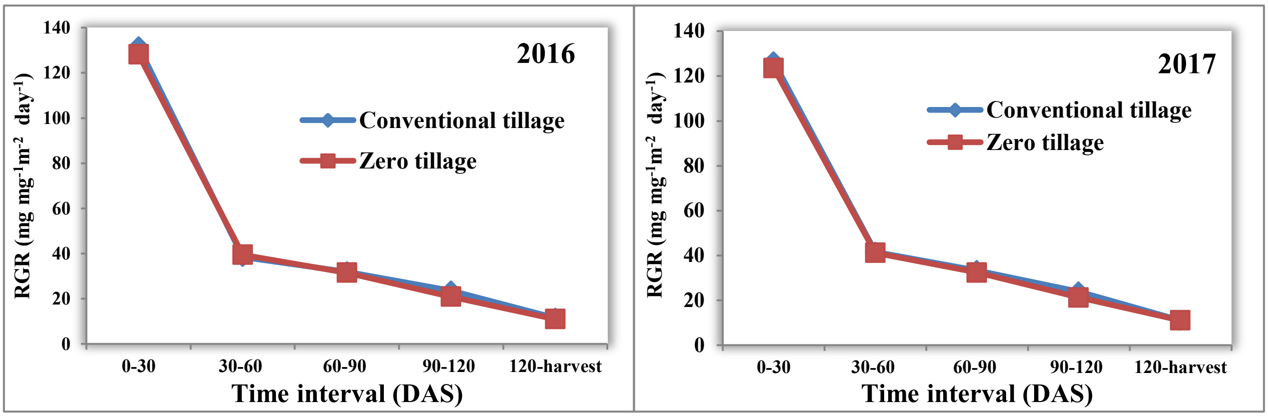
The results recorded that the effect of tillage practices in rice, residual of residues in maize and nitrogen management in rice as well as their interactions did not have significant impact on relative growth rate of rice at 0 – 30, 30 – 60, 60 – 90, 90 – 120 DAS and 120 DAS – at harvest during both the years and on mean basis. However, KT_1 – conventional tillage (CT), KR_3 – RDF + residue mulching (6 t ha^{-1}) and KN_1 – LCC based (100 % RDN) registered the higher relative growth rate in comparison to their respective treatments at 0 – 30, 30 – 60, 60 – 90, 90 – 120 DAS and 120 DAS – at harvest during both the years and on mean basis.

4.1.1.7 SPAD value

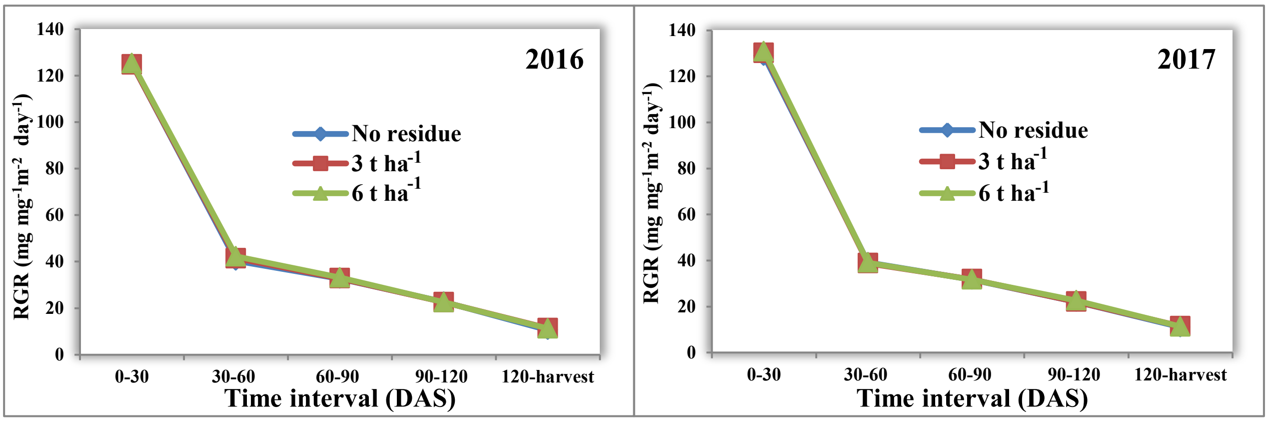
The data on SPAD value recorded at 30, 60, 90 and 120 DAS of rice as influenced by tillage practices in rice, residual of residues in maize and nitrogen management in rice are presented in Table 4.5.

The tillage practices in rice and residual of residues in maize did not have significant impact on SPAD value of rice at 30, 60, 90 and 120 DAS during both the years and on mean basis. However, KT_1 – conventional tillage (CT) and KR_3 – RDF + residue mulching (6 t ha^{-1}) noted the higher SPAD value in comparison to their respective treatments at 30, 60, 90 and 120 DAS during both the years and on mean basis.

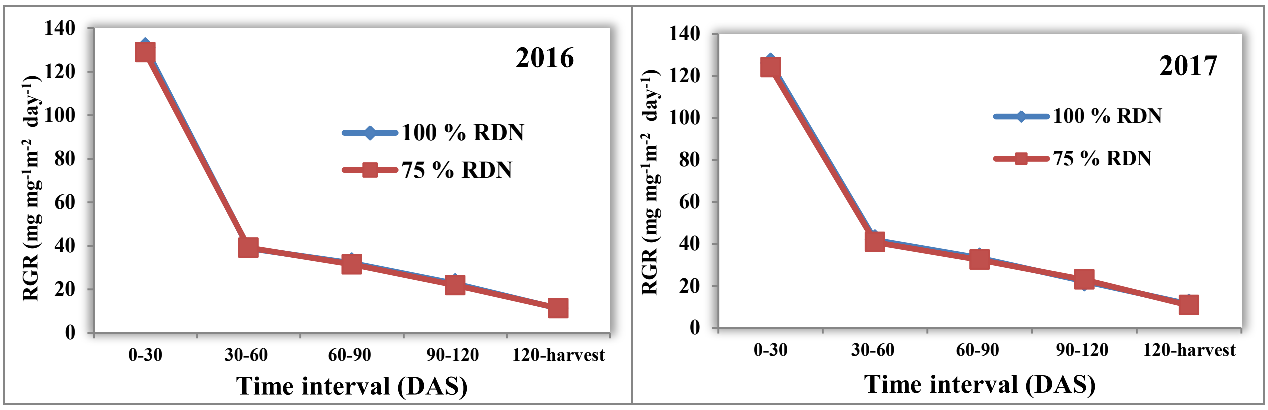
The significantly higher SPAD value was registered under treatment KN_1 – LCC based (100 % RDN) as compared to treatment KN_2 – LCC based (75 % RDN) at 60, 90 and 120 DAS except at 30 DAS during both the years and on mean basis.



(a) Tillage vs RGR

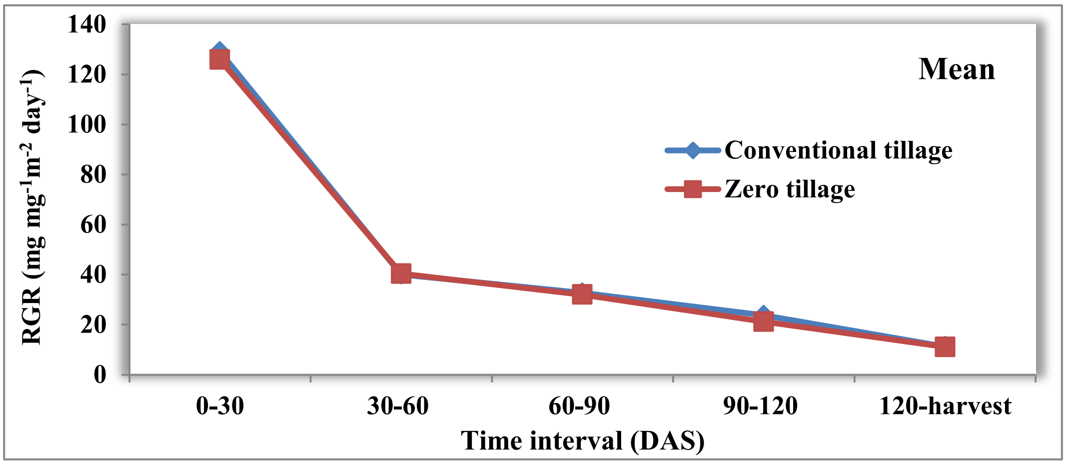


(b) Residual of residues vs RGR

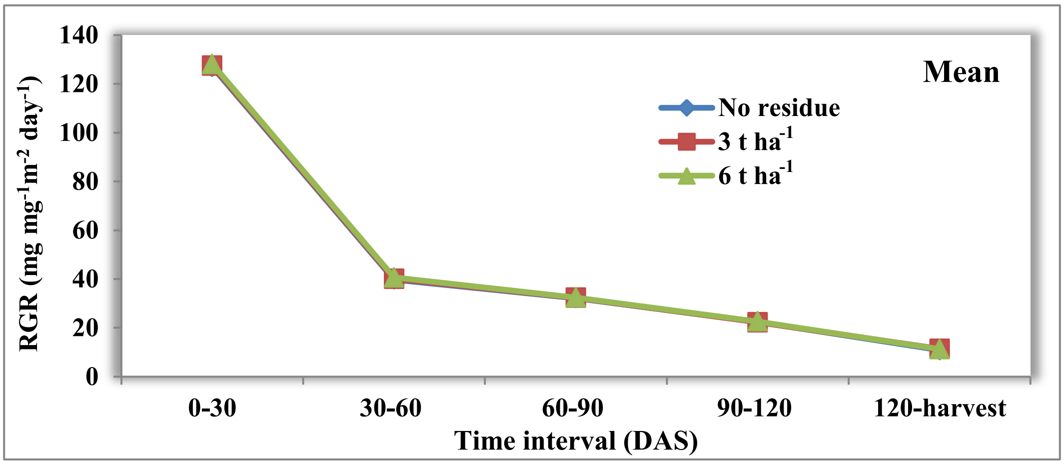


(c) Nitrogen management vs RGR

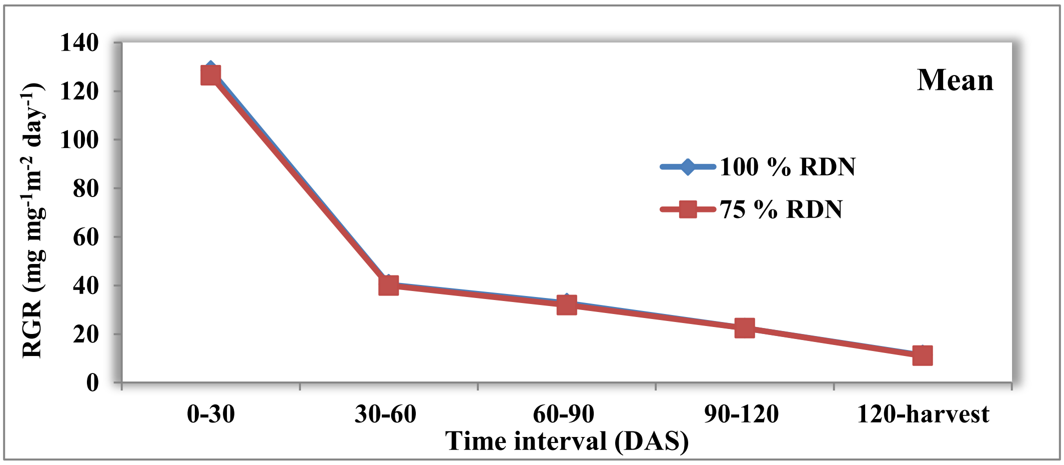
Fig 4.3: Relative growth rate (RGR) of rice at different time intervals as influenced by tillage, residual of residues and nitrogen management (2016 and 2017)



(a) Tillage vs RGR



(b) Residual of residues vs RGR



(c) Nitrogen management vs RGR

Fig 4.4: Relative growth rate (RGR) of rice at different time intervals as influenced by tillage, residual of residues and nitrogen management (mean)

Table 4.5: SPAD value of rice at different durations as influenced by tillage, residual of residues and nitrogen management

Treatment	SPAD value											
	30 DAS			60 DAS			90 DAS			120 DAS		
	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean
Tillage												
KT_1: Conventional tillage (CT)	30.31	30.54	30.43	32.21	32.29	32.25	41.88	41.21	41.54	37.96	38.11	38.03
KT_2: Zero tillage (ZT)	29.80	28.58	29.19	32.15	32.23	32.19	41.09	40.92	41.01	37.34	37.93	37.64
SEm±	0.72	0.66	0.69	0.78	0.78	0.78	0.91	1.04	0.98	0.82	1.06	0.94
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Residual of residues												
KR_1: RDF + No residue	29.37	28.07	28.72	31.41	31.49	31.45	41.08	40.08	40.58	37.00	37.14	37.07
KR_2: RDF + Residue mulching (3 t ha^{-1})	30.26	30.46	30.36	31.96	32.24	32.10	41.55	41.15	41.35	37.52	38.05	37.79
KR_3: RDF + Residue mulching (6 t ha^{-1})	30.54	30.16	30.35	33.16	33.04	33.10	41.83	41.96	41.89	38.44	38.86	38.65
SEm±	0.66	0.64	0.65	0.65	0.59	0.58	0.84	0.94	0.89	0.76	0.92	0.84
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Nitrogen management												
KN_1: LCC based (100 % RDN)	30.96	29.27	30.11	33.01	33.25	33.13	42.87	42.83	42.85	38.76	39.38	39.07
KN_2: LCC based (75 % RDN)	29.15	29.86	29.50	31.35	31.27	31.31	40.10	39.30	39.70	36.54	36.66	36.60
SEm±	0.72	0.64	0.54	0.49	0.47	0.47	0.71	0.95	0.80	0.60	0.73	0.66
CD (P=0.05)	NS	NS	NS	1.50	1.45	1.45	2.18	2.92	2.47	1.85	2.25	2.05
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

The interaction effect of tillage practices in rice, residual of residues in maize and nitrogen management in rice was found non - significant with respect to SPAD value at 30, 60, 90 and 120 DAS during both the years and on mean basis.

Discussion on growth parameters of rice

Between the tillage practices in rice, the growth parameters like plant height, dry matter accumulation, leaf area index and crop growth rate were noted significantly higher under conventional tillage (CT) as compared to zero tillage (ZT) which might be due to better initial emergence and suitable growth environment conditions resulting more cell division and cell elongation in the meristematic tissues of plant which led to significant enhance in growth parameters. Tallest plant recorded under conventional tillage compared to other tillage practices was observed by Zein *et al.* (2008). Under conventional tillage better soil physical properties like lower bulk density help in better root development and nutrient uptake (Seema, 2014). The higher value of total dry matter per plant might be due to maximum value of photosynthetic organ i.e. active leaves and more number of tillers, which enabled the plant to intercept highest amount of radiant energy and converted the same into chemical energy (Gzazia *et al*., 2003 and Kudtarkar, 2005). Increased availability of soil moisture under conventional tillage might have led to effective absorption and utilization of available nutrients and better production of roots resulting more in leaf area, leaf area index and crop growth rate (Sivanappana, 1998). Tillage improved soil condition for crop growth and development also reported by Basunia (2000).

Among the residual of residues in maize, significantly higher plant height, dry matter accumulation, leaf area index and crop growth rate were observed under RDF + residue mulching (6 t ha^{-1}) as compared to RDF + no residue, but it was at par to RDF + residue mulching (3 t ha^{-1}). This might be due to the addition of nutrients through decomposition of crop residue as well as increased the availability of soil nutrients, obviously promote maximum growth of rice. Further, rice residues undergo decomposition at a slower rate under submerged conditions, releasing available nutrients over a long period of time. Similar results were reported by Prasad *et al*. (2010) and Rathod *et al*. (2012).

As regards to nitrogen management in rice, the growth parameters like plant height, dry matter accumulation, leaf area index and crop growth rate were recorded significantly higher under LCC based (100 % RDN) as compared to LCC based (75 % RDN) which might be due to fact that nitrogen is the main growth promoter element and help in more synthesis of food resulting into maximum cell division and cell enlargement (Singh and Jain (2000) and Meena *et al*. (2003) also recorded significant improvement in dry matter accumulation of rice with increasing nutrition on account of better growth and development of the plant. The positive effect of nitrogen on dry matter accumulation of rice has been documented earlier by Singh *et al*. (2006). Nitrogen plays a vital role in the formation of new tissues which are dependent on the protoplasmic structure, cell division and cell elongation. Moreover increase of leaves plant^{-1} means increase in the photosynthesis surface area as well as increase leaf area (Singh and Singh, 2014). Increased levels of nitrogen favours greater absorption of nutrients resulting in rapid expansion of foliage, better accumulation of photosynthates and eventually resulting in increased growth structure. These results are in conformity with the findings of Shekara *et al*. (2010) and Sandy (2012).

Between the nitrogen management in rice, significantly higher SPAD value was recorded under LCC based (100 % RDN) as compared to LCC based (75 % RDN). This might be due to influence of nitrogen nutrition on the content of photosynthetic pigments, the synthesis of enzymes and formation of the membrane system of chloroplast etc. Verma *et al*. (2004) recorded that the chlorophyll content increased with increasing nitrogen rate as compared to others.

4.1.2 Post-harvest observations

4.1.2.1 Effective tillers (No. m^{-2})

The data on effective tillers presented in the Table 4.6 indicated that between the tillage practices in rice, KT_1 – conventional tillage (CT) produced significantly higher number of effective tillers of rice as compared to KT_2 – zero tillage (ZT) during the both years and on mean basis.

Among the residual of residues in maize, treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) registered significantly highest number of effective tillers of rice which was at par to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}), whereas the minimum number of effective tillers was noted under treatment KR_1 – RDF + no residue during the both years and on mean basis.

As regards to nitrogen management in rice, treatment KN_1 – LCC based (100 % RDN) noticed significantly maximum number of tillers of rice as compared to treatment KN_2 – LCC based (75 % RDN) during both the years and on mean basis.

The interaction effect between residual of residues in maize and nitrogen management in rice was found significant during both the years and on mean basis (Table 4.8). The findings revealed that the interaction between KR_3 – RDF + residue mulching (6 t ha^{-1}) with KN_1 – LCC based (100 % RDN) registered significantly higher number of effective tillers as compared to other interactions. However, it was statistically similar to interactions of KR_2 – RDF + residue mulching (3 t ha^{-1}) with KN_1 – LCC based (100 % RDN), KR_3 – RDF + residue mulching (6 t ha^{-1}) with KN_2 – LCC based (75 % RDN) and KR_2 – RDF + residue mulching (3 t ha^{-1}) with KN_2 – LCC based (75 % RDN) during both the years and on mean basis.

4.1.2.2 Panicle weight (g)

The data on panicle weight as influenced by tillage practices in rice, residual of residues in maize and nitrogen management in rice are presented in Table 4.6.

As regards to tillage practices in rice, the panicle weight was registered significantly higher under KT_1 – conventional tillage (CT) as compared to KT_2 – zero tillage (ZT) during both the years and on mean basis.

Among the residual of residues in maize, treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) registered significantly maximum panicle weight of rice as compared to treatment KR_1 – RDF + no residue, however, it was at par to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis.

Table 4.6: Effective tillers, weight and length of panicle and test weight of rice as influenced by tillage, residual of residues and nitrogen management

Treatment	Effective tillers (No. m^{-2})			Panicle weight (g)			Panicle length (cm)			Test weight (g)		
	2016	**2017**	**Mean**	**2016**	**2017**	**Mean**	**2016**	**2017**	**Mean**	**2016**	**2017**	**Mean**
Tillage												
KT_1: Conventional tillage (CT)	258.00	266.67	262.33	2.97	3.05	3.01	24.32	23.35	23.83	21.01	20.06	20.54
KT_2: Zero tillage (ZT)	225.22	237.44	231.33	2.59	2.67	2.63	23.99	23.01	23.50	20.65	20.70	20.68
SEm±	3.51	4.28	3.89	0.05	0.05	0.05	0.54	0.41	0.48	0.45	0.42	0.41
CD (P=0.05)	21.37	26.06	23.69	0.29	0.31	0.30	NS	NS	NS	NS	NS	NS
Residual of residues												
KR_1: RDF + No residue	227.00	232.33	229.67	2.65	2.73	2.69	23.82	22.84	23.33	20.23	20.65	20.44
KR_2: RDF + Residue mulching (3 t ha^{-1})	245.42	257.45	251.43	2.83	2.89	2.86	24.29	23.31	23.80	20.80	20.03	20.42
KR_3: RDF + Residue mulching (6 t ha^{-1})	252.41	266.39	259.40	2.87	2.96	2.91	24.36	23.38	23.87	21.46	20.48	20.97
SEm±	4.25	4.57	4.37	0.05	0.05	0.05	0.50	0.37	0.43	0.41	0.28	0.26
CD (P=0.05)	13.85	14.92	14.26	0.16	0.17	0.17	NS	NS	NS	NS	NS	NS
Nitrogen management												
KN_1: LCC based (100 % RDN)	248.17	259.89	254.03	2.88	2.97	2.93	24.20	23.22	23.71	21.18	20.41	20.80
KN_2: LCC based (75 % RDN)	235.05	244.22	239.64	2.68	2.75	2.72	24.11	23.13	23.62	20.48	20.35	20.42
SEm±	2.39	2.33	2.02	0.05	0.05	0.05	0.50	0.38	0.44	0.42	0.37	0.27
CD (P=0.05)	7.36	7.17	6.24	0.14	0.15	0.14	NS	NS	NS	NS	NS	NS
Interaction	S	S	S	NS	NS	NS	NS	NS	NS	NS	NS	NS

Treatment KN_1 – LCC based (100 % RDN) showed significantly higher panicle weight of rice as compared to treatment KN_2 – LCC based (75 % RDN) throughout both the years and on mean basis.

The interactions among tillage practices in rice, residual of residues in maize and nitrogen management in rice were found non-significant with respect to panicle weight of rice throughout both the years and on mean basis.

4.1.2.3 Panicle length (cm) and test weight (g)

The data on panicle length and test weight of rice as influenced by tillage practices in rice, residual of residues in maize and nitrogen management in rice are presented in Table 4.6.

The results revealed that the effect of tillage practices in rice, residual of residues in maize and nitrogen management in rice as well as their interactions did not have significant impact on panicle length and test weight of rice throughout both the years and on mean basis.

4.1.2.4 Total number of grains panicle^{-1}

The data on total number of grains panicle^{-1} of rice presented in Table 4.7 indicates that between the tillage practices in rice, KT_1 – conventional tillage (CT) observed significantly maximum total number of grains panicle^{-1} of rice as compared to KT_2 – zero tillage (ZT) during both the years and on mean basis.

Among the residual of residues in maize, significantly maximum total number of grains panicle^{-1} of rice was recorded under treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) which was at par to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}), whereas significantly minimum total number of grains panicle^{-1} was recorded under treatment KR_1 – RDF + no residue throughout both the years and on mean basis.

Among the nitrogen management in rice, significantly maximum total number of grains panicle^{-1} of rice was recorded under treatment KN_1 – LCC based (100 % RDN) as compared to treatment KN_2 – LCC based (75 % RDN) during both the years and on mean basis.

Table 4.7: Number of grains and sterility percentage of rice as influenced by tillage, residual of residues and nitrogen management

Treatment	Total number of grains panicle^{-1}			Filled grains panicle^{-1}			Unfilled grains panicle^{-1}			Sterility percentage		
	2016	**2017**	**Mean**	**2016**	**2017**	**Mean**	**2016**	**2017**	**Mean**	**2016**	**2017**	**Mean**
Tillage												
KT_1: Conventional tillage (CT)	162.58	165.42	164.00	140.48	143.07	141.78	22.10	22.19	22.15	12.83	13.95	13.39
KT_2: Zero tillage (ZT)	150.52	155.14	152.83	129.92	132.54	131.23	20.60	22.60	21.60	14.55	15.15	14.85
SEm±	1.96	1.63	1.80	1.23	1.57	1.40	0.47	0.32	0.36	0.33	0.31	0.31
CD (P=0.05)	11.91	9.95	10.93	7.49	9.57	8.53	NS	NS	NS	NS	NS	NS
Residual of residues												
KR_1: RDF + No residue	147.00	152.93	149.96	125.81	130.40	128.11	21.19	22.03	21.61	13.73	14.85	14.29
KR_2: RDF + Residue mulching (3 t ha^{-1})	159.14	161.12	160.13	137.73	138.70	138.22	21.42	22.42	21.92	13.71	14.58	14.14
KR_3: RDF + Residue mulching (6 t ha^{-1})	163.51	166.80	165.16	142.07	144.31	143.19	21.45	22.74	22.10	13.63	14.23	13.93
SEm±	2.20	2.25	2.21	1.47	1.83	1.65	0.47	0.54	0.22	0.28	0.34	0.27
CD (P=0.05)	7.16	7.33	7.20	4.80	5.98	5.39	NS	NS	NS	NS	NS	NS
Nitrogen management												
KN_1: LCC based (100 % RDN)	160.30	164.65	162.47	138.38	140.86	139.62	21.20	22.38	21.79	13.46	14.31	13.88
KN_2: LCC based (75 % RDN)	152.81	155.91	154.36	132.02	134.76	133.39	21.51	22.41	21.96	13.92	14.79	14.36
SEm±	1.79	1.63	1.70	0.92	1.17	0.97	0.40	0.30	0.26	0.23	0.20	0.16
CD (P=0.05)	5.53	5.02	5.25	2.84	3.62	2.98	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	S	S	S	NS	NS	NS	NS	NS	NS

Table 4.8: Effective tillers and filled grains of rice as affected by interaction between residual of residues in maize and nitrogen management in rice

Residual of Residues / Nitrogen management	KR_1: RDF + No residue	KR_2: RDF + Residue mulching (3 t ha^{-1})	KR_3: RDF + Residue mulching (6 t ha^{-1})	Mean
	Effective tillers (No m^{-2})			
	2016			
KN_1: LCC based (100 % RDN)	240.67	246.51	257.33	248.17
KN_2: LCC based (75 % RDN)	213.33	244.33	247.49	235.05
Mean	227.00	245.42	252.41	
	2017			
KN_1: LCC based (100 % RDN)	248.67	262.22	268.78	259.89
KN_2: LCC based (75 % RDN)	216.00	252.67	264.00	244.22
Mean	232.33	257.45	266.39	
	Mean			
KN_1: LCC based (100 % RDN)	244.67	254.37	263.06	254.03
KN_2: LCC based (75 % RDN)	214.67	248.50	255.74	239.64
Mean	229.67	251.43	259.40	

	2016		**2017**		**Mean**	
	SEm±	**CD (P=0.05)**	**SEm±**	**CD (P=0.05)**	**SEm±**	**CD (P=0.05)**
Comparison of two nitrogen management at same levels of residual of residues	4.14	12.75	4.03	12.41	4.63	14.27
Comparison of two residual of residues at same levels of nitrogen management	5.15	16.42	5.38	17.30	5.02	16.18

Residual of Residues / Nitrogen management	KR_1	KR_2	KR_3	Mean
	Filled grains $panicle^{-1}$			
	2016			
KN_1: LCC based (100 % RDN)	132.73	138.74	143.66	138.38
KN_2: LCC based (75 % RDN)	118.90	136.71	140.47	132.02
Mean	125.81	137.73	142.07	
	2017			
KN_1: LCC based (100 % RDN)	136.92	139.57	146.08	140.86
KN_2: LCC based (75 % RDN)	123.88	137.84	142.54	134.76
Mean	130.40	138.70	144.31	
	Mean			
KN_1: LCC based (100 % RDN)	134.83	139.16	144.87	139.62
KN_2: LCC based (75 % RDN)	121.39	137.28	141.51	133.39
Mean	128.11	138.22	143.19	

	2016		**2017**		**Mean**	
	SEm±	**CD (P=0.05)**	**SEm±**	**CD (P=0.05)**	**SEm±**	**CD (P=0.05)**
Comparison of two nitrogen management at same levels of residual of residues	2.30	7.30	2.85	8.90	2.59	8.12
Comparison of two residual of residues at same levels of nitrogen management	3.01	8.37	3.13	9.13	2.82	8.77

The interactions among tillage practices in rice, residual of residues in maize and nitrogen management in rice were found non-significant with respect to total number of grains panicle^{-1} of rice during both the years and on mean basis.

4.1.2.5 Number of filled grains panicle^{-1}

The data regarding number of filled grains panicle^{-1} given in Table 4.7 reveals that between the tillage practices in rice, significantly higher number of filled grains panicle^{-1} of rice was registered under KT_1 – conventional tillage (CT) as compared to KT_2 – zero tillage (ZT) throughout both the years and on mean basis.

Among the residual of residues in maize, treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) registered significantly maximum number of filled grains panicle^{-1} which was at par to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) and significantly lowest number of filled grains panicle^{-1} was recorded under treatment KR_1 – RDF + no residue during both the years and on mean basis.

Treatment KN_1 – LCC based (100 % RDN) observed significantly higher number of filled grains panicle^{-1} of rice as compared to treatment KN_2 – LCC based (75 % RDN) throughout both the years and on mean basis.

The interactions between residual of residues in maize and nitrogen management in rice on number of filled grains panicle^{-1} were found significant during both the years and on basis (Table 4.8). Interaction between KR_3 – RDF + residue mulching (6 t ha^{-1}) with KN_1 – LCC based (100 % RDN) registered significantly maximum number of filled grains panicle^{-1} of rice as compared to other interactions during both the years and on mean basis. However, it was at par to interactions of KR_2 – RDF + residue mulching (3 t ha^{-1}) with KN_1 – LCC based (100 % RDN), KR_3 – RDF + residue mulching (6 t ha^{-1}) with KN_2 – LCC based (75 % RDN) and KR_2 – RDF + residue mulching (3 t ha^{-1}) with KN_2 – LCC based (75 % RDN) throughout both the years and on mean basis.

4.1.2.6 Number of unfilled grains panicle^{-1} and sterility percentage

The data on number of unfilled grains panicle^{-1} and sterility percentage as influenced by tillage practices in rice, residual of residues in maize and nitrogen management in rice are given in Table 4.7.

The results indicated that the effect of tillage practices in rice, residual of residues in maize and nitrogen management in rice as well as their interactions did not have significant impact on number of unfilled grains panicle^{-1} and sterility percentage of rice throughout both the years and on mean basis.

Discussion on yield attributes

Between tillage practices in rice, significantly maximum number of effective tillers, panicle weight, total and filled grains panicle^{-1} were recorded under conventional tillage (CT) as compared to zero tillage (ZT) which might be attributed due to better vegetative growth i.e. dry matter accumulation, leaf area index, plant height which contributed to translocation of nutrients from source to sink and ultimately led into higher number of panicles m^{-2} and maximum panicle weight (Jadhav *et al*., 2014). Surin *et al*. (2013) also recorded that conventionally tilled rice produced 9.3 per cent filled grains compared to zero tilled rice. The similar results confirm the findings of Gupta *et al.* (2007). The highest yield attributes i.e. effective tillers m^{-2}, total and filled grains panicle^{-1} were obtained under conventional tillage might be attributed due to fine tilth, good aeration, less weed competition and better in nutrient uptake which reflected to higher yield attributes in concerned treatment (Gangwar and Singh, 2004).

Among the residual of residues in maize, significantly highest effective tillers, panicle weight, total and filled grains panicle^{-1} were recorded under RDF + residue mulching (6 t ha^{-1}) as compared to RDF + no residue, but it was at par to RDF + residue mulching (3 t ha^{-1}) which may be owing to plant nutrient addition from the residual of mulched biomass which might have improved nutrient supply and thus resulted in better growth and development as well as higher yield attributes of rice (Sharma *et al*., 2010). Similar results were recorded by Prasad *et al*. (2010), Rathod *et al*. (2012) and Das *et al*. (2012).

As regards to nitrogen management in rice, significantly higher effective tillers, panicle weight, total and filled grains panicle^{-1} were recorded under LCC based (100 % RDN) as compared to LCC based (75 % RDN). This might be due to supply of nitrogen at critical stages of crop growth, which resulted in higher growth and yield attributes. The similar results are in conformity with the findings of Jakhar *et al*. (2005) and Pandey *et al*. (2008). Moharnana *et al*. (2017) also indicated that application of nitrogen based on LCC threshold value 4 produced significantly maximum number of ear bearing tillers m^{-2} (403.71) and 148.94 filled grains $panicle^{-1}$ compared to other treatments.

Interaction between RDF + residue mulching (6 t ha^{-1}) with LCC based (100 % RDN) registered significantly maximum number of effective tillers m^{-2} and filled grains $panicle^{-1}$ of rice as compared to other interactions, however, it was comparable to interactions of RDF + residue mulching (3 t ha^{-1}) with LCC based (100 % RDN), RDF + residue mulching (6 t ha^{-1}) with LCC based (75 % RDN) and RDF + residue mulching (3 t ha^{-1}) with LCC based (75 % RDN). This may be attributed to improvement of nutrient availability in soil resulting better growth and yield attributes ultimately enhanced number of effective tillers m^{-2} and filled grains $panicle^{-1}$ in concerned treatment combination (Sharma, 2009).

4.1.2.7 Grain yield (t ha^{-1})

The data pertaining to grain yield of rice as increased by tillage practices in rice, residual of residues in maize and nitrogen management in rice are presented in Table 4.9.

In case of tillage practices in rice, KT_1 – conventional tillage (CT) produced significantly higher grain yield of rice as compared to KT_2 – zero tillage (ZT) throughout both the years and on mean basis.

Among the residual of residues in maize, significantly higher grain yield of rice was registered under treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) as compared to treatment KR_1 – RDF + no residue, but it was statistically similar to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) throughout both the years and on mean basis.

Regarding to nitrogen management in rice, treatment KN_1 – LCC based (100 % RDN) recorded significantly highest grain yield of rice as compared to treatment KN_2 – LCC based (75 % RDN) throughout both the years and on mean basis.

Table 4.9: Grain and straw yields and harvest index of rice as influenced by tillage, residual of residues and nitrogen management

Treatment	Grain yield (t ha^{-1})			Straw yield (t ha^{-1})			Harvest index (%)		
	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean
Tillage									
KT_1: Conventional tillage (CT)	5.91	6.02	5.96	7.33	7.49	7.41	44.58	44.49	44.53
KT_2: Zero tillage (ZT)	5.39	5.46	5.42	6.62	6.72	6.67	44.85	44.80	44.82
SEm±	0.08	0.09	0.08	0.11	0.09	0.10	1.02	1.02	1.02
CD (P=0.05)	0.50	0.52	0.51	0.67	0.55	0.61	NS	NS	NS
Residual of residues									
KR_1: RDF + No residue	5.18	5.25	5.22	6.60	6.74	6.67	43.96	43.77	43.87
KR_2: RDF + Residue mulching (3 t ha^{-1})	5.81	5.88	5.84	7.08	7.19	7.13	45.07	44.95	45.01
KR_3: RDF + Residue mulching (6 t ha^{-1})	5.96	6.09	6.02	7.25	7.39	7.32	45.11	45.20	45.16
SEm±	0.10	0.10	0.10	0.12	0.11	0.11	0.97	0.97	0.97
CD (P=0.05)	0.31	0.32	0.31	0.38	0.37	0.37	NS	NS	NS
Nitrogen management									
KN_1: LCC based (100 % RDN)	5.85	5.96	5.90	7.13	7.28	7.21	45.04	45.02	45.03
KN_2: LCC based (75 % RDN)	5.45	5.52	5.49	6.82	6.93	6.87	44.38	44.27	44.33
SEm±	0.05	0.06	0.05	0.06	0.06	0.05	0.77	0.77	0.77
CD (P=0.05)	0.15	0.18	0.16	0.18	0.18	0.17	NS	NS	NS
Interaction	S	S	S	S	S	S	NS	NS	NS

Table 4.10: Grain and straw yields of rice as affected by interaction between residual of residues in maize and nitrogen management in rice

Nitrogen management \ Residual of Residues	KR_1: RDF + No residue	KR_2: RDF + Residue mulching (3 t ha^{-1})	KR_3: RDF + Residue mulching (6 t ha^{-1})	Mean
	Grain yield (t ha^{-1})			
	2016			
KN_1: LCC based (100 % RDN)	5.63	5.89	6.02	5.85
KN_2: LCC based (75 % RDN)	4.73	5.72	5.90	5.45
Mean	5.18	5.81	5.96	
	2017			
KN_1: LCC based (100 % RDN)	5.71	6.05	6.12	5.96
KN_2: LCC based (75 % RDN)	4.78	5.72	6.06	5.52
Mean	5.25	5.88	6.09	
	Mean			
KN_1: LCC based (100 % RDN)	5.67	5.97	6.07	5.90
KN_2: LCC based (75 % RDN)	4.76	5.72	5.98	5.49
Mean	5.22	5.84	6.02	

	2016		**2017**		**Mean**	
	SEm±	**CD (P=0.05)**	**SEm±**	**CD (P=0.05)**	**SEm±**	**CD (P=0.05)**
Comparison of two nitrogen management at same levels of residual of residues	0.08	0.26	0.10	0.31	0.09	0.28
Comparison of two residual of residues at same levels of nitrogen management	0.11	0.36	0.12	0.38	0.11	37

Nitrogen management \ Residual of Residues	KR_1	KR_2	KR_3	Mean
	Straw yield (t ha^{-1})			
	2016			
KN_1: LCC based (100 % RDN)	6.91	7.18	7.30	7.13
KN_2: LCC based (75 % RDN)	6.28	6.97	7.20	6.82
Mean	6.60	7.08	7.25	
	2017			
KN_1: LCC based (100 % RDN)	7.08	7.29	7.48	7.28
KN_2: LCC based (75 % RDN)	6.39	7.10	7.30	6.93
Mean	6.74	7.19	7.39	
	Mean			
KN_1: LCC based (100 % RDN)	7.00	7.23	7.39	7.21
KN_2: LCC based (75 % RDN)	6.33	7.04	7.25	6.87
Mean	6.67	7.13	7.32	

	2016		**2017**		**Mean**	
	SEm±	**CD (P=0.05)**	**SEm±**	**CD (P=0.05)**	**SEm±**	**CD (P=0.05)**
Comparison of two nitrogen management at same levels of residual of residues	0.10	0.31	0.10	0.32	0.09	0.29
Comparison of two residual of residues at same levels of nitrogen management	0.11	0.38	0.12	0.39	0.11	0.38

The interactions between residual of residues in maize and nitrogen management in rice were found significant with respect to grain yield of rice throughout both the years and on mean basis (Table 4.10). Interaction between KR_3 – RDF + residue mulching (6 t ha^{-1}) with KN_1 – LCC based (100 % RDN) produced significantly higher grain yield of rice as compared to other interactions, but it was at par to interactions of KR_2 – RDF + residue mulching (3 t ha^{-1}) with KN_1 – LCC based (100 % RDN), KR_3 – RDF + residue mulching (6 t ha^{-1}) with KN_2 – LCC based (75 % RDN) and KR_2 – RDF + residue mulching (3 t ha^{-1}) with KN_2 – LCC based (75 % RDN) throughout both the years and on mean basis.

4.1.2.8 Straw yield (t ha^{-1})

The data on straw yield of rice as increased by tillage practices in rice, residual of residues in maize and nitrogen management in rice are presented in Table 4.9.

Regarding tillage practices in rice, KT_1 – conventional tillage (CT) produced significantly higher straw yield of rice as compared to KT_2 – zero tillage (ZT) throughout both the years and on mean basis.

Among the residual of residues in maize, significantly higher straw yield of rice was recorded under treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) as compared to treatment KR_1 – RDF + no residue, but it was statistically similar to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis.

Regarding nitrogen management in rice, treatment KN_1 – LCC based (100 % RDN) observed significantly higher straw yield of rice as compared to treatment KN_2 – LCC based (75 % RDN) during both the years and on mean basis.

The interactions between residual of residues in maize and nitrogen management in rice had given significant impact on straw yield of rice during both the years and on mean basis (Table 4.10). Interaction between KR_3 – RDF + residue mulching (6 t ha^{-1}) with KN_1 – LCC based (100 % RDN) produced significantly higher straw yield of rice as compared to other interactions, but it was at par to interactions of KR_2 – RDF + residue mulching (3 t ha^{-1}) with KN_1 –

LCC based (100 % RDN), KR_3 – RDF + residue mulching (6 t ha^{-1}) with KN_2 – LCC based (75 % RDN) and KR_2 – RDF + residue mulching (3 t ha^{-1}) with KN_2 – LCC based (75 % RDN) during both the years and on mean basis.

4.1.2.9 Harvest index (%)

The data on harvest index as increased by tillage practices in rice, residual of residues in maize and nitrogen management in rice are presented in Table 4.9.

The results found that the effect of tillage practices in rice, residual of residues in maize and nitrogen management in rice as well as their interactions did not have significant effect on harvest index of rice during both the years and on mean basis.

Discussion on yield of grain and straw

Between the tillage practices in rice, conventional tillage (CT) produced significantly higher grain and straw yields of rice as compared to zero tillage (ZT). This might own to better availability of nutrients even during later reproductive and grain filling stage, which resulted in increased rate of photosynthesis, better assimilation of carbohydrates which has direct bearing on grain weight per panicle and yield. This could be ascribed to more number of effective tillers and highest number of grains $panicle^{-1}$ as well as maximum grain and straw yields of rice. The similar results are in agreement with the findings of Gangwar and Singh (2004) and Gill and Walia (2013). Similar or higher rice yields with conventional tillage treatments (Sapkota *et al*., 2015) might be due to favourable effect of tillage practices on hastening of organic matter decomposition and higher nutrient availability and enhanced root growth. The lowest yield was recorded under zero tillage treatments where lower yield is attributed to mainly high infestation of weeds, high bulk density which causes higher tillering mortality, lower dry matter accumulation, stunted growth and ultimately lower grain yield. Similar results were also noted by Bhatacharaya *et al*. (2006).

As regards to effect of residual of residues in maize, significantly maximum grain and straw yields of rice was recorded under RDF + residue mulching (6 t ha^{-1}) as compared to RDF + no residue, but it was statistically similar to RDF + residue mulching (3 t ha^{-1}). This might be due to better vegetative growth *i.e.* dry matter accumulation, leaf area index as well as yield attributes like effective tillers, panicle weight, number of total and filled grains in above treatments. These results are in agreement with the reported by Sharma *et al*. (2009) and Gangwar *et al*. (2014).

Regarding effect of nitrogen management in rice, LCC based (100 % RDN) observed significantly higher grain and straw yields of rice as compared to LCC based (75 % RDN). This might be due to better supply of nitrogen at critical stages of crop growth as well as increased accumulation of photosynthetic from the source to the sink, which resulted in higher yield (Singh and Kumar, 2014). Significant increase in grain and straw yields could be attributed to the fact that nitrogen application improved the N, P and K uptake by the crop plants and ultimately photosynthetic activities, resulting in growth and yield attributes, which laid down the foundation of higher yield (Sharma *et al*., 2007). These results are in agreement with the finding of Jakhar *et al*. (2005) and Pandey *et al*. (2008).

Interaction between RDF + residue mulching (6 t ha^{-1}) with LCC based (100 % RDN) produced significantly higher grain and straw yields of rice as compared to other interactions, but it was at par to interactions of RDF + residue mulching (3 t ha^{-1}) with LCC based (100 % RDN), RDF + residue mulching (6 t ha^{-1}) with LCC based (75 % RDN) and RDF + residue mulching (3 t ha^{-1}) with LCC based (75 % RDN). This might be due to fact that higher yield attributes like effective tillers, panicle weight, total and filled grains $panicle^{-1}$ were recorded under above interactions which in turn resulted in higher grain and straw yields of rice. These results are in accordance to the finding of Casky *et al*. (1998) and Okonji *et al*. (2010).

4.1.3 Studies on weeds

Weed growth was measured in terms of density and dry weight of weeds. As wide variations existed across the different treatments, data on density and dry weight of different weed species were transformed through square root method before analysis of variance and original values are presented in parentheses in Table 4.11 to 4.16.

4.1.3.1 Total weed density (No. m^{-2})

The data pertaining to total weed density noted at 25 and 50 DAS in rice as influenced by tillage practices in rice, residual of residues in maize and nitrogen management in rice are presented in Table 4.11.

Between the tillage practices in rice, except at 50 DAS, significantly lower total weed density at 25 DAS was recorded under KT_1 – conventional tillage (CT) as compared to KT_2 – zero tillage (ZT) during both the years and on mean basis.

The results revealed that the effect of residual of residues in maize and nitrogen management in rice as well as interactions of different treatments did not have significant impact on total weed density at different durations during both the years and on mean basis.

4.1.3.2 Density of different weed species (No. m^{-2})

The data on density of different weed species recorded at 25 and 50 DAS in rice as influenced by tillage practices in rice, residual of residues in maize and nitrogen management in rice are presented in Table 4.12 and Table 4.13, respectively.

As regards to tillage practices in rice, except at 50 DAS, significantly lower density of *Echinochloa colona*, *Digitaria sanguinalis*, *Cyperus iria* and other weeds at 25 DAS were recorded under KT_1 – conventional tillage (CT) as compared to KT_2 – zero tillage (ZT) throughout both the years and on mean basis. The density of *Spilanthes acmella* and *Ludwigia parviflora* remained unaffected at 25 and 50 DAS throughout both the years and on mean basis.

The results indicated that the effect of residual of residues in maize and nitrogen management in rice as well as interactions of different treatments did not have significant effect on density of different weed species at 25 and 50 DAS during both the years and on mean basis.

4.1.3.3 Total weed dry weight (g m^{-2})

The data on total weed dry weight presented in Table 4.14 reveals that between the tillage practices in rice, except at 50 DAS, KT_1 – conventional tillage (CT) recorded significantly lower total weed dry weight at 25 DAS as compared to KT_2 – zero tillage (ZT) during both the years and on mean basis.

Table 4.11: Effect of tillage, residual of residues and nitrogen management on total weed density at 25 and 50 DAS in rice

Treatment	Total weed density (No. m^{-2})					
	25 DAS			50 DAS		
	2016	2017	Mean	2016	2017	Mean
Tillage						
KT_1: Conventional tillage (CT)	7.84 (61.17)	7.90 (62.27)	7.87 (61.72)	8.39 (70.20)	8.43 (82.68)	8.41 (82.57)
KT_2: Zero tillage (ZT)	9.74 (94.61)	9.80 (95.63)	9.77 (95.12)	9.09 (82.46)	9.11 (82.68)	9.10 (82.57)
SEm±	0.22	0.25	0.23	0.24	0.25	0.24
CD (P=0.05)	1.34	1.53	1.42	NS	NS	NS
Residual of residues						
R_1: RDF + No residue	9.19 (84.79)	9.16 (84.36)	9.17 (84.58)	9.08 (82.35)	9.19 (84.36)	9.14 (83.35)
KR_2: RDF + Residue mulching (3 t ha^{-1})	8.83 (78.56)	8.83 (78.43)	8.83 (78.49)	8.77 (76.82)	8.74 (76.25)	8.76 (76.54)
KR_3: RDF + Residue mulching (6 t ha^{-1})	8.36 (70.32)	8.57 (74.07)	8.46 (72.19)	8.37 (69.82)	8.36 (69.66)	8.37 (69.74)
SEm±	0.25	0.28	0.27	0.23	0.24	0.24
CD (P=0.05)	NS	NS	NS	NS	NS	NS
Nitrogen management						
KN_1: LCC based (100 % RDN)	8.94 (80.53)	9.06 (82.58)	9.00 (81.55)	9.01 (80.93)	9.00 (80.84)	9.00 (80.88)
KN_2: LCC based (75 % RDN)	8.65 (75.25)	8.64 (75.32)	8.64 (75.29)	8.48 (71.73)	8.53 (72.67)	8.50 (72.20)
SEm±	0.20	0.19	0.19	0.19	0.20	0.19
CD (P=0.05)	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS

***Original data are given in parenthesis.**

Table 4.12: Effect of tillage, residual of residues and nitrogen management on density of different weed species at 25 DAS in rice

Treatment	Weed density (No. m^{-2})																	
	Echinochloa colona			*Digiteria sanguinalis*			*Cyperus iria*			*Ludwigia parviflora*			*Spilanthes acmella*			Others		
	2016	**2017**	**Mean**	**2016**	**2017**	**mean**	**2016**	**2017**	**Mean**	**2016**	**2017**	**Mean**	**2016**	**2017**	**Mean**	**2016**	**2017**	**Mean**
Tillage																		
KT_1: Conventional tillage (CT)	3.9	3.6	3.7	3.4	3.8	3.6	3.24	3.58	3.41	2.8	3.3	3.1	2.8	2.5	2.7	3.2	2.7	2.9
	(14.7)	(12.3)	(13.5)	(11.4)	(14.2)	(12.8)	(10.1)	(12.4)	(11.2)	(7.6)	(10.8)	(9.2)	(7.6)	(5.9)	(6.7)	(9.8)	(6.7)	(8.3)
KT_2: Zero tillage (ZT)	5.1	4.9	5.0	4.6	4.8	4.7	4.2	4.6	4.4	3.3	3.6	3.5	3.1	2.6	2.9	3.6	3.2	3.4
	(25.2)	(23.6)	(24.4)	(20.3)	(22.7)	(21.5)	(17.1)	(20.5)	(18.8)	(10.3)	(12.8)	(11.6)	(9.4)	(6.1)	(7.8)	(12.2)	(9.9)	(11.1)
SEm±	0.11	0.11	0.11	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.11	0.10	0.08	0.07	0.08	0.05	0.05	0.05
CD (P=0.05)	0.65	0.67	0.66	0.67	0.70	0.68	0.62	0.59	0.60	NS	NS	NS	NS	NS	NS	0.32	0.33	0.33
Residual of residues																		
KR_1: RDF + No residue	4.7	4.4	4.5	4.2	4.4	4.3	3.8	4.2	4.0	3.3	3.6	3.5	3.1	2.6	2.8	3.5	3.1	3.3
	(21.5)	(19.5)	(20.5)	(17.4)	(19.2)	(18.3)	(14.6)	(17.6)	(16.1)	(10.3)	(12.9)	(11.6)	(9.3)	(6.2)	(7.7)	(11.8)	(9.1)	(10.4)
KR_2: RDF + Residue mulching (3 t ha^{-1})	4.5	4.2	4.4	4.0	4.3	4.2	3.7	4.1	3.9	3.0	3.5	3.3	3.0	2.5	2.8	3.4	2.9	3.2
	(20.0)	(17.8)	(18.9)	(16.1)	(18.2)	(17.3)	(13.7)	(16.4)	(15.0)	(8.8)	(11.8)	(10.3)	(8.6)	(5.9)	(7.2)	(11.3)	(8.0)	(9.7)
KR_3: RDF + Residue mulching (6 t ha^{-1})	4.3	4.1	4.2	3.8	4.2	4.0	3.6	4.0	3.8	2.9	3.3	3.1	2.9	2.5	2.7	3.3	2.9	3.1
	(18.3)	(16.6)	(17.5)	(14.0)	(17.6)	(15.8)	(12.6)	(15.5)	(14.0)	(7.7)	(10.7)	(9.2)	(7.7)	(5.8)	(6.8)	(10.0)	(7.8)	(8.9)
SEm±	0.11	0.12	0.11	0.11	0.12	0.12	0.11	0.12	0.11	0.10	0.13	0.11	0.09	0.08	0.08	0.07	0.06	0.06
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Nitrogen management																		
KN_1: LCC based (100 % RDN)	4.5	4.3	4.4	4.0	4.4	4.2	3.8	4.2	4.0	3.2	3.6	3.4	3.1	2.6	2.8	3.4	3.0	3.2
	(20.0)	(18.6)	(19.3)	(16.0)	(19.0)	(17.5)	(14.4)	(17.4)	(15.9)	(9.6)	(12.8)	(11.2)	(9.1)	(6.1)	(7.6)	(11.3)	(8.6)	(10.0)
KN_2: LCC based (75 % RDN)	4.5	4.2	4.3	4.0	4.2	4.1	3.6	4.0	3.8	2.9	3.3	3.1	2.9	2.5	2.7	3.3	2.9	3.1
	(19.9)	(17.4)	(18.6)	(15.7)	(17.8)	(16.8)	(12.8)	(15.5)	(14.1)	(8.3)	(10.8)	(9.5)	(7.9)	(5.8)	(6.9)	(10.7)	(8.0)	(9.4)
SEm±	0.08	0.09	0.08	0.07	0.08	0.07	0.07	0.09	0.08	0.07	0.10	0.09	0.07	0.06	0.07	0.05	0.04	0.04
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

***Original data are given in parenthesis.**

Table 4.13: Effect of tillage, residual of residues and nitrogen management on density of different weed species at 50 DAS in rice

Treatment	Weed density (No. m^{-2})																	
	Echinochloa colona			*Digiteria sanguinalis*			*Cyperus iria*			*Ludwigia parviflora*			*Spilanthes acmella*			Others		
	2016	**2017**	**Mean**	**2016**	**2017**	**Mean**	**2016**	**2017**	**Mean**	**2016**	**2017**	**Mean**	**2016**	**2017**	**Mean**	**2016**	**2017**	**Mean**
Tillage																		
KT_1: Conventional tillage (CT)	3.9	3.8	3.8	3.7	3.8	3.7	3.3	3.4	3.4	3.1	3.3	3.2	3.3	3.5	3.4	3.5	3.1	3.3
	(14.9)	(13.7)	(14.3)	(13.3)	(14.0)	(13.7)	(10.7)	(11.4)	(11.0)	(9.1)	(10.7)	(9.9)	(10.2)	(11.7)	(10.9)	(12.0)	(9.4)	(10.7)
KT_2: Zero tillage (ZT)	4.3	4.0	4.2	4.0	4.1	4.1	3.6	3.7	3.7	3.2	3.6	3.4	3.6	3.8	3.7	3.6	3.3	3.5
	(18.4)	(15.6)	(17.0)	(15.6)	(16.7)	(16.1)	(12.9)	(13.2)	(13.1)	(10.1)	(12.3)	(11.2)	(12.6)	(14.3)	(13.4)	(12.8)	(10.6)	(11.7)
SEm±	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.06	0.08	0.07	0.0	0.0	0.0
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Residual of residues																		
KR_1: RDF + No residue	4.2	4.0	4.1	4.0	4.2	4.1	3.7	3.9	3.8	3.4	3.6	3.5	3.5	3.8	3.7	3.7	3.3	3.5
	(17.7)	(15.6)	(16.7)	(15.3)	(17.0)	(16.1)	(13.5)	(14.4)	(14.0)	(11.0)	(12.5)	(11.8)	(11.8)	(14.1)	(12.9)	(13.1)	(10.6)	(11.8)
KR_2: RDF + Residue mulching	4.2	3.9	4.0	3.8	4.0	3.9	3.4	3.5	3.5	3.1	3.4	3.3	3.5	3.6	3.6	3.6	3.2	3.4
(3 t ha^{-1})	(17.1)	(14.4)	(15.8)	(14.3)	(15.4)	(14.8)	(11.6)	(12.1)	(11.8)	(9.4)	(11.5)	(10.4)	(12.0)	(12.9)	(12.4)	(12.5)	(10.0)	(11.2)
KR_3: RDF + Residue mulching	3.9	3.8	3.9	3.8	3.8	3.8	3.3	3.3	3.3	3.0	3.3	3.1	3.3	3.5	3.4	3.5	3.1	3.3
(6 t ha^{-1})	(15.1)	(13.9)	(14.5)	(13.7)	(13.7)	(13.7)	(10.4)	(10.4)	(10.4)	(8.4)	(10.5)	(9.5)	(10.5)	(11.9)	(11.2)	(11.7)	(9.4)	(10.6)
SEm±	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.07	0.09	0.08	0.0	0.1	0.1
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Nitrogen management																		
KN_1: LCC based (100 % RDN)	4.1	3.8	4.0	3.7	3.9	3.8	3.3	3.4	3.3	3.0	3.3	3.1	3.5	3.7	3.6	3.5	3.2	3.3
	(17.1)	(15.1)	(16.1)	(15.3)	(15.8)	(15.6)	(13.2)	(13.3)	(13.2)	(10.6)	(12.7)	(11.6)	(11.8)	(13.6)	(12.7)	(12.9)	(10.5)	(11.7)
KN_2: LCC based (75 % RDN)	4.2	3.9	4.1	4.0	4.0	4.0	3.7	3.7	3.7	3.3	3.6	3.5	3.4	3.6	3.5	3.7	3.3	3.5
	(16.2)	(14.2)	(15.2)	(13.5)	(14.9)	(14.2)	(10.4)	(11.4)	(10.9)	(8.6)	(10.3)	(9.5)	(11.0)	(12.4)	(11.7)	(11.9)	(9.5)	(10.7)
SEm±	0.0	0.1	0.0	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.05	0.06	0.06	0.0	0.1	0.0
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

***Original data are given in parenthesis.**

Table 4.14: Effect of tillage, residual of residues and nitrogen management on total weed dry weight at 25 and 50 DAS in rice

Treatment	Total weed dry weight (g m^{-2})					
	25 DAS			50 DAS		
	2016	2017	Mean	2016	2017	Mean
Tillage						
KT_1: Conventional tillage (CT)	3.17 (9.55)	3.23 (9.92)	3.20 (9.74)	6.34 (39.73)	6.67 (44.05)	6.51 (41.89)
KT_2: Zero tillage (ZT)	3.75 (13.56)	3.77 (13.70)	3.76 (13.63)	7.00 (48.54)	7.23 (51.78)	7.12 (50.16)
SEm±	0.08	0.07	0.08	0.17	0.18	0.17
CD (P=0.05)	0.50	0.45	0.48	NS	NS	NS
Residual of residues						
KR_1: RDF + No residue	3.50 (11.84)	3.54 (12.14)	3.52 (11.99)	6.72 (44.83)	7.00 (48.53)	6.86 (46.68)
KR_2: RDF + Residue mulching (3 t ha^{-1})	3.46 (11.57)	3.49 (11.79)	3.48 (11.68)	6.69 (44.35)	6.94 (47.80)	6.82 (46.07)
KR_3: RDF + Residue mulching (6 t ha^{-1})	3.42 (11.27)	3.45 (11.50)	3.44 (11.39)	6.60 (43.23)	6.92 (47.41)	6.76 (45.32)
SEm±	0.09	0.08	0.08	0.17	0.18	0.18
CD (P=0.05)	NS	NS	NS	NS	NS	NS
Nitrogen management						
KN_1: LCC based (100 % RDN)	3.49 (11.76)	3.52 (11.98)	3.51 (11.87)	6.72 (44.78)	7.00 (48.61)	6.86 (46.70)
KN_2: LCC based (75 % RDN)	3.43 (11.36)	3.47 (11.64)	3.45 (11.50)	6.62 (43.49)	6.90 (47.22)	6.76 (45.35)
SEm±	0.06	0.05	0.06	0.11	0.12	0.11
CD (P=0.05)	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS

***Original data are given in parenthesis.**

Whereas, effect of residual of residues in maize and nitrogen management in rice as well as interaction effect of different treatments did not have significant effect on total weed dry weight at 25 and 50 DAS throughout both the years and on mean basis.

4.1.3.4 Dry weight of different weed species (g m^{-2})

The data on dry weight of different weed species recorded at 25 and 50 DAS as influenced by tillage practices in rice, residual of residues in maize and nitrogen management in rice are presented in Table 4.15 and Table 4.16, respectively.

Between the tillage practices, except at 50 DAS, significantly lower dry weight of *Echinochloa colona*, *Digitaria sanguinalis*, *Cyperus iria* and other weeds at 25 DAS were recorded under KT_1 – conventional tillage (CT) as compared to KT_2 – zero tillage (ZT) during both the years and on mean basis. The dry weight of *Spilanthes acmella* and *Ludwigia parviflora* were found non-significant at 25 and 50 DAS throughout both the years and on mean basis.

The results indicated that the effect of residual of residues in maize, nitrogen management in rice and interaction effect of different treatments were found non – significant with respect to dry weight of different weed species at 25 and 50 DAS during both the years and on mean basis.

Discussion on weeds

As regards to tillage practices in rice, conventional tillage (CT) registered significantly lower total and species wise density and dry weight of weeds as compared to zero tillage (ZT). This might be due to the deposition of more weed seeds and propagation of weeds near the soil surface and reduced herbicide availability as well as higher weed seed bank under conservation tillage and 16.70 per cent yield loss has been observed under conservation tillage in comparison to conventional tillage (Jadhav *et al.*, 2014). These results indicated that low soil disturbance systems as a result of zero tillage is likely to leave a large portion of the weed seeds on the soil surface, where light stimulates seed germination, resulting in higher seedling emergence than high soil disturbance system (Chauhan

Table 4.15: Effect of tillage, residual of residues and nitrogen management on dry weight of different weed species at 25 DAS in rice

Treatment	Weed dry weight (g m^{-2})																	
	Echinochloa colona			*Digiteria sanguinalis*			*Cyperus iria*			*Ludwigia parviflora*			*Spilanthes acmella*			Others		
	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean
Tillage																		
KT_1: Conventional tillage (CT)	1.50 (1.74)	1.46 (1.64)	1.48 (1.69)	1.58 (2.00)	1.71 (2.41)	1.64 (2.21)	1.30 (1.18)	1.41 (1.48)	1.35 (1.33)	1.52 (1.81)	1.59 (2.02)	1.55 (1.92)	1.30 (1.19)	1.24 (1.11)	1.27 (1.15)	1.46 (1.62)	1.32 (1.26)	1.39 (1.44)
KT_2: Zero tillage (ZT)	1.82 (2.80)	1.71 (2.41)	1.76 (2.61)	1.89 (3.10)	2.03 (3.62)	1.96 (3.36)	1.44 (1.59)	1.55 (1.89)	1.50 (1.74)	1.71 (2.43)	1.77 (2.65)	1.74 (2.54)	1.31 (1.22)	1.25 (1.19)	1.30 (1.21)	1.71 (2.43)	1.56 (1.93)	1.63 (2.18)
SEm±	0.05	0.04	0.04	0.05	0.05	0.05	0.02	0.02	0.02	0.03	0.02	0.03	0.03	0.02	0.02	0.02	0.03	0.03
CD (P=0.05)	0.28	0.23	0.26	0.29	0.28	0.28	0.15	0.13	0.14	NS	NS	NS	NS	NS	NS	0.12	0.21	0.16
Residual of residues																		
KR_1: RDF + No residue	1.68 (2.35)	1.63 (2.17)	1.65 (2.26)	1.76 (2.63)	1.88 (3.08)	1.82 (2.85)	1.39 (1.43)	1.48 (1.71)	1.44 (1.57)	1.62 (2.14)	1.70 (2.41)	1.66 (2.27)	1.31 (1.21)	1.25 (1.17)	1.29 (1.19)	1.60 (2.08)	1.45 (1.61)	1.52 (1.84)
KR_2: RDF + Residue mulching (3 t ha^{-1})	1.65 (2.26)	1.58 (2.02)	1.62 (2.14)	1.74 (2.58)	1.87 (3.01)	1.81 (2.80)	1.37 (1.38)	1.48 (1.69)	1.42 (1.53)	1.62 (2.12)	1.67 (2.30)	1.64 (2.21)	1.30 (1.20)	1.24 (1.15)	1.29 (1.18)	1.58 (2.03)	1.44 (1.60)	1.51 (1.82)
KR_3: RDF + Residue mulching (6 t ha^{-1})	1.64 (2.20)	1.54 (1.89)	1.59 (2.05)	1.71 (2.45)	1.85 (2.96)	1.78 (2.70)	1.36 (1.35)	1.47 (1.66)	1.41 (1.51)	1.61 (2.11)	1.67 (2.29)	1.64 (2.20)	1.30 (1.19)	1.24 (1.13)	1.28 (1.16)	1.57 (1.97)	1.43 (1.57)	1.50 (1.77)
SEm±	0.05	0.04	0.05	0.05	0.06	0.05	0.03	0.02	0.03	0.03	0.03	0.03	0.03	0.02	0.03	0.02	0.04	0.02
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Nitrogen management																		
KN_1: LCC based (100 % RDN)	1.67 (2.33)	1.61 (2.09)	1.64 (2.21)	1.76 (2.61)	1.87 (3.04)	1.81 (2.83)	1.38 (1.41)	1.49 (1.73)	1.43 (1.57)	1.63 (2.16)	1.68 (2.35)	1.66 (2.25)	1.31 (1.21)	1.24 (1.16)	1.29 (1.19)	1.59 (2.04)	1.45 (1.61)	1.52 (1.83)
KN_2: LCC based (75 % RDN)	1.64 (2.22)	1.56 (1.96)	1.60 (2.09)	1.72 (2.49)	1.86 (2.99)	1.79 (2.74)	1.36 (1.36)	1.46 (1.65)	1.41 (1.51)	1.60 (2.09)	1.68 (2.32)	1.64 (2.21)	1.30 (1.19)	1.24 (1.14)	1.28 (1.17)	1.58 (2.01)	1.43 (1.57)	1.51 (1.79)
SEm±	0.04	0.03	0.03	0.03	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

***Original data are given in parenthesis.**

Table 4.16: Effect of tillage, residual of residues and nitrogen management on dry weight of different weed species at 50 DAS in rice

Treatment	Weed dry weight (g m^{-2})																	
	Echinochloa colona			*Digiteria sanguinalis*			*Cyperus iria*			*Ludwigia parviflora*			*Spilanthes acmella*			Others		
	2016	**2017**	**Mean**	**2016**	**2017**	**Mean**	**2016**	**2017**	**Mean**	**2016**	**2017**	**Mean**	**2016**	**2017**	**Mean**	**2016**	**2017**	**Mean**
Tillage																		
KT_1: Conventional tillage (CT)	2.96	3.15	3.05	2.77	3.11	2.94	2.69	2.82	2.76	2.77	2.85	2.81	2.37	2.58	2.47	2.40	2.17	2.28
	(8.26)	(9.40)	(8.83)	(7.16)	(9.17)	(8.16)	(6.75)	(7.47)	(7.11)	(7.19)	(7.66)	(7.42)	(5.12)	(6.15)	(5.63)	(5.26)	(4.21)	(4.73)
KT_2: Zero tillage (ZT)	3.20	3.38	3.29	3.09	3.35	3.22	3.03	3.10	3.07	3.01	3.08	3.04	2.49	2.61	2.55	2.70	2.49	2.59
	(9.21)	(10.90)	(10.06)	(9.05)	(10.03)	(9.54)	(8.70)	(9.13)	(8.92)	(8.56)	(8.98)	(8.77)	(5.70)	(6.33)	(6.02)	(6.78)	(5.71)	(6.24)
SEm±	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.05	0.02	0.03	0.05	0.05	0.05
CD (P=0.05)																		
Residual of residues																		
KR_1: RDF + No residue	3.12	3.30	3.21	2.94	3.23	3.09	2.88	2.98	2.93	2.90	3.00	2.95	2.44	2.60	2.52	2.57	2.34	2.45
	(8.96)	(10.39)	(9.68)	(8.20)	(9.62)	(8.91)	(7.86)	(8.41)	(8.14)	(7.94)	(8.51)	(8.23)	(5.44)	(6.25)	(5.85)	(6.15)	(5.00)	(5.58)
KR_2: RDF + Residue mulching	3.09	3.25	3.17	2.93	3.23	3.08	2.88	2.96	2.92	2.89	2.96	2.92	2.43	2.60	2.52	2.55	2.33	2.44
(3 t ha^{-1})	(8.81)	(10.10)	(9.46)	(8.12)	(9.60)	(8.86)	(7.81)	(8.31)	(8.06)	(7.86)	(8.27)	(8.06)	(5.43)	(6.24)	(5.84)	(6.04)	(4.94)	(5.49)
KR_3: RDF + Residue mulching	3.03	3.23	3.13	2.91	3.23	3.07	2.82	2.94	2.88	2.88	2.94	2.91	2.42	2.59	2.50	2.52	2.32	2.42
(6 t ha^{-1})	(8.43)	(9.96)	(9.20)	(7.99)	(9.58)	(8.79)	(7.50)	(8.19)	(7.84)	(7.82)	(8.17)	(8.00)	(5.36)	(6.22)	(5.79)	(5.86)	(4.93)	(5.40)
SEm±	0.08	0.07	0.08	0.07	0.08	0.07	0.06	0.07	0.06	0.04	0.05	0.04	0.05	0.02	0.02	0.06	0.05	0.05
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Nitrogen management																		
KN_1: LCC based (100 % RDN)	3.11	3.28	3.19	2.95	3.25	3.10	2.89	3.00	2.94	2.91	3.00	2.95	2.44	2.60	2.52	2.55	2.34	2.44
	(8.90)	(10.29)	(9.59)	(8.25)	(9.72)	(8.99)	(7.87)	(8.51)	(8.19)	(8.00)	(8.49)	(8.25)	(5.45)	(6.27)	(5.86)	(6.04)	(4.98)	(5.51)
KN_2: LCC based (75 % RDN)	3.05	3.24	3.14	2.90	3.21	3.06	2.84	2.93	2.88	2.87	2.94	2.90	2.42	2.59	2.51	2.54	2.32	2.43
	(8.57)	(10.01)	(9.29)	(7.96)	(9.47)	(8.72)	(7.58)	(8.09)	(7.83)	(7.75)	(8.14)	(7.94)	(5.38)	(6.21)	(5.79)	(5.99)	(4.94)	(5.46)
SEm±	0.05	0.06	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.02	0.03	0.03	0.04	0.02	0.03	0.05	0.04	0.04
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

***Original data are given in parenthesis.**

and Johnson, 2009). Singh *et al*. (2005) also reported that *Cyperus rotundus* and *Commelina diffusa* Burn. were dominant weeds of drill sown rice under zero tillage. The zero tillage with residues retention suppressed weed seedling emergence, delayed the time of emergence and allowed the crop to gain an advantage over weeds that ultimately enhanced the crop growth (Nath *et al*., 2015).

The effect of residual of residues in maize and nitrogen management in rice did not have significant impact on density and dry weight of different weed species at 25 and 50 DAS. These results were also reported by Gupta *et al*. (2006) and Singh *et al*. (2008). Ramesh *et al*. (2009) also reported that weed density as well as weed dry weights in rice were not influenced by different nitrogen levels at all the stages of crop growth.

4.1.4 Chemical studies

4.1.4.1 N, P and K content (%) in grain and straw

The data on N, P and K content in grain and straw of rice as influenced by tillage practices in rice, residual of residues in maize and nitrogen management in rice are presented in Table 4.17 and Table 4.18, respectively.

The findings revealed that the effect of tillage practices in rice, residual of residues in maize and nitrogen management in rice as well as their interactions did not show any significant influence with respect to N, P and K content in grain and straw of rice throughout both the years and on mean basis.

4.1.4.2 N, P and K uptake (kg ha^{-1}) by rice

The data regarding N, P and K uptake by rice as influenced by tillage practices in rice, residual of residues in maize and nitrogen management in rice are presented in Table 4.19.

As regards to the tillage practices in rice, N, P and K uptake by rice were recorded significantly maximum under KT_1 – conventional tillage (CT) as compared to KT_2 – zero tillage (ZT) during both the years and on mean basis.

In case of residual of residues in maize, treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) registered significantly maximum N, P and K uptake by rice as

Table 4.17: Nutrient content in grain of rice as influenced by tillage, residual of residues and nitrogen management

Treatment	N content in grain (%)			P content in grain (%)			K content in grain (%)		
	2016	**2017**	**Mean**	**2016**	**2017**	**Mean**	**2016**	**2017**	**Mean**
Tillage									
KT_1: Conventional tillage (CT)	1.27	1.29	1.28	0.24	0.26	0.25	0.41	0.43	0.42
KT_2: Zero tillage (ZT)	1.25	1.28	1.27	0.23	0.24	0.23	0.40	0.41	0.40
SEm±	0.03	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.01
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Residual of residues									
KR_1: RDF + No residue	1.25	1.27	1.26	0.23	0.24	0.24	0.40	0.41	0.40
KR_2: RDF + Residue mulching (3 t ha^{-1})	1.26	1.29	1.27	0.23	0.25	0.24	0.40	0.42	0.41
KR_3: RDF + Residue mulching (6 t ha^{-1})	1.27	1.30	1.28	0.24	0.26	0.25	0.41	0.43	0.42
SEm±	0.03	0.03	0.02	0.01	0.01	0.00	0.01	0.01	0.01
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Nitrogen management									
KN_1: LCC based (100 % RDN)	1.27	1.30	1.29	0.24	0.26	0.25	0.41	0.42	0.42
KN_2: LCC based (75 % RDN)	1.25	1.27	1.26	0.23	0.24	0.24	0.40	0.41	0.41
SEm±	0.02	0.02	0.02	0.01	0.00	0.00	0.01	0.01	0.01
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 4.18: Nutrient content in straw of rice as influenced by tillage, residual of residues and nitrogen management

Treatment	N content in straw (%)			P content in straw (%)			K content in straw (%)		
	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean
Tillage									
KT_1: Conventional tillage (CT)	0.36	0.38	0.37	0.10	0.11	0.10	1.31	1.29	1.30
KT_2: Zero tillage (ZT)	0.34	0.37	0.35	0.10	0.10	0.10	1.29	1.26	1.28
SEm±	0.01	0.01	0.01	0.00	0.00	0.00	0.03	0.03	0.00
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Residual of residues									
KR_1: RDF + No residue	0.33	0.36	0.35	0.10	0.10	0.10	1.29	1.27	1.28
KR_2: RDF + Residue mulching (3 t ha^{-1})	0.35	0.37	0.36	0.10	0.11	0.10	1.30	1.28	1.29
KR_3: RDF + Residue mulching (6 t ha^{-1})	0.36	0.38	0.37	0.11	0.11	0.11	1.31	1.29	1.30
SEm±	0.01	0.01	0.01	0.00	0.00	0.00	0.04	0.03	0.03
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Nitrogen management									
KN_1: LCC based (100 % RDN)	0.35	0.38	0.37	0.10	0.11	0.10	1.31	1.28	1.30
KN_2: LCC based (75 % RDN)	0.34	0.37	0.35	0.10	0.10	0.10	1.29	1.27	1.28
SEm±	0.01	0.01	0.01	0.00	0.00	0.00	0.02	0.02	0.01
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 4.19: N, P and K uptake by rice as influenced by tillage, residual of residues and nitrogen management

Treatment	N uptake (kg ha^{-1})			P uptake (kg ha^{-1})			K uptake (kg ha^{-1})		
	2016	**2017**	**Mean**	**2016**	**2017**	**Mean**	**2016**	**2017**	**Mean**
Tillage									
KT_1: Conventional tillage (CT)	101.38	106.41	103.89	21.98	23.92	22.95	120.36	122.43	121.40
KT_2: Zero tillage (ZT)	90.28	94.51	92.39	19.07	19.96	19.51	107.27	107.41	107.34
SEm±	1.58	1.73	1.65	0.42	0.48	0.45	1.92	2.33	2.12
CD (P=0.05)	9.64	10.53	10.01	2.54	2.90	2.72	11.67	14.15	12.90
Residual of residues									
KR_1: RDF + No residue	87.09	91.22	89.16	18.71	19.77	19.24	106.25	107.00	106.63
KR_2: RDF + Residue mulching (3 t ha^{-1})	98.18	102.67	100.43	20.75	22.19	21.47	115.55	116.75	116.15
KR_3: RDF + Residue mulching (6 t ha^{-1})	102.22	107.48	104.85	22.10	23.85	22.98	119.65	121.01	120.33
SEm±	1.98	1.87	1.91	0.51	0.59	0.55	2.21	2.44	2.32
CD (P=0.05)	6.46	6.10	6.24	1.65	1.92	1.79	7.21	7.96	7.57
Nitrogen management									
KN_1: LCC based (100 % RDN)	99.93	104.88	102.40	21.51	23.11	22.31	117.43	118.77	118.10
KN_2: LCC based (75 % RDN)	91.73	96.04	93.88	19.54	20.76	20.15	110.20	111.07	110.64
SEm±	1.49	1.46	1.46	0.38	0.42	0.40	1.67	1.99	1.83
CD (P=0.05)	4.60	4.49	4.51	1.17	1.30	1.24	5.15	6.12	5.63
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS

compared to treatment KR_1 – RDF + no residue, but it was at par to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) throughout both the years and on mean basis.

Between nitrogen management in rice, treatment KN_1 – LCC based (100 % RDN) recorded significantly higher N, P and K uptake by rice as compared to treatment KN_2 – LCC based (75 % RDN) during both the years and on mean basis.

The interaction among tillage practices in rice, residual of residues in maize and nitrogen management in rice were found non-significant with respect to N, P and K uptake by rice during both the years and on mean basis.

Discussion on uptake of rice

Regarding tillage practices in rice, nutrient uptake (N, P and K) by rice were recorded significantly higher under conventional tillage (CT) as compared to zero tillage (ZT). This might be because of more available form of these nutrients in the soil under conventional tillage. Conventional tillage resulted highest nutrient uptake than zero tillage which might be due to higher nutrient content and dry matter production. Similar observations were recorded by Gangwar and Singh (2004) and Mahajan and Timsina (2011). Huang *et al*. (2016b) also reported that no tillage rice had 17 – 43 per cent less N, P and K uptake than conventional tillage rice. Whereas Singh *et al.* (2018) noted that the total K uptake in rice was significantly higher under TPR/CTM as compared to CTDSR/CTM and ZTDSR/ZTM.

Among the residual of residues in maize, RDF + residue mulching (6 t ha^{-1}) registered significantly highest N, P and K uptake by rice as compared to RDF + no residue, but it was comparable to RDF + residue mulching (3 t ha^{-1}). This might be due to slow decomposition of mulched biomass and increased nutrient availability, which benefited rice in term of nutrient uptake. Similar findings were observed by Narendra and Gautam (2004). Singh *et al*. (2011) also revealed that pronounced increase in N, P and K uptake of succeeding crop due to mulching with 23.8, 31.3 and 21.5 per cent increase in uptake, respectively than non – mulching.

As regards to nitrogen management in rice, LCC based (100 % RDN) recorded significantly highest N, P and K uptake by rice as compared to LCC based (75 % RDN). This might be owing to more vegetative growth and increased foraging capacity of roots which in turn increased the uptake of N, P and K by crop. The uptake of nutrient is a function of dry matter and nutrients, the increased grain and straw yields together. The similar results are in agreement with the findings of Kour *et al.* (2005)

4.1.4.3 Partial factor productivity (kg kg^{-1}) and Production efficiency (kg ha^{-1} day^{-1})

The data regarding partial factor productivity of nitrogen, phosphorus and potassium in rice and production efficiency of rice as influenced by tillage practices in rice, residual of residues in maize and nitrogen management in rice are presented in Table 4.20.

The findings indicated that the effect of tillage practices in rice did not show any significant influence with respect to partial factor productivity of nitrogen, phosphorus and potassium in rice throughout both the years and on mean basis. However, significantly highest production efficiency was recorded under KT_1 – conventional tillage (CT) as compared to KT_2 – zero tillage (ZT) during both the years and on mean basis.

In case of residual of residues in maize, treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) registered significantly highest partial factor productivity of nitrogen, phosphorus and potassium as well as production efficiency of rice which was at par to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) and significantly lowest partial factor productivity of nitrogen, phosphorus and potassium as well as production efficiency of rice were noted under treatment KR_1 – RDF + no residue throughout both the years and on mean basis.

Treatment KN_2 – LCC based (75 % RDN) obtained significantly higher partial factor productivity of nitrogen in rice as compared to treatment KN_1 – LCC based (100 % RDN), whereas significantly maximum partial factor productivity of phosphorus and potassium as well as production efficiency of rice was recorded

Table 4.20: Partial factor productivity and production efficiency of rice as influenced by tillage, residual of residues and nitrogen management

Treatment	Partial factor productivity (kg kg^{-1})									Production efficiency (kg ha^{-1} day^{-1})		
	Nitrogen			Phosphorus			Potassium					
	2016	**2017**	**Mean**	**2016**	**2017**	**Mean**	**2016**	**2017**	**Mean**	**2016**	**2017**	**Mean**
Tillage												
KT_1: Conventional tillage (CT)	39.40	39.97	39.69	23.64	23.98	23.81	88.65	89.95	89.30	36.94	37.48	37.21
KT_2: Zero tillage (ZT)	35.94	36.39	36.17	21.56	21.84	21.70	80.84	81.91	81.38	33.68	34.13	33.90
SEm±	0.63	0.65	0.64	0.53	0.55	0.54	2.07	1.93	2.00	0.49	0.51	0.50
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	2.97	3.12	3.04
Residual of residues												
KR_1: RDF + No residue	34.35	34.63	34.49	20.73	20.94	20.84	77.74	78.54	78.14	32.39	32.72	32.55
KR_2: RDF + Residue mulching (3 t ha^{-1})	38.75	39.16	38.95	23.23	23.48	23.35	87.13	88.05	87.59	36.30	36.68	36.49
KR_3: RDF + Residue mulching (6 t ha^{-1})	39.92	40.76	40.34	23.83	24.32	24.08	89.39	91.20	90.29	37.24	38.00	37.62
SEm±	0.67	0.69	0.68	0.53	0.55	0.54	2.03	1.99	2.01	0.51	0.52	0.52
CD (P=0.05)	2.18	2.24	2.21	1.73	1.78	1.76	6.62	6.49	6.55	1.66	1.71	1.68
Nitrogen management												
KN_1: LCC based (100 % RDN)	33.84	34.42	34.13	23.54	23.95	23.74	88.29	89.81	89.05	35.95	36.48	36.22
KN_2: LCC based (75 % RDN)	41.50	41.94	41.72	21.65	21.88	21.77	81.21	82.06	81.63	34.67	35.12	34.90
SEm±	0.54	0.56	0.55	0.41	0.43	0.42	1.59	1.53	1.56	0.41	0.43	0.42
CD (P=0.05)	1.66	1.72	1.69	1.26	1.32	1.29	4.91	4.70	4.80	1.28	1.33	1.30
Interaction	S	S	S	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 4.21: Interaction effect of residual of residues and nitrogen management on partial factor productivity of nitrogen in rice

Nitrogen management \ Residual of residues	KR_1: RDF + No residue	KR_2: RDF + Residue mulching (3 t ha^{-1})	KR_3: RDF + Residue mulching (6 t ha^{-1})	Mean
		2016		
KN_1: LCC based (100 % RDN)	32.28	34.66	34.59	33.84
KN_2: LCC based (75 % RDN)	36.41	42.85	45.25	41.50
Mean	34.35	38.75	39.92	
		2017		
KN_1: LCC based (100 % RDN)	33.07	35.07	35.13	34.42
KN_2: LCC based (75 % RDN)	36.19	43.24	46.38	41.94
Mean	34.63	39.16	40.76	
		Mean		
KN_1: LCC based (100 % RDN)	32.68	34.86	34.86	34.13
KN_2: LCC based (75 % RDN)	36.30	43.04	45.82	41.72
Mean	34.49	38.95	40.34	

	2016		2017		Mean	
	SEm±	**CD (P=0.05)**	**SEm±**	**CD (P=0.05)**	**SEm±**	**CD (P=0.05)**
Comparison of two nitrogen management at same levels of residual of residues	0.93	2.87	0.96	2.97	0.94	2.92
Comparison of two residual of residues at same levels of nitrogen management	0.94	2.98	0.97	3.07	0.95	3.02

under treatment KN_1 – LCC based (100 % RDN) as compared to treatment KN_2 – LCC based (75 % RDN) during both the years and on mean basis.

The interaction effect of residual of residues in maize and nitrogen management in rice on partial factor productivity of nitrogen was found significant for the period of both the years and on mean basis. Interaction between KR_3 – RDF + residue mulching (6 t ha^{-1}) with KN_2 – LCC based (75 % RDN) recorded significantly higher partial factor productivity of nitrogen as compared to other interactions during both the years and on mean basis. However, it was at par to interaction between KR_2 – RDF + residue mulching (3 t ha^{-1}) with KN_2 – LCC based (75 % RDN) and significantly lowest partial factor productivity of nitrogen was noted under interaction between KR_1 – RDF + no residue with KN_1 – LCC based (100 % RDN) for the period of both the years and on mean basis (Table 4.21).

Discussion on partial factor productivity and production efficiency

As regards to residual of residues in maize, RDF + residue mulching (6 t ha^{-1}) registered significantly higher partial factor productivity of nitrogen, phosphorus and potassium as well as production efficiency of rice as compared to RDF + no residue, but it was comparable to RDF + residue mulching (3 t ha^{-1}). This might be owing to higher uptake and more utilization of nutrients form residual of crop residue. Straw return increased the activities of soil microorganism and enzyme, which significantly promoted the availability of soil nitrogen (Xu *et al*., 2009). The higher partial factor productivity of nitrogen from all treatments with the residue application was due to maximum grain yield and it is consistent with the findings of Zhao and Chen (2008). reported to Cassman *et al*. (1996), the partial factor productivity can be improved by increasing the uptake and utilization of indigenous nutrients."

Regarding nitrogen management in rice, LCC based (75 % RDN) obtained significantly highest partial factor productivity of nitrogen in rice as compared to LCC based (100 % RDN). This might be due to higher requirement by the crop at lower rates of application. Declining trend of PFP of N with increasing dose of nitrogen has also been reported by Shivay *et al*, (2016). Sharma *et al*. (2007) also reported that the crop fed with high nitrogen levels increased the grain yield but showed less efficient in recording PFPN. LCC based (100 % RDN) obtained significantly higher partial factor productivity of phosphorus and potassium in rice as well as production efficiency of rice as compared to LCC based (75 % RDN). The similar results are in agreement with the findings of Thakur *et al*. (2013) and Reddy and Padmaja (2013).

4.1.4.4 Carbon pools in soil

The data on total and soil organic carbon, water soluble carbon (WSC), acid hydrolysable carbon (AHC), permanganate oxidizable carbon (POSC), microbial biomass carbon (MBC) and readily mineralizable carbon (RMC) in soil after the harvest of rice as influenced by different tillage practices in rice, residual of residues in maize and nitrogen management in rice are presented in Table 4.22 and Table 4.23.

In case of tillage practices in rice, significantly higher total and soil organic carbon, water soluble carbon, permanganate oxidizable carbon, microbial biomass carbon and readily mineralizable carbon in soil after the harvest of rice were recorded under KT_2 – zero tillage (ZT) as compared to KT_1 – conventional tillage (CT) throughout both the years and on mean basis.

Among the residual of residues in maize, significantly higher total and soil organic carbon, water soluble carbon, acid hydrolysable carbon, permanganate oxidizable carbon, microbial biomass carbon and readily mineralizable carbon in soil after the harvest of rice were recorded under treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) as compared to treatment KR_1 – RDF + no residue, however, it was at par to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) under during both years and on mean basis.

Treatment KN_1 – LCC based (100 % RDN) estimated significantly higher microbial biomass carbon as compared to treatment KN_2 – LCC based (75 % RDN), but total and soil organic carbon, water soluble carbon, acid hydrolysable carbon, permanganate oxidizable carbon and readily mineralizable carbon in soil after the harvest of rice were recorded non-significantly during both the years and on mean basis.

Table 4.22: Total and soil organic carbon, water soluble carbon and acid hydrolysable carbon in soil after the harvest of rice as influenced by tillage, residual of residues and nitrogen management

Treatment	Total organic carbon ($g\ kg^{-1}$ soil)			Soil organic carbon ($g\ kg^{-1}$ soil)			WSC ($mg\ kg^{-1}$ soil)			AHC ($mg\ kg^{-1}$ soil)		
	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean
Tillage												
KT_1: Conventional tillage (CT)	6.78	6.83	6.80	5.54	5.59	5.57	51.46	52.58	52.02	396.81	399.71	398.26
KT_2: Zero tillage (ZT)	7.57	7.74	7.65	6.22	6.31	6.27	58.01	59.73	58.87	447.92	452.10	450.01
SEm±	0.12	0.13	0.12	0.11	0.13	0.11	1.02	1.13	1.07	8.70	9.27	8.99
CD (P=0.05)	0.73	0.78	0.76	0.67	0.78	0.70	6.18	6.88	6.53	NS	NS	NS
Residual of residues												
KR_1: RDF + No residue	6.18	6.20	6.19	5.50	5.56	5.53	52.28	53.43	52.85	401.98	405.46	403.72
KR_2: RDF + Residue mulching (3 t ha^{-1})	7.29	7.45	7.37	5.85	5.94	5.90	54.71	55.94	55.32	425.41	428.43	426.92
KR_3: RDF + Residue mulching (6 t ha^{-1})	8.05	8.21	8.13	6.29	6.35	6.32	57.22	59.11	58.16	439.69	443.83	441.76
SEm±	0.23	0.23	0.23	0.19	0.18	0.19	1.09	1.18	1.13	8.60	9.11	7.54
CD (P=0.05)	0.76	0.74	0.75	0.61	0.60	0.61	3.55	3.85	3.70	28.05	29.72	24.58
Nitrogen management												
KN_1: LCC based (100 % RDN)	7.22	7.31	7.26	5.96	5.99	5.97	55.20	56.71	55.96	426.78	429.91	428.35
KN_2: LCC based (75 % RDN)	7.13	7.27	7.20	5.80	5.91	5.86	54.27	55.60	54.94	417.94	421.90	419.92
SEm±	0.20	0.21	0.21	0.16	0.15	0.16	0.79	0.85	0.82	7.49	6.46	5.99
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

WSC, water soluble carbon; AHC, acid hydrolysable carbon;

Table 4.23: KMnO4 extractable carbon, microbial biomass carbon and readily mineralizable carbon in soil after the harvest of rice as influenced by tillage, residual of residues and nitrogen, management

Treatment	POSC (mg kg^{-1} soil)			MBC (mg kg^{-1} soil)			RMC (mg kg^{-1} soil)		
	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean
Tillage									
KT_1: Conventional tillage (CT)	316.97	320.52	318.75	243.25	246.14	244.69	131.65	135.02	133.34
KT_2: Zero tillage (ZT)	342.42	347.67	345.04	264.20	272.05	268.12	143.64	151.66	147.65
SEm±	4.04	3.51	3.78	3.18	3.36	3.32	1.60	1.78	1.68
CD (P=0.05)	24.60	21.38	22.99	19.32	20.43	20.20	9.71	10.81	10.24
Residual of residues									
KR_1: RDF + No residue	316.66	325.35	321.00	246.78	251.05	248.92	133.14	138.97	136.06
KR_2: RDF + Residue mulching (3 t ha^{-1})	331.28	334.86	333.07	252.18	257.89	255.04	138.41	145.16	141.78
KR_3: RDF + Residue mulching (6 t ha^{-1})	341.15	342.07	341.61	262.21	268.34	265.27	141.39	145.90	143.64
SEm±	4.07	3.82	3.92	3.47	3.89	3.85	1.68	1.78	1.49
CD (P=0.05)	13.27	12.45	12.78	11.32	12.68	12.55	5.48	5.82	4.85
Nitrogen management									
KN_1: LCC based (100 % RDN)	331.25	338.54	334.90	258.57	263.68	261.12	138.63	144.38	141.50
KN_2: LCC based (75 % RDN)	328.14	329.65	328.90	248.88	254.51	251.70	136.66	142.31	139.49
SEm±	3.68	3.38	3.50	2.85	2.90	2.88	1.51	1.61	1.37
CD (P=0.05)	NS	NS	NS	8.78	8.94	8.86	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS

POSC, KMnO4 extractable carbon; MBC, microbial biomass carbon; RMC, Readily mineralizable carbon

The interaction effect of tillage practices in rice, residual of residues in maize and nitrogen management in rice was found non – significant with respect to total and soil organic carbon, water soluble carbon, acid hydrolysable carbon, permanganate oxidizable carbon, microbial biomass carbon and readily mineralizable carbon during both the years and on mean basis.

Discussion on carbon pools in soil

Between the tillage practices in rice, significantly higher total and soil organic carbon, water soluble carbon, permanganate oxidizable carbon, microbial biomass carbon and readily mineralizable carbon in soil after the harvest of rice were recorded under zero tillage (ZT) as compared to conventional tillage (CT). This might be due to reduced biological oxidation of soil organic carbon to CO_2 and higher conversion efficiency of residue carbon to soil carbon under zero tillage as compared to conventional tillage (Duiker and Lal, 1999). Sherrod *et al.* (2005) reported that an active soil carbon and microbial biomass carbon with no – tillage although microbial biomass carbon is correlated with plant carbon input. The general increase of microbial biomass carbon under zero tillage over conventional tillage could be attributed to several factors, such as a lower temperature, higher moisture content, greater soil aggregation and higher soil organic carbon content. Moreover, reduced disturbance of soil under zero tillage prevents disruption in microbial population and soil aggregates (Gonza *et al.*, 2010). The Walkley Black and permanganate oxidizable carbon under conservation agriculture were increased mainly due to less disruption of soil aggregates and consequently more physical protection of SOC inside macroaggregates and permanganate oxidizable carbon were mainly contributed to the improvement of very labile SOC under different conservation agriculture practices (Six *et al.*, 2000). Chen *et al.* (2009) also reported that soil organic carbon and nitrogen stocks, MBC, DOC, HWC, $KMnO_4$ – C and POC were all significantly maximum under no – tillage as compared to conventional tillage.

Among the residual of residues in maize, significantly higher total and soil organic carbon, water soluble carbon, acid hydrolysable carbon, permanganate oxidizable carbon, microbial biomass carbon and readily mineralizable carbon in soil after the harvest of rice were recorded under RDF + residue mulching (6 t ha^{-1})

as compared to RDF + no residue, but it was at par to treatment R_2 – RDF + residue mulching (3 t ha^{-1}). This might be attributed to the fact that continuous addition of organic matter through crop residue increased the microbial population which enhanced the decomposition of crop residue resulting in increased organic carbon. Similar results were reported by Prasad *et al.* (2010) and Adhikari *et al.* (2012).

As regards to nitrogen management in rice, LCC based (100 % RDN) recorded significantly higher microbial biomass carbon as compared to LCC based (75 % RDN) in soil after the harvest of rice. Nitrogen application is mainly attributed to addition of fresh residue through root biomass, which might have triggered higher microbial activities in soil in these treatments. Soil microbial biomass has been generally thought to be limited by energy substrates rather than mineral nutrients. However, studies have demonstrated that soil microbial growth can be constrained by nitrogen vailability (Kaye and Hart, 1997). Nitrogen is a nutrient required by both crops and soil micros. Application of nitrogen fertilizers to field crops in split doses can improve the synchrony between plant nitrogen demand and soil nitrogen availability (Gehl *et al.*, 2005). Joergensen and Scheu (1990) also reported that nitrogen levels induced an increase in microbial biomass carbon content. No significant differences in water soluble carbon, permanganate oxidizable carbon and readily mineralizable carbon were observed in between the nitrogen management in rice treatments. These results were reported by Lee and Jose (2003) and Reid *et al.* (2012).

4.1.4.5 Soil nitrogen pools

The data on total nitrogen, available nitrogen, microbial biomass nitrogen, ammonical nitrogen and nitrate nitrogen in soil after the harvest of rice as influenced by different tillage practices in rice, residual of residues in maize and nitrogen management in rice are presented in Table 4.24.

As regards to tillage practices in rice, significantly higher value of total nitrogen, available nitrogen, microbial biomass nitrogen ammonical nitrogen and nitrate nitrogen in soil after the harvest of rice were recorded under treatment KT_2 – zero tillage (ZT) as compared to KT_1 – conventional tillage (CT) throughout both the years and on mean basis .

Table 4.24: Nitrogen pools in soil after the harvest of rice as influenced by tillage, residual of residues and nitrogen management

Treatment	Nitrogen pools of soil														
	Total Nitrogen (mg kg^{-1})			Available Nitrogen (kg ha^{-1})			Microbial biomass nitrogen (mg kg^{-1})			Ammonical nitrogen (mg kg^{-1})			Nitrate nitrogen (mg kg^{-1})		
	2016	**2017**	**Mean**	**2016**	**2017**	**Mean**	**2016**	**2017**	**Mean**	**2016**	**2017**	**Mean**	**2016**	**2017**	**Mean**
Tillage															
KT_1: Conventional tillage (CT)	657.39	668.20	662.79	285.92	294.28	290.10	32.33	32.84	32.59	26.31	27.39	26.85	10.43	11.33	10.88
KT_2: Zero tillage (ZT)	718.07	730.23	724.15	315.60	321.80	318.70	36.56	36.27	36.41	32.94	33.26	33.10	12.10	13.18	12.64
SEm±	9.64	9.89	9.76	4.15	4.12	4.11	0.67	0.54	0.60	0.51	0.58	0.54	0.18	0.29	0.24
CD (P=0.05)	58.67	60.16	59.36	25.23	25.05	25.03	4.10	3.26	3.67	3.10	3.56	3.30	1.12	1.79	1.44
Residual of residues															
KR_1: RDF + No residue	659.94	661.60	660.77	286.96	290.22	288.59	32.52	33.50	33.01	28.31	28.53	28.42	10.33	11.44	10.88
KR_2: RDF + Residue mulching (3 t ha^{-1})	677.15	698.91	688.03	302.63	309.23	305.93	34.91	33.80	34.35	29.72	30.68	30.20	11.49	12.35	11.92
KR_3: RDF + Residue mulching (6 t ha^{-1})	726.11	737.13	731.62	312.69	324.67	318.68	35.90	36.36	36.13	30.85	31.77	31.31	11.96	12.97	12.46
SEm±	10.96	11.92	11.42	4.25	4.79	4.49	0.67	0.60	0.63	0.59	0.62	0.38	0.21	0.32	0.25
CD (P=0.05)	35.73	38.87	37.25	13.86	15.64	14.64	2.18	1.96	2.06	1.92	2.03	1.24	0.68	1.04	0.82
Nitrogen management															
KN_1: LCC based (100 % RDN)	708.62	724.76	716.69	310.57	318.66	314.62	36.17	35.77	35.97	30.61	31.36	30.98	11.68	12.66	12.17
KN_2: LCC based (75 % RDN)	666.85	673.66	670.25	290.95	297.42	294.19	32.72	33.33	33.03	28.64	29.29	28.97	10.84	11.85	11.34
SEm±	9.04	9.49	9.25	3.00	2.56	2.58	0.53	0.43	0.48	0.39	0.62	0.40	0.25	0.21	0.20
CD (P=0.05)	27.84	29.26	28.49	9.24	7.88	7.94	1.62	1.32	1.47	1.21	1.92	1.22	0.77	0.64	0.62
Interaction	NS	NS	NS	S	S	S	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 4.25: Interaction effect of residual of residues and nitrogen management on available nitrogen in soil after the harvest of rice

Residual of residues / Nitrogen management	KR_1: RDF + No residue	KR_2: RDF + Residue mulching (3 t ha^{-1})	KR_3: RDF + Residue mulching (6 t ha^{-1})	Mean
		2016		
KN_1: LCC based (100 % RDN)	302.46	311.13	316.62	310.07
KN_2: LCC based (75 % RDN)	271.13	294.13	308.93	291.40
Mean	286.80	302.63	312.78	
		2017		
KN_1: LCC based (100 % RDN)	308.06	318.96	328.97	318.66
KN_2: LCC based (75 % RDN)	272.39	299.50	320.36	297.42
Mean	290.22	309.23	324.67	
		Mean		
KN_1: LCC based (100 % RDN)	305.26	315.04	322.80	314.37
KN_2: LCC based (75 % RDN)	271.76	296.81	314.65	294.41
Mean	288.51	305.93	318.72	

	2016		**2017**		**Mean**	
	SEm±	**CD (P=0.05)**	**SEm±**	**CD (P=0.05)**	**SEm±**	**CD (P=0.05)**
Comparison of two nitrogen management at same levels of residual of residues	4.26	12.96	4.43	13.66	3.98	12.11
Comparison of two residual of residues at same levels of nitrogen management	4.68	14.58	4.79	14.53	4.53	13.69

Among residual of residues in rice, treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) showed significantly maximum value of total nitrogen, available nitrogen, microbial biomass nitrogen, ammonical nitrogen and nitrate nitrogen in soil after the harvest of rice which was at par to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) and significantly minimum value of total nitrogen, available nitrogen, microbial biomass nitrogen, ammonical nitrogen and nitrate nitrogen were recorded under treatment KR_1 – RDF + no residue during both the years and on mean basis.

Between nitrogen management in rice, significantly higher value of total nitrogen, available nitrogen, microbial biomass nitrogen, ammonical nitrogen and nitrate nitrogen in soil after the harvest of rice were estimated under treatment KN_1 – LCC based (100 % RDN) as compared to treatment KN_2 – LCC based (75 % RDN) throughout both the years and on mean basis.

The interaction effect of residual of residues in maize and nitrogen management in rice on available nitrogen in soil after the harvest of rice was found significant during both the years and on mean basis (Table 4.24). Interaction between KR_3 – RDF + residue mulching (6 t ha^{-1}) with KN_1 – LCC based (100 % RDN) recorded significantly higher value of available nitrogen in soil after the harvest of rice as compared to other interactions during both the years and on mean basis. However, it was at par to interactions of KR_3 – RDF + residue mulching (6 t ha^{-1}) with KN_1 – LCC based (75 % RDN), KR_2 – RDF + residue mulching (3 t ha^{-1}) with KN_1 – LCC based (100 % RDN) and KR_1 – KRDF + no residue with KN_1 – LCC based (100 % RDN) and significantly minimum value of available nitrogen was noted under interaction of KR_1 – RDF + no residue with KN_1 – LCC based (75 % RDN) during both the years and on mean basis.

4.1.4.6 Available phosphorus and potassium in soil (kg ha^{-1})

The data on available phosphorus and potassium in soil after the harvest of rice as influenced by tillage practices in rice, residual of residues in maize and nitrogen management in rice are presented in Table 4.26.

As regards to tillage practices in rice, significantly higher values of available phosphorus and potassium in soil after the harvest of rice were observed

Table 4.26: Available phosphorus and potassium in soil after the harvest of rice as influenced by tillage, residual of residues and nitrogen Management

Treatment	Available phosphorus (kg ha^{-1})			Available potassium (kg ha^{-1})		
	2016	**2017**	**Mean**	**2016**	**2017**	**Mean**
Tillage						
KT_1: Conventional tillage (CT)	21.85	22.75	22.30	172.17	173.33	172.75
KT_2: Zero tillage (ZT)	24.29	25.24	24.76	190.94	192.76	191.85
SEm±	0.39	0.40	0.39	2.99	3.12	3.05
CD (P=0.05)	2.37	2.41	2.39	18.17	18.97	18.57
Residual of residues						
KR_1: RDF + No residue	21.73	22.55	22.14	172.67	173.07	172.87
KR_2: RDF + Residue mulching (3 t ha^{-1})	23.16	23.90	23.53	180.83	184.05	182.44
KR_3: RDF + Residue mulching (6 t ha^{-1})	24.32	25.52	24.92	191.15	192.01	191.58
SEm±	0.44	0.46	0.45	3.45	3.50	3.48
CD (P=0.05)	1.44	1.49	1.47	11.25	11.43	11.34
Nitrogen management						
KN_1: LCC based (100 % RDN)	23.78	25.32	24.55	185.51	187.99	186.75
KN_2: LCC based (75 % RDN)	22.37	22.66	22.51	177.60	178.10	177.85
SEm±	0.30	0.31	0.31	2.30	2.38	2.34
CD (P=0.05)	0.92	0.97	0.94	7.10	7.33	7.21
Interaction	NS	NS	NS	NS	NS	NS

under KT_2 – zero tillage (ZT) as compared to KT_1 – conventional tillage (CT) during both the years and on mean basis.

Among the residual of residues in maize, treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) recorded significantly highest values of available phosphorus and potassium in soil after the harvest of rice as compared to treatment KR_1 – RDF + no residue, but it was at par to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis.

In case to nitrogen management, significantly higher values of available phosphorus and potassium in soil after the harvest of rice were estimated under treatment KN_1 – LCC based (100 % RDN) as compared to treatment KN_2 – LCC based (75 % RDN) during both the years and on mean basis.

Regarding interaction effect of different treatments on available phosphorus and potassium in soil after the harvest of rice was found non - significant during both the years and on mean basis.

Discussion on soil nitrogen pools, available phosphorus and potassium in soil

Between the tillage practices in maize, significantly higher value of total nitrogen, available nitrogen, microbial biomass nitrogen, ammonical nitrogen, nitrate nitrogen, available phosphorus and potassium in soil after the harvest of rice were recorded under zero tillage (ZT) as compared to conventional tillage (CT). This show that in conventional tillage plots, because of more mineralization of organic nitrogen, there is higher availability and consequent higher uptake in the crop, the amount left in soil is lower as compared to zero tillage plots (Pasricha, 2017). Intensive tillage can lead to a decline in total nitrogen concentrations due to destroying soil structure, exposing soil aggregates and aggravating soil organic matter decomposition (Xue, *et al*., 2015). Similar results were reported by Puget *et al*. (2005) and Baker *et al*. (2007).

Among the residual of residues in maize, RDF + residue mulching (6 t ha^{-1}) showed significantly higher values of total nitrogen, available nitrogen, microbial biomass nitrogen, ammonical nitrogen, nitrate nitrogen, available phosphorus and potassium in soil after the harvest of rice as compared to RDF + no residue, but it was at par to RDF + residue mulching (3 t ha^{-1}). This might be due to slow decomposition of residue and increased nutrients availability in soil. Party (2011) decomposition of residue and increased nutrients availability in soil. Party (2011) and Babu *et al.* (2014) also noted improvement in soil fertility through addition of crop residue and available potassium is the most rapidly released nutrient from residual of crop residues as reported by Matos *et al.* (2011).

As regards to nitrogen management in rice, the significantly maximum values of total nitrogen, available nitrogen, microbial biomass nitrogen, ammonical nitrogen and nitrate nitrogen, available phosphorus and potassium in soil after the harvest of rice were estimated under LCC based (100 % RDN) as compared to LCC based (75 % RDN). This might be due to the addition of nitrogen fertilizers could be envisaged as the direct enrichment of available nitrogen pool as the inputs of nitrogen contributors and it also emphasized that it could have enhanced the decomposition of organic nitrogenous material as well as increase NH_4 N due to continuous application of fertilizer on long term basis. These results were in agreement with Kumar *et al.* (1994). In another study, Reddy and Patter (2006) reported that the LCC based nitrogen applications avoid the losses of applied nitrogen resulting in higher nitrogen use efficiency. Angas *et al.* (2006) also found that soil mineral nitrogen increased with the increased of nitrogen fertilization rates and applying more nitrogen than the crop needed elevated the superfluous accumulation of inorganic nitrogen and its loss. Similarly, Lu *et al.* (2010) also reported that high nitrogen application rate significantly enhanced the amount of NH_4^+ N and NO_3^- in soil inorganic nitrogen pool. These results were in accordance with those by Garcia *et al.* (1997), Liebig *et al.* (2002) and Russell *et al.* (2006).

4.1.5 Economics

4.1.5.1 Cost of cultivation (× 10^3 ₹ ha^{-1})

The data presented in Table 4.27 pertains to cost of cultivation as influenced by tillage practices in rice, residual of residues in maize and nitrogen management in rice.

Between tillage practices in rice, KT_1 – conventional tillage (CT) recorded highest cost of cultivation and the lowest cost of cultivation was recorded under KT_2 – zero tillage (ZT) throughout both the years and on mean basis.

The cost of cultivation was calculated similar under different treatments of residual of residues in maize throughout both the years and on mean basis.

In case of nitrogen management in rice, treatment KN_1 – LCC based (100 % RDN) recorded highest cost of cultivation and lowest cost of cultivation was recorded under treatment KN_2 – LCC based (75 % RDN) throughout both the years and on mean basis.

4.1.5.2 Gross return (× 10^3 ₹ ha^{-1})

The data pertaining to gross return of rice as influenced by tillage practices in rice, residual of residues in maize and nitrogen management in rice are presented in Table 4.27.

Between tillage practices in rice, KT_1 – conventional tillage (CT) recorded significantly higher gross return of rice as compared to KT_2 – zero tillage (ZT) throughout both the years and on mean basis.

Among the residual of residues in maize, treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) recorded significantly higher gross return of rice as compared to treatment KR_1 – RDF + no residue, but it was at par to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis.

In case of nitrogen management in rice, treatment KN_1 – LCC based (100 % RDN) recorded significantly higher gross return of rice as compared to treatment KN_2 – LCC based (75 % RDN) during both the years and on mean basis.

The interactions between residual of residues in maize and nitrogen management in rice had given significant impact on gross return of rice during both the years and on mean basis (Table 4.27). Interaction between KR_3 – RDF + residue mulching (6 t ha^{-1}) with KN_1 – LCC based (100 % RDN) registered significantly higher gross return of rice as compared to other interactions, but it was at par to interactions of KR_2 – RDF + residue mulching (3 t ha^{-1}) with KN_1 – LCC based (100 % RDN) and KR_3 – RDF + residue mulching (6 t ha^{-1}) with KN_2 – LCC based (75 % RDN) throughout both the years and on mean basis.

4.1.5.2 Net return (× 10^3 ₹ ha^{-1}) and benefit cost ratio

The data related to net return and benefit cost ratio of rice as influenced by tillage practices in rice, residual of residues in maize and nitrogen management in rice are presented in Table 4.27.

Table 4.27: Economics of rice as influenced by tillage, residual of residues and nitrogen management

Treatment	Cost of cultivation (× 10^3 ₹ ha^{-1})			Gross return (× 10^3 ₹ ha^{-1})			Net return (× 10^3 ₹ ha^{-1})			Benefit cost ratio		
	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean
Tillage												
KT_1: Conventional tillage (CT)	38	40	39	89	96	92	52	56	54	2.37	2.42	2.40
KT_2: Zero tillage (ZT)	34	36	35	81	87	84	48	51	49	2.42	2.43	2.43
SEm±	-	-	-	1	1	1	1	1	1	0.05	0.05	0.05
CD (P=0.05)	-	-	-	8	8	8	4	5	4	NS	NS	NS
Residual of residues												
KR_1: RDF + No residue	36	38	37	78	83	81	43	46	44	2.20	2.22	2.21
KR_2: RDF + Residue mulching (3 t ha^{-1})	36	38	37	87	93	90	52	56	54	2.46	2.48	2.47
KR_3: RDF + Residue mulching (6 t ha^{-1})	36	38	37	90	97	93	54	59	57	2.53	2.57	2.55
SEm±	-	-	-	1	2	1	1	1	1	0.05	0.05	0.05
CD (P=0.05)	-	-	-	5	5	5	2	3	3	0.16	0.16	0.16
Nitrogen management												
KN_1: LCC based (100 % RDN)	36	38	37	88	95	91	52	57	55	2.47	2.51	2.49
KN_2: LCC based (75 % RDN)	35	37	36	82	88	85	47	50	49	2.32	2.34	2.33
SEm±	-	-	-	1	1	1	1	1	1	0.04	0.04	0.04
CD (P=0.05)	-	-	-	2	3	2	2	2	2	0.12	0.12	0.12
Interaction	-	-	-	S	S	S	S	NS	NS	NS	NS	NS

Rice - ₹ 1470 q^{-1} (2016) and ₹ 1550 q^{-1}(2017)

Table 4.28: Gross and net return of rice as affected by interaction between residual of residues in maize and nitrogen management in rice

Residual of Residues / Nitrogen management	KR_1: RDF + No residue	KR_2: RDF + Residue mulching (3 t ha^{-1})	KR_3: RDF + Residue mulching (6 t ha^{-1})	Mean
	Gross return (× 10^3 ₹ ha^{-1})			
	2016			
KN_1: LCC based (100 % RDN)	85	89	91	88
KN_2: LCC based (75 % RDN)	71	86	89	82
Mean	78	87	90	
	2017			
KN_1: LCC based (100 % RDN)	91	96	97	95
KN_2: LCC based (75 % RDN)	76	91	96	88
Mean	83	93	97	
	Mean			
KN_1: LCC based (100 % RDN)	88	92	94	91
KN_2: LCC based (75 % RDN)	74	88	93	85
Mean	81	90	93	

	2016		**2017**		**Mean**	
	SEm±	**CD (P=0.05)**	**SEm±**	**CD (P=0.05)**	**SEm±**	**CD (P=0.05)**
Comparison of two nitrogen management at same levels of residual of residues	1	4	2	5	1	4
Comparison of two residual of residues at same levels of nitrogen management	1	4	2	5	2	5

Residual of Residues / Nitrogen management	KR_1: RDF + No residue	KR_2: RDF + Residue mulching (3 t ha^{-1})	KR_3: RDF + Residue mulching (6 t ha^{-1})	Mean
	Net return (× 10^3 ₹ ha^{-1})			
	2016			
KN_1: LCC based (100 % RDN)	49	53	55	52
KN_2: LCC based (75 % RDN)	36	51	53	47
Mean	43	52	54	
	2017			
KN_1: LCC based (100 % RDN)	53	58	59	57
KN_2: LCC based (75 % RDN)	39	53	58	50
Mean	46	56	59	
	Mean			
KN_1: LCC based (100 % RDN)	51	56	57	55
KN_2: LCC based (75 % RDN)	37	52	56	49
Mean	44	54	57	

	2016		**2017**		**Mean**	
	SEm±	**CD (P=0.05)**	**SEm±**	**CD (P=0.05)**	**SEm±**	**CD (P=0.05)**
Comparison of two nitrogen management at same levels of residual of residues	1	3	1	4	1	3
Comparison of two residual of residues at same levels of nitrogen management	1	3	1	4	1	4

Regarding tillage practices in rice, although non – significant effect was noted, however, KT_1 – conventional tillage (CT) recorded maximum net return and lowest benefit cost ratio of rice, whereas the lowest net return with highest benefit cost ratio of rice were noted under KT_2 – zero tillage (ZT) during both the years and on mean basis.

Among the residual of residues in maize, treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) recorded significantly higher net return and benefit cost ratio of rice as compared to treatment KR_1 – RDF + no residue, but it was found at par to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) throughout both the years and on mean basis.

Treatment KN_1 – LCC based (100 % RDN) recorded significantly higher net return and benefit cost ratio of rice as compared to treatment KN_2 – LCC based (75 % RDN) during both the years and on mean basis.

The interactions between residual of residues in maize and nitrogen management in rice had given significant impact on net return of rice during both the years and on mean basis (Table 4.28). Interaction between KR_3 – RDF + residue mulching (6 t ha^{-1}) with KN_1 – LCC based (100 % RDN) registered significantly higher net return of rice as compared to other interactions, but it was at par to interactions of KR_2 – RDF + residue mulching (3 t ha^{-1}) with KN_1 – LCC based (100 % RDN) and KR_3 – RDF + residue mulching (6 t ha^{-1}) with KN_2 – LCC based (75 % RDN) during both the years and on mean basis.

Discussion on economics

Between the tillage practices in rice, conventional tillage (CT) recorded higher gross return and net return as compared to zero tillage (ZT). This might be the result of more grain and straw yields of rice in above treatment. Higher economic returns due to conventional tillage in rice have also been reported by Mishra and Singh (2007), Gopinath *et al*. (2007) and Pandey *et al*. (2008). The maximum cost benefit ratio was recorded under zero tillage (ZT) because of low cost of cultivation. Erenstein *et al*. (2007) also obtained 15 – 16 per cent saving on operational costs in zero tillage.

Among the residual of residues in maize, RDF + residue mulching (6 t ha^{-1}) recorded significantly higher gross return, net return and benefit cost ratio of rice as compared to RDF + no residue, but it was found comparable to RDF + residue mulching (3 t ha^{-1}). This might be due to higher grain and straw yields of rice in above treatments which leads to the higher gross return, net return and cost benefit ration of rice.

As regards to nitrogen management in rice, LCC based (100 % RDN) recorded significantly higher gross return, net return and benefit cost ratio of rice as compared to LCC based (75 % RDN) which may be owing to higher grain and straw yields in above treatment. Moharana *et al*. (2017) also reported that application of nitrogen based LCC 4 registered significantly the highest return per rupee invested (1.94) and cost of cultivation did not differ appreciably due to various treatments when compared with no N treatments.

4.1.6 Energetics

4.1.6.1 Input energy (× 10^3 MJ ha^{-1})

The data on input energy of rice as influenced by tillage practices in rice, residual of residues in maize and nitrogen management in rice are presented in Table 4.29.

Between tillage practices in rice, KT_1 – conventional tillage (CT) recorded highest input energy of rice and the lowest input energy of rice was recorded under KT_2 – zero tillage (ZT) throughout both the years and on mean basis.

The input energy of rice was recorded similar under different treatments of residual of residues in maize throughout both the years and on mean basis.

In case of nitrogen management in rice, treatment KN_1 – LCC based (100 % RDN) recorded maximum input energy of rice, whereas the lowest input energy of rice was recorded under treatment KN_2 – LCC based (75 % RDN) during both the years and on mean basis.

4.1.6.2 Output energy (× 10^3 MJ ha^{-1})

The data pertaining to output energy of rice as influenced by tillage practices in rice, residual of residues in maize and nitrogen management in rice are presented in Table 4.29.

Regarding tillage practices in rice, KT_1 – conventional tillage (CT) recorded significantly highest output energy of rice, whereas the lowest value was noted under KT_2 – zero tillage (ZT) throughout both the years and on mean basis.

In case of residual of residues in maize, treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) recorded significantly higher output energy of rice as compared to treatment KR_1 – RDF + no residue, but it was at par to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) throughout both the years and on mean basis.

Between nitrogen management in rice, treatment KN_1 – LCC based (100 % RDN) recorded significantly higher output energy of rice as compared to treatment KN_2 – LCC based (75 % RDN) throughout both the years and on mean basis.

The interaction effect of tillage practices in rice, residual of residues in maize and nitrogen management in rice was noted non- significant with respect to output energy of rice during both the years and on mean basis.

4.1.6.3 Net energy (× 10^3 MJ ha^{-1})

The data on net energy of rice as influenced by tillage practices in rice, residual of residues in maize and nitrogen management in rice are presented in Table 4.29.

Between the tillage practices in rice, although non – significant effect was noted, however, treatment KT_1 – conventional tillage (CT) recorded the highest net energy of rice and the lowest net energy was recorded under treatment KT_2 – zero tillage (ZT) throughout both the years and on mean basis.

In case of residual of residues in maize, treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) obtained significantly highest net energy of rice which was at par to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) and significantly lowest net energy of rice was noted under treatment KR_1 – RDF + no residue throughout both the years and on mean basis.

Treatment KN_1 – LCC based (100 % RDN) obtained significantly higher net energy of rice as compared to treatment KN_2 – LCC based (75 % RDN) during both the years and on mean basis.

Table 4.29: Input and output energy, net energy, energy use efficiency and energy profitability of rice as influenced by tillage, residual of residues and nitrogen management

Treatment	Energy input ($\times 10^3$ MJ ha^{-1})			Energy output ($\times 10^3$ MJ ha^{-1})			Net energy ($\times 10^3$ MJ ha^{-1})			Energy use efficiency		
	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean
Tillage												
KT_1: Conventional tillage (CT)	14.11	14.55	14.33	178.43	182.12	180.27	162.54	164.63	163.59	12.67	12.53	12.60
KT_2: Zero tillage (ZT)	10.93	10.95	10.94	162.01	164.28	163.14	151.17	154.11	152.64	14.86	15.05	14.95
SEm±	-	-	-	2.49	2.73	2.61	1.81	1.67	1.74	0.24	0.24	0.24
CD (P=0.05)	-	-	-	15.14	16.62	15.88	11.00	10.17	10.58	1.46	1.49	1.47
Residual of residues												
KR_1: RDF + No residue	12.52	12.75	12.63	158.62	161.34	159.98	145.68	149.14	147.41	12.80	12.81	12.80
KR_2: RDF + Residue mulching (3 t ha^{-1})	12.52	12.75	12.63	173.81	176.38	175.09	160.54	162.32	161.43	14.06	14.05	14.05
KR_3: RDF + Residue mulching (6 t ha^{-1})	12.52	12.75	12.63	178.21	181.89	180.05	164.34	166.66	165.50	14.44	14.51	14.48
SEm±	-	-	-	3.16	3.28	3.22	2.02	1.95	1.99	0.29	0.29	0.29
CD (P=0.05)	-	-	-	10.29	10.71	10.49	6.60	6.37	6.48	0.95	0.96	0.95
Nitrogen management												
KN_1: LCC based (100 % RDN)	13.30	13.53	13.42	175.09	178.65	176.87	163.63	166.05	164.84	13.28	13.35	13.32
KN_2: LCC based (75 % RDN)	11.74	11.97	11.85	165.34	167.75	166.55	150.08	152.69	151.39	14.25	14.23	14.24
SEm±	-	-	-	2.24	2.40	2.32	1.78	1.68	1.73	0.20	0.21	0.21
CD (P=0.05)	-	-	-	6.90	7.39	7.14	5.50	5.18	5.34	0.63	0.64	0.63
Interaction	-	-	-	NS	NS	NS	NS	NS	NS	NS	NS	NS

The interaction effect of tillage practices in rice, residual of residues in maize and nitrogen management in rice on net energy of rice was noted non-significant during both the years and on mean basis.

4.1.6.4 Energy use efficiency

The data on energy use efficiency of rice as influenced by tillage practices in rice, residual of residues in maize and nitrogen management in rice are presented in Table 4.29.

Treatment KT_2 – zero tillage (ZT) obtained significantly highest energy use efficiency of rice as compared to KT_1 – conventional tillage (CT) throughout both the years and on mean basis.

In case of residual of residues in maize, treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) recorded significantly higher energy use efficiency of rice than treatment KR_1 – RDF + no residue, but it was at par to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) throughout both the years and on mean basis.

As regards to nitrogen management in rice, treatment KN_2 – LCC based (75 % RDN) obtained significantly higher energy use efficiency of rice as compared to treatment KN_1 – LCC based (100 % RDN) throughout both the years and on mean basis.

The interaction effect of tillage practices in rice, residual of residues in maize and nitrogen management in rice was noted non- significant with respect to energy use efficiency of rice throughout both the years and on mean basis.

4.1.6.5 Energy productivity (kg MJ^{-1})

The data pertaining to energy productivity of rice as influenced by tillage practices in rice, residual of residues in maize and nitrogen management in rice are presented in Table 4.30.

Between the tillage practices in rice, KT_2 – zero tillage (ZT) registered significantly higher energy productivity of rice as compared to KT_1 – conventional tillage (CT) during both the years and on mean basis

In case of residual of residues in maize, treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) obtained significantly higher energy productivity of rice than treatment KR_1 – RDF + no residue, but it was at par to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis.

As regards to nitrogen management in rice, treatment KN_2 – LCC based (75 % RDN) obtained significantly higher energy productivity of rice as compared to treatment KN_1 – LCC based (100 % RDN) during both the years and on mean basis.

The interaction effect of tillage practices in rice, residual of residues in maize and nitrogen management in rice was noted non- significantly with respect to energy productivity during both the years and on mean basis.

4.1.6.6 Specific energy (MJ kg^{-1}) and energy intensity in physical term (MJ kg^{-1})

The data related to specific energy of rice and energy intensity in physical term as influenced by tillage practices in rice, residual of residues in maize and nitrogen management in rice are presented in Table 4.30.

Between the tillage practices in rice, KT_1 – conventional tillage (CT) recorded significantly higher specific energy of rice and energy intensity in physical term as compared to KT_2 – zero tillage (ZT) during both the years and on mean basis.

In case of residual of residues in maize, treatment KR_1 – RDF + no residue obtained significantly higher specific energy of rice and energy intensity in physical term as compared to other treatments during both the years and on mean basis.

None of the treatments of nitrogen management in rice and interaction effect of different treatments had significant influence on specific energy of rice and energy intensity in physical term during both the years and on mean basis .

4.1.6.7 Energy intensity in economic term (MJ ₹$^{-1}$)

The data pertaining to energy intensity in economics term of rice as influenced by tillage practices in rice, residual of residues in maize and nitrogen management in rice are presented in Table 4.30.

Table 4.30: Energy productivity, specific energy, energy intensity in economic and physical term of rice as influenced by tillage, residual of residues and nitrogen management

Treatment	Energy productivity (kg MJ^{-1})			Specific energy (MJ kg^{-1})			Energy intensity in economic term (MJ ₹$^{-1}$)			Energy intensity in physical term (MJ kg^{-1})		
	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean
Tillage												
KT_1: Conventional tillage (CT)	0.420	0.412	0.416	2.40	2.45	2.42	4.75	4.61	4.68	1.07	1.08	1.08
KT_2: Zero tillage (ZT)	0.495	0.503	0.499	2.04	2.00	2.02	4.83	4.61	4.72	0.91	0.90	0.91
SEm±	0.007	0.007	0.007	0.04	0.04	0.04	0.09	0.09	0.09	0.03	0.02	0.02
CD (P=0.05)	0.041	0.041	0.041	0.26	0.27	0.26	NS	NS	NS	0.15	0.13	0.14
Residual of residues												
KR_1: RDF + No residue	0.420	0.418	0.419	2.41	2.43	2.42	4.46	4.29	4.38	1.06	1.06	1.06
KR_2: RDF + Residue mulching (3 t ha^{-1})	0.470	0.467	0.469	2.15	2.16	2.16	4.89	4.70	4.79	0.97	0.97	0.97
KR_3: RDF + Residue mulching (6 t ha^{-1})	0.483	0.486	0.485	2.09	2.10	2.09	5.02	4.84	4.93	0.94	0.94	0.94
SEm±	0.008	0.008	0.008	0.04	0.04	0.04	0.11	0.11	0.11	0.03	0.02	0.02
CD (P=0.05)	0.026	0.026	0.026	0.13	0.14	0.14	0.36	0.35	0.36	0.08	0.08	0.08
Nitrogen management												
KN_1: LCC based (100 % RDN)	0.434	0.435	0.434	2.32	2.33	2.33	4.91	4.74	4.83	1.02	1.02	1.02
KN_2: LCC based (75 % RDN)	0.481	0.482	0.481	2.11	2.12	2.12	4.67	4.48	4.58	0.96	0.96	0.96
SEm±	0.006	0.006	0.006	0.03	0.03	0.03	0.08	0.07	0.08	0.02	0.02	0.02
CD (P=0.05)	0.018	0.018	0.018	NS	NS	NS	0.24	0.23	0.24	0.06	0.05	0.06
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Among residual of residues in maize, significantly higher energy intensity in economics term of rice was obtained under treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) as compared to treatment KR_1 – RDF + no residue, but it was at par to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis.

In case of nitrogen management in rice, treatment KN_1 – LCC based (100 % RDN) recorded significantly higher energy intensity in economics term of rice as compared to treatment KN_2 – LCC based (75 % RDN) during both the years and on mean basis.

None of the treatments of tillage practices in rice and interaction effect of different treatments had significant influence on energy intensity in economics term of rice during both the years and on mean basis.

Discussion on energetics

In case of tillage practices in rice, significantly higher input and output energy, specific energy and energy intensity in physical term were recorded under conventional tillage (CT) as compared to zero tillage (ZT) which might be due to increased productivity of rice. The results were similar to the findings of Jha *et al.* (2011). However, zero tillage (ZT) recorded significantly higher energy use efficiency, energy profitability and energy productivity as compared to conventional tillage (CT). This might be due to saving of energy in zero tillage as compared to conventional tillage. Sorokhaibam *et al.* (2017) showed that the higher input energy was consumed by conventional tillage (16.82×10^3 MJ ha^{-1}) than no - tillage practices and gross energy output of conventional tillage was at par with no - tillage but net energy output was higher under no - tillage.

Among the residual of residues in maize, significantly higher output energy, net energy, energy use efficiency, energy profitability, energy productivity and energy intensity in economic term were recorded under RDF + residue mulching (6 t ha^{-1}) as compared to RDF + no residue, but it was at par to RDF + residue mulching (3 t ha^{-1}). This might be due to maximum grain and straw yields of rice under the above said treatments.

As regards to nitrogen management in rice, LCC based (100 % RDN) recorded significantly highest output energy, net energy and energy intensity in economic term due to higher grain and straw yields, whereas, significantly highest energy use efficiency, energy profitability and energy productivity of rice were noted under LCC based (75 % RDN) during both the years and on mean basis owing to less input energy involved in this treatment. The Similar results were also reported by Ravi *et al*. (2007) and Alam *et al*. (2013).

4.2 Studies on maize (*rabi* 2016-17 and 2017-18)

4.2.1 Pre – harvest observations

4.2.1.1 Plant height (cm)

The data on plant height of maize recorded at 30, 60, 90 DAS and at harvest as influenced by tillage practices in maize, residue management in maize and residual of nitrogen management in rice are presented in Table 4.31.

The findings indicated that the effect of tillage practices in maize, residual of nitrogen management in rice as well as interactions among different treatments did not have significant influence on plant height of maize at 30, 60, 90 DAS and at harvest during both the years and on mean basis

Among the residue management in maize, except at 30 DAS, significantly the taller plants were recorded under treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) as compared to treatment RR_1 – RDF + no residue, but it was at par to treatment RR_2 – RDF + residue mulching (3 t ha^{-1}) at 60, 90 DAS and at harvest during both the years and on mean basis.

4.2.1.2 Number of leaves plant^{-1}

The data related to number of leaves plant^{-1} recorded at 30, 60, 90 DAS and at harvest as influenced by tillage practices in maize, residue management in maize and residual of nitrogen management in rice are presented in Table 4.32.

The findings revealed that the effect of tillage practices and residue management in maize and residual of nitrogen management in rice as well as their interactions did not show any significant influence with respect to number of leaves plant^{-1} of maize at 30, 60, 90 DAS and at harvest during both the years and on mean basis.

Table 4.31: Plant height of maize at different durations as influenced by tillage, residue and residual of nitrogen management

Treatment	Plant height (cm)											
	30 DAS			60 DAS			90 DAS			At harvest		
	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean
Tillage												
RT_1: Conventional tillage (CT)	34.15	35.42	34.78	84.03	88.64	86.34	175.64	172.85	174.24	205.64	210.56	208.10
RT_2: Zero tillage (ZT)	33.16	34.67	33.91	81.89	87.61	84.75	167.38	162.85	165.11	197.38	198.22	197.80
SEm±	0.80	0.85	0.83	3.29	2.27	2.77	4.12	4.09	4.11	5.16	4.96	5.06
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Residue management												
RR_1: RDF + No residue	32.80	34.14	33.47	76.71	78.54	77.63	158.59	150.96	154.77	188.59	186.17	187.38
RR_2: RDF + Residue mulching (3 t ha^{-1})	33.53	34.33	33.93	81.88	90.13	86.00	172.23	172.29	172.26	206.73	207.50	207.11
RR_3: RDF + Residue mulching (6 t ha^{-1})	34.63	36.65	35.64	90.30	95.71	93.00	183.71	180.29	182.00	209.21	219.50	214.35
SEm±	0.78	0.83	0.80	3.00	2.04	2.52	3.73	3.71	3.72	4.65	4.50	4.58
CD (P=0.05)	NS	NS	NS	9.79	6.67	8.21	12.18	12.10	12.13	15.18	14.68	14.93
Residual of nitrogen management												
RN_1: LCC based (100 % RDN)	34.47	36.00	35.23	84.45	88.65	86.55	172.78	169.51	171.15	202.78	205.17	203.97
RN_2: LCC based (75 % RDN)	32.84	34.08	33.46	81.47	87.60	84.54	170.24	166.18	168.21	200.24	203.61	201.93
SEm±	0.67	0.71	0.69	3.01	2.04	2.51	3.76	3.74	3.75	4.68	4.53	4.61
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 4.32: Number of leaves plant^{-1} of maize at different durations as influenced by tillage, residue and residual of nitrogen management

Treatment	Number of leaves plant^{-1}											
	30 DAS			60 DAS			90 DAS			At harvest		
	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean
Tillage												
RT_1: Conventional tillage (CT)	6.72	6.63	6.68	9.94	10.13	10.03	11.17	13.39	12.28	9.64	10.19	9.91
RT_2: Zero tillage (ZT)	6.56	6.62	6.59	9.69	9.97	9.83	10.92	12.89	11.90	9.39	9.77	9.58
SEm±	0.16	0.17	0.16	0.24	0.25	0.25	0.26	0.33	0.30	0.19	0.25	0.22
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Residue management												
RR_1: RDF + No residue	6.54	6.58	6.56	9.56	9.90	9.73	10.79	12.58	11.69	9.26	9.51	9.39
RR_2: RDF + Residue mulching (3 t ha^{-1})	6.67	6.64	6.65	9.69	10.04	9.86	10.92	13.33	12.13	9.39	10.13	9.76
RR_3: RDF + Residue mulching (6 t ha^{-1})	6.71	6.65	6.68	10.19	10.21	10.20	11.42	13.50	12.46	9.89	10.30	10.09
SEm±	0.14	0.15	0.15	0.22	0.23	0.22	0.24	0.30	0.27	0.17	0.23	0.20
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Residual of nitrogen management												
RN_1: LCC based (100 % RDN)	6.64	6.69	6.66	9.92	10.13	10.02	11.26	13.19	12.22	9.56	10.03	9.80
RN_2: LCC based (75 % RDN)	6.64	6.56	6.60	9.71	9.97	9.84	10.83	13.09	11.96	9.46	9.93	9.70
SEm±	0.14	0.15	0.15	0.22	0.23	0.22	0.24	0.30	0.27	0.17	0.23	0.20
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

4.2.1.3 Dry matter accumulation (g m^{-2})

The data pertaining to dry matter accumulation of maize recorded at 30, 60, 90 DAS and at harvest as influenced by tillage practices in maize, residue management in maize and residual of nitrogen management in rice are presented in Table 4.33.

The findings indicated that the effect of tillage practices in maize, residual of nitrogen management in rice as well as interactions among different treatments failed to give significant influence on dry matter accumulation of maize at 30, 60, 90 DAS and at harvest during both the years and on mean basis.

Among the residue management in maize, except at 30 DAS, the dry matter accumulation of maize was significantly higher under treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) as compared to RR_1 – RDF + no residue, but it was at par to treatment RR_2 – RDF + residue mulching (3 t ha^{-1}) at 60, 90 DAS and at harvest during both the years and on mean basis.

4.2.1.4 Leaf area index

The data regarding leaf area index of maize recorded at 30, 60 and 90 DAS as influenced by tillage practices in maize, residue management in maize and residual of nitrogen management in rice are presented in Table 4.34.

The data reveals that effect of tillage practices in maize at 30, 60 and 90 DAS; residue management in maize at 30 DAS and residual of nitrogen management in rice at 30, 60 and 90 DAS as well as their interactions were found non – significantly during both the years and on mean basis.

However, among the treatments of residue management in maize, significantly the highest leaf area index of maize was registered under treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) which was at par to treatment RR_2 – RDF + residue mulching (3 t ha^{-1}) and lowest leaf area index of maize was recorded under treatment RR_1 – RDF + no residue at 60 and 90 DAS throughout both the years and on mean basis.

Table 4.33: Dry matter accumulation of maize at different durations as influenced by tillage, residue and residual of nitrogen management

Treatment	Dry matter accumulation (g m^{-2})											
	30 DAS			60 DAS			90 DAS			At harvest		
	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean
Tillage												
RT_1: Conventional tillage (CT)	100.2	132.1	116.2	409.5	486.1	447.8	1135.3	1229.6	1182.5	1636.4	1651.9	1644.1
RT_2: Zero tillage (ZT)	98.6	131.4	115.0	395.8	472.4	434.1	1126.4	1220.6	1173.5	1619.4	1626.6	1623.0
SEm±	1.9	2.8	2.3	10.1	12.3	11.2	28.2	30.8	28.5	25.0	28.2	26.6
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Residue management												
RR_1: RDF + No residue	94.8	124.4	109.6	372.6	441.6	407.1	1033.3	1127.6	1080.4	1484.3	1494.9	1489.6
RR_2: RDF + Residue mulching (3 t ha^{-1})	101.4	135.1	118.2	407.1	490.0	448.6	1173.3	1267.6	1220.5	1650.2	1661.4	1655.8
RR_3: RDF + Residue mulching (6 t ha^{-1})	102.0	135.7	118.9	428.1	506.1	467.1	1185.9	1280.2	1233.0	1749.1	1761.4	1755.2
SEm±	2.4	3.2	2.8	9.5	11.5	10.4	28.8	28.9	26.6	28.6	30.1	29.3
CD (P=0.05)	NS	NS	NS	31.0	37.5	33.9	94.0	94.4	86.9	93.4	98.1	95.6
Residual of nitrogen management												
RN_1: LCC based (100 % RDN)	100.4	133.2	116.8	407.7	484.8	446.2	1138.7	1232.9	1185.8	1641.0	1651.6	1646.3
RN_2: LCC based (75 % RDN)	98.4	130.3	114.4	397.5	473.7	435.6	1123.1	1217.3	1170.2	1614.8	1626.8	1620.8
SEm±	1.9	2.8	2.3	9.5	11.5	10.5	20.3	29.1	24.0	20.4	22.5	21.4
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 4.34: Leaf area index of maize at different durations as influenced by tillage, residue and residual of nitrogen management

Treatment	Leaf area index								
	30 DAS			60 DAS			90 DAS		
	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean
Tillage									
RT_1: Conventional tillage (CT)	0.74	0.73	0.74	2.76	2.81	2.81	5.43	5.44	5.43
RT_2: Zero tillage (ZT)	0.70	0.71	0.71	2.60	2.65	2.56	5.36	5.37	5.36
SEm±	0.02	0.02	0.02	0.06	0.06	0.07	0.09	0.07	0.08
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Residue management									
RR_1: RDF + No residue	0.71	0.70	0.71	2.52	2.57	2.46	5.18	5.26	5.22
RR_2: RDF + Residue mulching (3 t ha^{-1})	0.72	0.72	0.72	2.67	2.72	2.68	5.31	5.35	5.33
RR_3: RDF + Residue mulching (6 t ha^{-1})	0.73	0.74	0.74	2.84	2.90	2.90	5.69	5.60	5.65
SEm±	0.03	0.01	0.02	0.05	0.08	0.07	0.10	0.07	0.08
CD (P=0.05)	NS	NS	NS	0.18	0.28	0.23	0.32	0.23	0.27
Residual of nitrogen management									
RN_1: LCC based (100 % RDN)	0.74	0.73	0.73	2.71	2.77	2.72	5.45	5.45	5.45
RN_2: LCC based (75 % RDN)	0.70	0.72	0.71	2.64	2.69	2.65	5.34	5.36	5.35
SEm±	0.02	0.01	0.02	0.04	0.06	0.05	0.09	0.06	0.07
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS

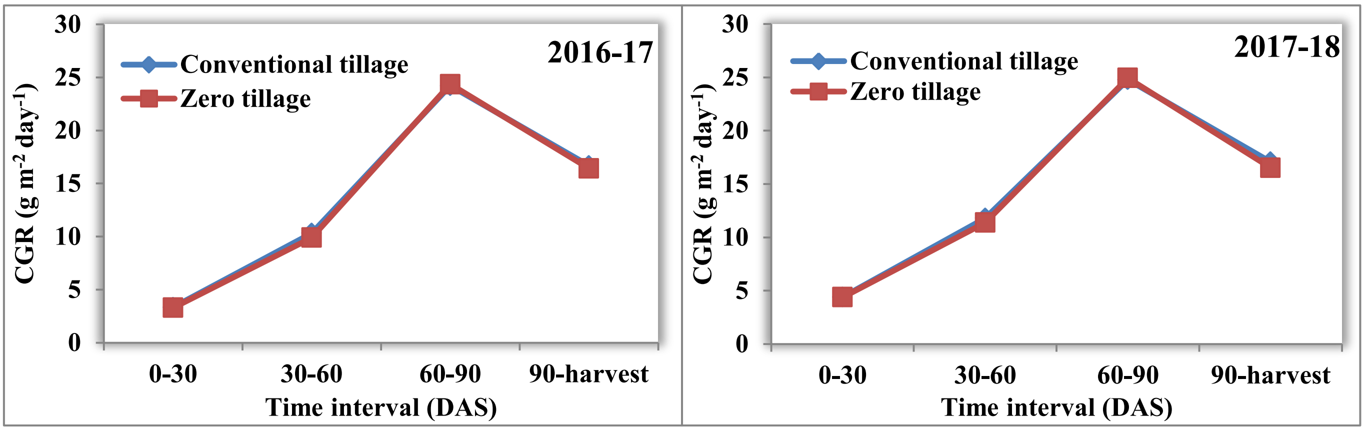
4.2.1.5 Crop growth rate (g m^{-2} day^{-1})

The data on crop growth rate (CGR) of maize recorded at 0 – 30, 30 – 60, 60 – 90 DAS and 90 DAS - at harvest as influenced by tillage practices in maize, residue management in maize and residual of nitrogen management in rice are depicted in Fig. 4.5 (2016-17 and 2017-18) and Fig 4.6 (mean). It was noted that crop growth rate increased from 0 – 30 DAS to 60 – 90 DAS, but later declined at 90 DAS – at harvest during both the years and on mean basis.

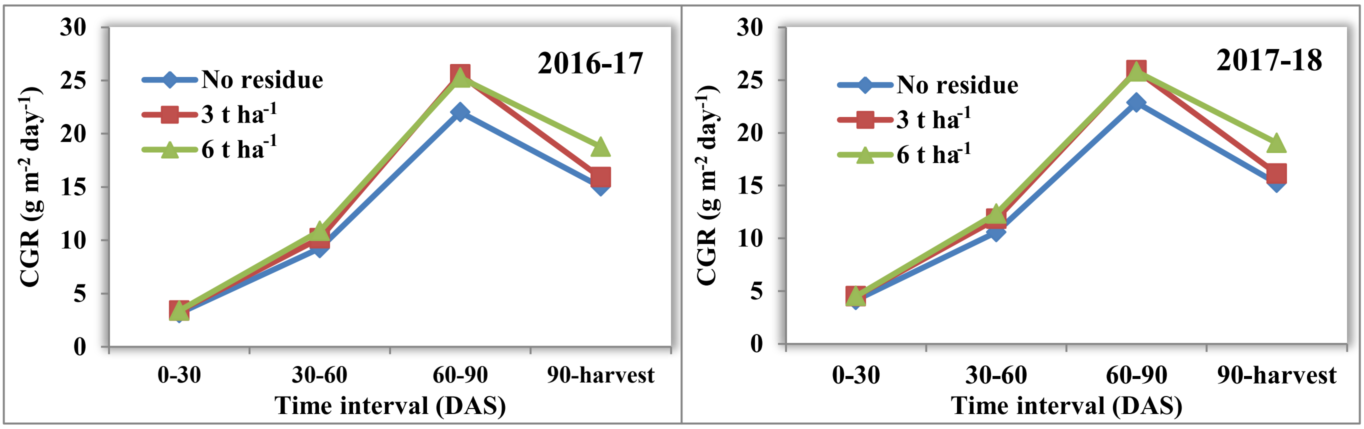
The results revealed that the effect of tillage practices in maize and residual of nitrogen management in rice did not have significant effect on crop growth rate of maize, however, RT_1 – conventional tillage (CT) and RN_1 – LCC based (100 % RDN) recorded higher crop growth rate of maize in comparison to their respective treatments at 0 – 30, 30 – 60, 60 – 90 DAS and 90 DAS - at harvest throughout both the years and on mean basis.

As regards to treatments of residue management in maize, the crop growth rate was significantly affected by different treatments of maize at different time intervals except 0-30 DAS during both the years and on mean basis. The significantly higher crop growth rate of maize was recorded under treatment R_3 – RDF + residue mulching (6 t ha^{-1}) as compared to treatment RR_1 – RDF + no residue, but it was at par to treatment RR_2 – RDF + residue mulching (3 t ha^{-1}) at 30 – 60 DAS and 60 – 90 DAS, whereas at 90 DAS – at harvest, significantly higher crop growth rate of maize was noted under treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) as compared to other treatments throughout both the years and on mean basis.

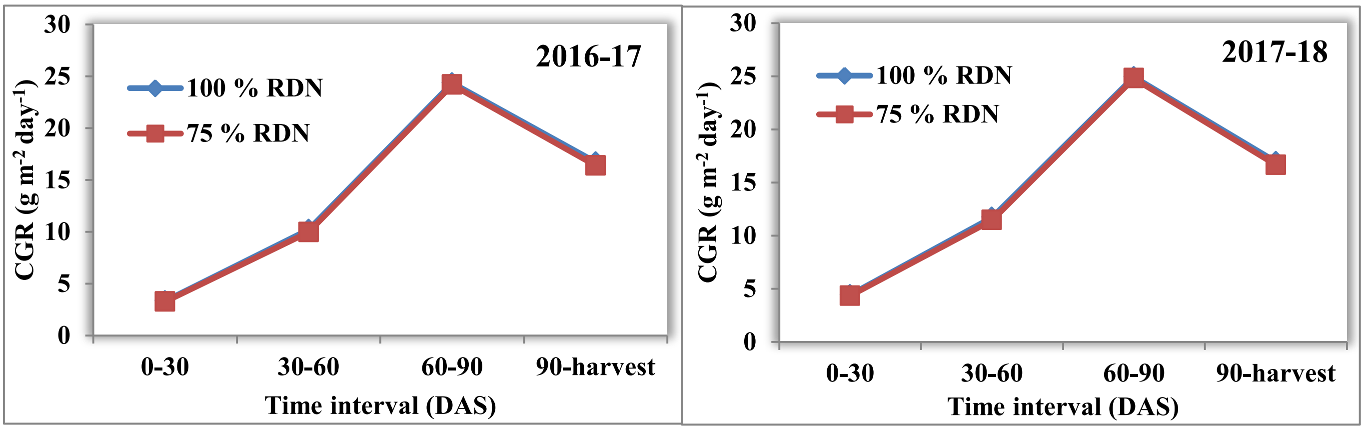
The interaction effect of the tillage practices and residue management in maize and residual of nitrogen management in rice remained unaffected with respect to crop growth rate of maize at 0 – 30, 30 – 60, 60 – 90 DAS and 90 DAS – at harvest during both the years and on mean basis.



(a) Tillage vs CGR

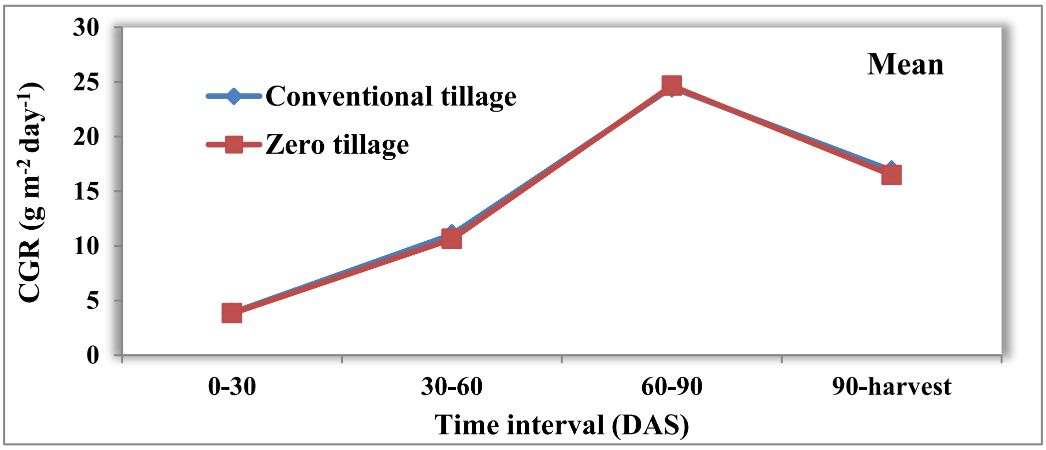


(b) Residue management vs CGR

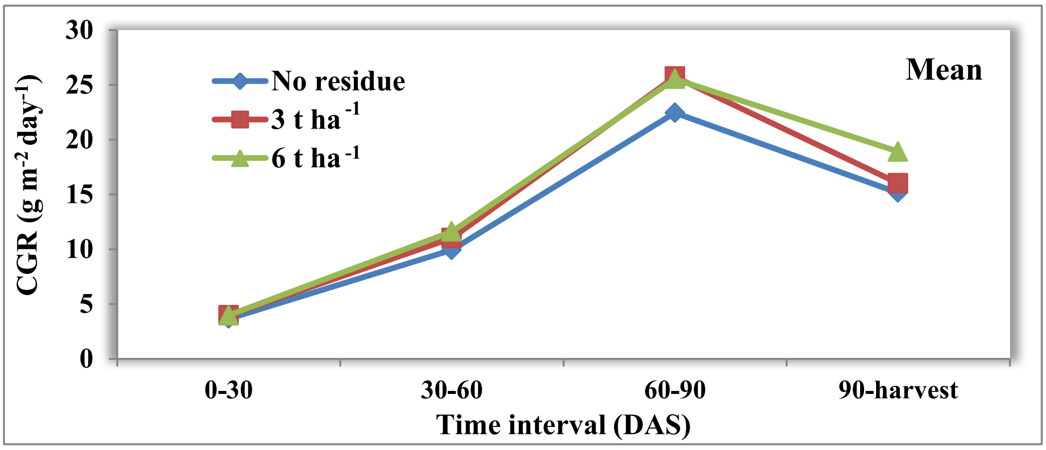


(c) Residual of nitrogen management vs CGR

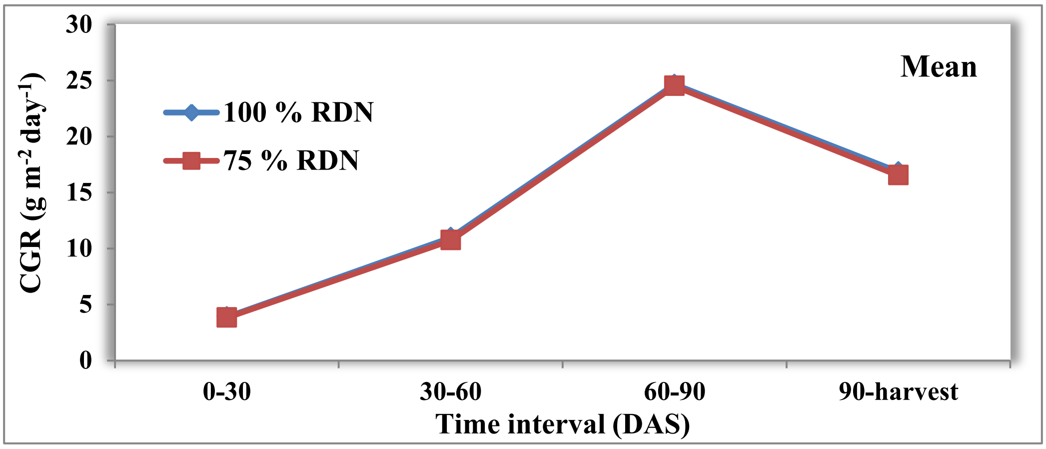
Fig 4.5: Crop growth rate (CGR) of maize at different durations as influenced by tillage, residue and residual of nitrogen management (2016-17 and 2017-18)



(a) Tillage vs CGR



(b) Residue management vs CGR



(c) Residual of nitrogen management vs CGR

Fig 4.6: Crop growth rate (CGR) of maize at different durations as influenced by tillage, residue management and residual of nitrogen management (mean)

4.2.1.6 Relative growth rate (gm mg^{-2} m^{-2} day^{-1})

The data on relative growth rate of maize recorded at different time intervals as influenced by tillage practices in maize, residue management in maize and residual of nitrogen management in rice are depicted in Fig. 4.7 (2016-17 and 2017-18) and Fig. 4.8 (mean). It is clear from the data that the relative growth rate progressively decreased with advancement of crop age.

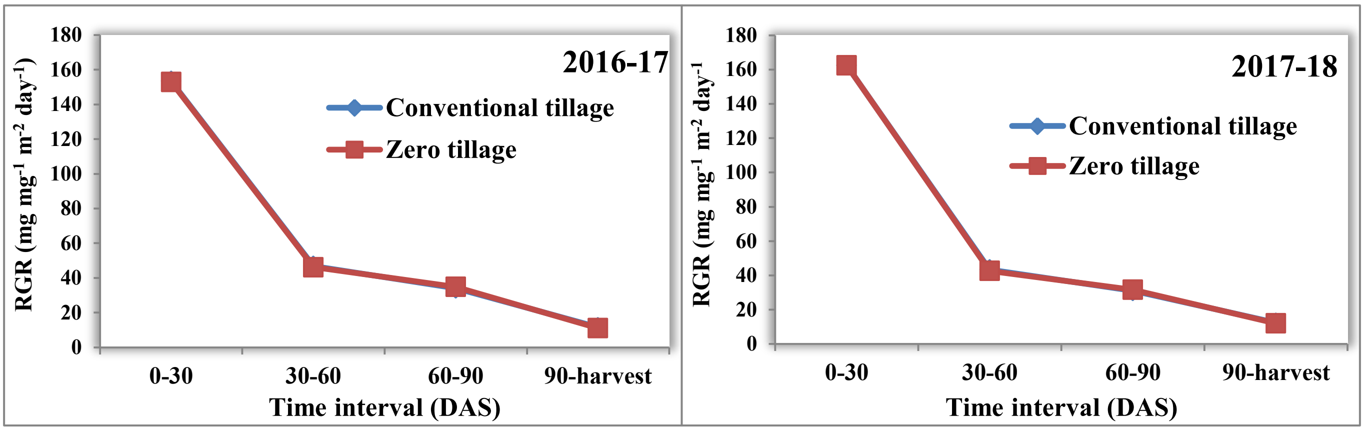
The effect of tillage practices in maize, residue management in maize and residual of nitrogen management in rice as well as their interactions failed to give significant impact on relative growth rate of maize at 0 – 30, 30 – 60, 60 – 90 DAS and 90 DAS – at harvest throughout both the years and on mean basis. However,

RT_1 – conventional tillage (CT), RR_3 – RDF + residue mulching (6 t ha^{-1}) and RN_1 – LCC based (100 % RDN) recorded higher relative growth rate of maize in comparison to their respective treatments at 0 – 30, 30 – 60, 60 – 90 DAS and 90 DAS – at harvest during both the years and on mean basis.

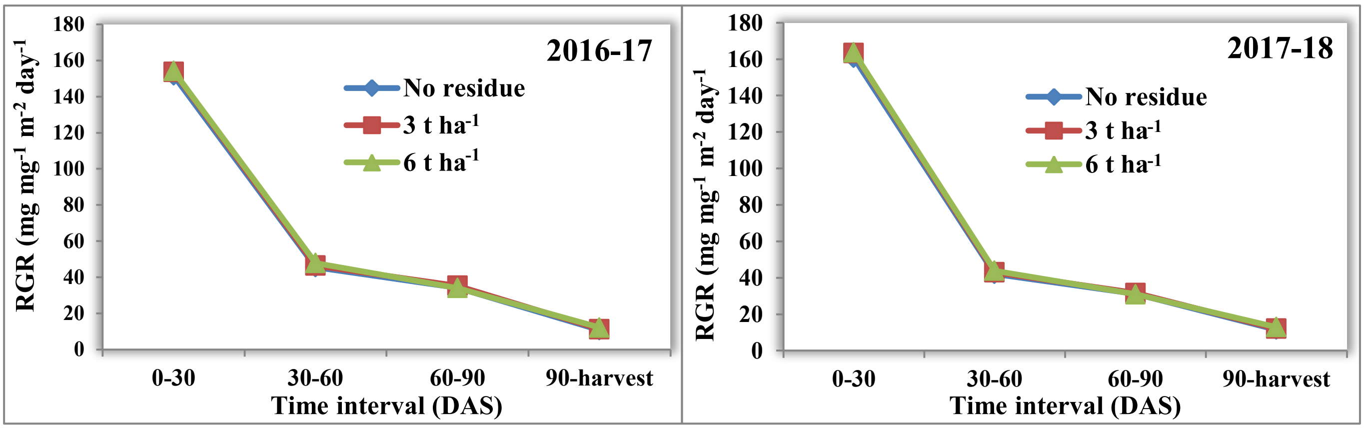
4.2.1.7 SPAD value

The data related to SPAD value of maize recorded at 30, 60 and 90 DAS as influenced by tillage practices in maize, residue management in maize and residual of nitrogen management in rice are presented in Table 4.35.

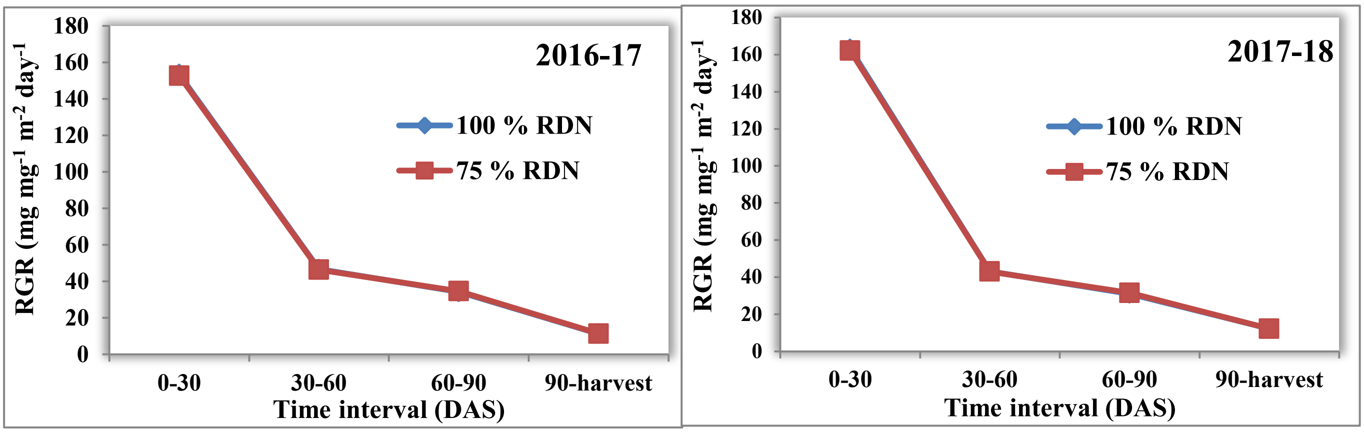
The findings revealed that the effect of tillage practices in maize, residue management in maize and residual of nitrogen management in rice as well as their interactions did not have significant effect on SPAD value of maize at 30, 60 and 90 DAS throughout both the years and on mean basis. However, RT_1 – conventional tillage (CT), RR_3 – RDF + residue mulching (6 t ha^{-1}) and RN_1 – LCC based (100 % RDN) recorded higher SPAD value of maize in comparison to their respective treatments at 30, 60 and 90 DAS during both the years and on mean basis.



(a) Tillage vs RGR

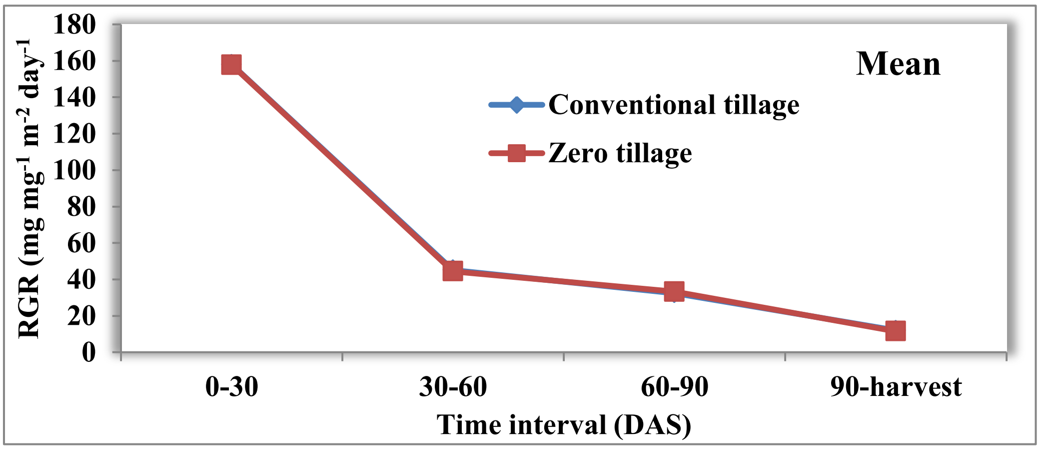


(b) Residue management vs RGR

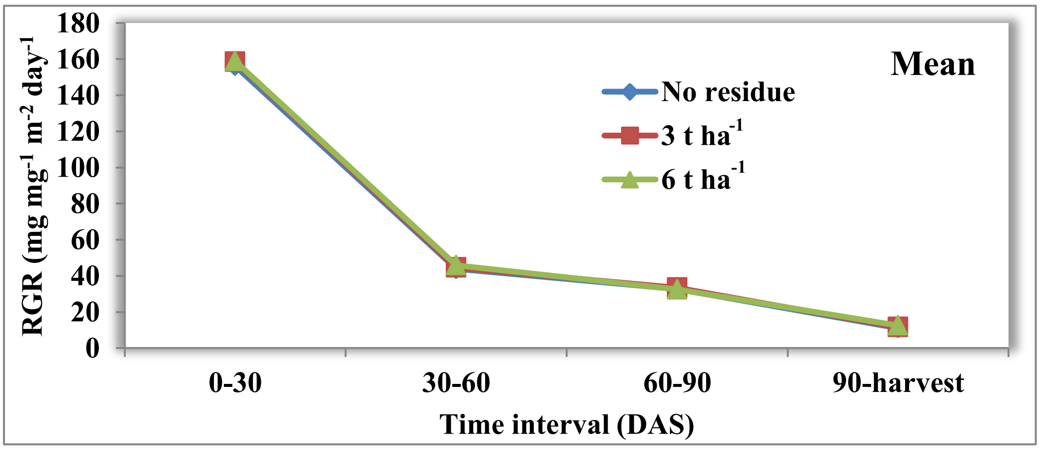


(c) Residual of nitrogen management vs RGR

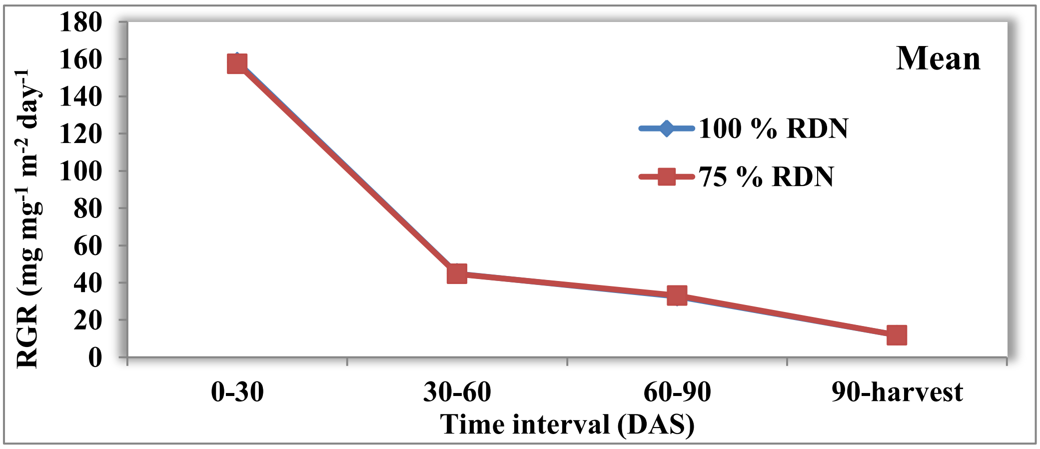
Fig 4.7: Relative growth rate (RGR) of maize at different durations as influenced by tillage, residue and residual of nitrogen management (2016-17 and 2017-18)



(a) Tillage vs RGR



(b) Residue management vs RGR



(c) Residual of nitrogen management vs RGR

Fig 4.8: Relative growth rate (RGR) of maize at different durations as influenced by tillage, residue and residual of nitrogen management (mean)

Table 4.35: SPAD value of maize at different durations as influenced by tillage, residue and residual of nitrogen management

Treatment	SPAD value								
	30 DAS			60 DAS			90 DAS		
	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean
Tillage									
RT_1: Conventional tillage (CT)	32.48	33.56	33.02	35.27	39.27	37.27	42.21	43.01	42.61
RT_2: Zero tillage (ZT)	32.32	33.52	32.92	35.33	37.11	36.22	41.15	41.60	41.36
SEm±	0.83	0.84	0.83	0.91	0.94	0.92	1.01	1.02	1.02
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Residue management									
RR_1: RDF + No residue	31.48	32.95	32.21	34.53	36.63	35.58	40.91	41.73	41.32
RR_2: RDF + Residue mulching (3 t ha^{-1})	33.58	33.69	33.64	35.28	38.50	36.89	41.66	42.55	42.11
RR_3: RDF + Residue mulching (6 t ha^{-1})	32.13	33.97	33.05	36.08	39.44	37.76	42.46	42.64	42.55
SEm±	0.76	0.76	0.76	0.84	0.72	0.75	0.92	0.93	0.93
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Residual of nitrogen management									
RN_1: LCC based (100 % RDN)	32.41	33.70	33.05	35.58	38.51	37.05	41.96	43.07	42.52
RN_2: LCC based (75 % RDN)	32.39	33.37	32.88	35.01	37.87	36.44	41.39	41.54	41.47
SEm±	0.76	0.76	0.76	0.74	0.79	0.74	0.93	0.93	0.93
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS

Discussion on growth parameters

The effect of tillage practices in maize remained unaffected with respect to growth parameters like plant height, dry matter accumulation, leaf area index and crop growth rate of maize. Similarly, Ram *et al*. (2010) and Afzalinia and Zabihi (2014) reported that all the growth parameters (plant height, dry matter and leaf area index) of maize were not significantly influenced by tillage practices, which means these attributes are more genetically governed and needs other practices like genetic/breeding approaches etc. for their manipulation .

Among the residue management in maize, significantly higher plant height, dry matter accumulation, leaf area index and crop growth rate were recorded under RDF + residue mulching (6 t ha^{-1}) as compared to RDF + no residue, but it was at par to RDF + residue mulching (3 t ha^{-1}). This might be due to better provision of growth requirements through epiterrian (solar radiation and CO_2) and subterrian (water, nutrient, air and CO_2 dissolved in water) environment under mulch than no mulch treatment plots. Ram (2006) reported that the higher plant height and dry matter accumulation was recorded under residue as compared to no-residue under both ZT and CT practices. Devasinghe *et al*. (2013) reported that the plant height, length of the longest root and total plant root length were increased by the rice straw mulch as compared to the non-mulched plots. Mulched plants usually grow and mature more uniformly than unmulched plants (Bhardwaj, 2011 and Sarolia and Bhardwaj, 2012). Khalak and Kumaraswamy (1992) reported that mulching either with rice straw or polythene recorded significantly higher plant height, dry matter accumulation $plant^{-1}$ and leaf area index compared to no mulch. Rice straw mulching recorded significantly highest crop growth rate, relative growth rate, net assimilation rate and dry matter partitioning was reported by Awal and Khan (2000). Zhang *et al*. (2011) reported that higher soil water stimulates maize growth, as indicated by a highest leaf area index and greater biomass accumulation was recorded under residue mulching treatments as compared to no mulch.

Regarding the effect of residual of nitrogen management in rice did not have significant influence with respect to growth parameters like plant height, dry matter accumulation, leaf area index and crop growth rate of maize due to the supply of residual fertilizer nitrogen available to subsequent crop will be affected by permanent losses through volatilization, leaching and denitrification and the short – term balance between nitrogen immobilization and mineralization, all of which are greatly affected by the local environment. Similar result was reported by Grant *et al*. (2016).

4.2.2 Post – harvest observations

4.2.2.1 Number of cobs m^{-2}

The data presented in Table 4.36 reveals that the effect of tillage practices in maize, residue management in maize and residual of nitrogen management in rice as well as their interactions failed to give significant impact on number of cobs m^{-2} of maize throughout both the years and on mean basis.

4.2.2.2 Cob length (cm), cob girth (cm) and weight of grains cob^{-1} (g)

The data given in Table 4.36 reveals that cob length, cob girth and weight of grains cob^{-1} of maize was significantly affected by residue management in maize, where significantly maximum values of these parameters were noticed under treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) as compared to others during both the years and on mean basis. Further, effect of tillage practices in maize, residual of nitrogen management in rice and interactions of different treatments failed to show significant effect on length and girth of cob during both the years and on mean basis.

However, the interaction effect of the tillage practices and residue management in maize was found significant with respect to weight of grains cob^{-1} of maize during both the years and on mean basis (Table 4.38). The interaction between RT_2 – zero tillage (ZT) with KR_3 – RDF + residue mulching (6 t ha^{-1}) registered significantly higher weight of grains cob^{-1} as compared to other interactions, but it was at par to interactions of RT_1 – conventional tillage (CT) with RR_3 – RDF + residue mulching (6 t ha^{-1}), RT_1 – conventional tillage (CT) with RR_2 – RDF + residue mulching (3 t ha^{-1}) and RT_2 – zero tillage (ZT) with RR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis.

Table 4.36: Number of cobs, length and girth of cob, and weight of grains cob^{-1} of maize as influenced by tillage, residue and residual of nitrogen Management

Treatment	Number of cobs m^{-2}			Cob length (cm)			Cob girth (cm)			Weight of grains cob^{-1} (g)		
	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean
Tillage												
RT_1: Conventional tillage (CT)	8.22	8.33	8.28	21.30	21.76	21.53	17.09	18.07	17.58	162.39	165.56	163.98
RT_2: Zero tillage (ZT)	8.17	8.22	8.19	20.20	20.77	20.49	16.55	17.25	16.90	158.33	161.45	159.89
SEm±	0.16	0.14	0.15	0.52	0.45	0.48	0.40	0.42	0.41	2.23	2.47	2.35
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Residue management												
RR_1: RDF + No residue	8.08	8.17	8.13	19.37	19.96	19.66	15.65	16.01	15.83	144.58	147.20	145.89
RR_2: RDF + Residue mulching (3 t ha^{-1})	8.17	8.25	8.21	20.58	21.17	20.88	16.75	17.72	17.24	163.17	165.87	164.52
RR_3: RDF + Residue mulching (6 t ha^{-1})	8.33	8.42	8.38	22.30	22.67	22.48	18.07	19.25	18.66	173.33	177.45	175.39
SEm±	0.08	0.13	0.06	0.49	0.45	0.40	0.38	0.42	0.40	2.36	2.65	2.49
CD (P=0.05)	NS	NS	NS	1.59	1.46	1.32	1.25	1.37	1.31	7.70	8.63	8.12
Residual of nitrogen management												
RN_1: LCC based (100 % RDN)	8.28	8.44	8.36	21.11	21.58	21.35	17.10	17.80	17.45	162.28	164.68	163.48
RN_2: LCC based (75 % RDN)	8.11	8.11	8.11	20.39	20.95	20.67	16.54	17.51	17.03	158.44	162.34	160.39
SEm±	0.10	0.11	0.08	0.47	0.34	0.39	0.30	0.32	0.31	2.01	2.12	2.06
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	S	S	S

4.2.2.3 Number of grains cob^{-1}, 100 grains weight (g) and shelling percentage

The data given in Table 4.37 reveals that number of grains cob-1 of maize was significantly affected by residue management in maize, where significantly higher value was noted under treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) during both the years and on mean basis.

As regards to data on 100 grains weight and shelling percentage given in Table 4.35 reveals that different treatments of tillage, residue management and residual of nitrogen management as well as their interactions failed to show significant impact on these parameters.

However, the interaction effect of the tillage practices in maize and residue management in maize on number of grains cob^{-1} of maize was found significantly during both the years and on mean basis (Table 4.38). The interaction between RT_2 – zero tillage (ZT) with RR_3 – RDF + residue mulching (6 t ha^{-1}) recorded significantly higher number of grains cob^{-1} as compared to other interactions, but it was statistically similar to interactions of RT_1 – conventional tillage (CT) with RR_3 – RDF + residue mulching (6 t ha^{-1}), RT_1 – conventional tillage (CT) with RR_2 – RDF + residue mulching (3 t ha^{-1}) and RT_2 – zero tillage (ZT) with RR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis.

Discussion on yield attributes

The effect of tillage practices in maize did not have significant effect on cob length, cob girth, weight of grains cob^{-1} and number of grains cob^{-1} of maize. Similarly, yield attributing characters (cobs plant^{-1} , granis cob^{-1}, and test weight) of maize did not differ significantly among various treatments (Yadav *et al*., 2016). Kaputsa *et al*. (1996) reported similar effect of different tillage methods on maize.

Among the residue management in maize, significantly higher cob length, cob girth, grain weight cob^{-1} and number of grains cob^{-1} were recorded under RDF + residue mulching (6 t ha^{-1}) as compared to R_2 – RDF + residue mulching (3 t ha^{-1}) and RDF + no residue. This might be due to better vegetative growth i.e. plant height, number of leaves, leaf area and dry matter accumulation which might have contributed towards translocation of assimilates from source to sink i.e. cob and ultimately resulted into more number of grains, cob weight and test weight of maize.

Table 4.37: Number of grains, 100 grains weight and shelling percentage of maize as influenced by tillage, residue and residual of nitrogen management

Treatment	Number of grains cob^{-1}			100 grains weight (g)			Shelling percentage		
	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean
Tillage									
RT_1: Conventional tillage (CT)	568.67	582.06	575.36	25.72	25.17	25.44	69.35	69.39	69.37
RT_2: Zero tillage (ZT)	561.80	567.71	564.75	24.55	25.68	25.12	69.23	68.27	68.75
SEm±	6.37	6.15	6.25	0.69	0.61	0.65	1.73	1.74	1.74
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Residue management									
RR_1: RDF + No residue	511.78	531.08	521.43	24.54	24.31	24.42	68.07	68.20	68.14
RR_2: RDF + Residue mulching (3 t ha^{-1})	584.97	583.48	584.23	25.03	25.33	25.18	69.70	68.79	69.25
RR_3: RDF + Residue mulching (6 t ha^{-1})	598.94	610.09	604.52	25.84	26.64	26.24	70.09	69.51	69.80
SEm±	3.24	5.55	4.22	0.60	0.58	0.58	1.63	1.62	0.83
CD (P=0.05)	10.55	18.10	13.76	NS	NS	NS	NS	NS	NS
Residual of nitrogen management									
RN_1: LCC based (100 % RDN)	570.81	576.76	573.78	25.49	26.15	25.82	69.73	69.14	69.43
RN_2: LCC based (75 % RDN)	559.66	573.01	566.33	24.78	24.70	24.74	68.85	68.53	68.69
SEm±	6.21	6.06	5.49	0.60	0.58	0.59	1.64	1.63	1.30
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	S	S	S	NS	NS	NS	NS	NS	NS

Table 4.38: Interaction effect of tillage and residue management on weight of grains and number of grains cob^{-1} of maize

Tillage \ Residue Management	RR_1: RDF + No residue	RR_2: RDF + Residue mulching (3 t ha^{-1})	RR_3: RDF + Residue mulching (6 t ha^{-1})	Mean
	Weight of grains cob^{-1}			
	2016 -17			
RT_1: Conventional tillage (CT)	152.33	164.17	170.67	162.39
RT_2: Zero tillage (ZT)	136.83	162.17	176.00	158.33
Mean	144.58	163.17	173.33	
	2017-18			
RT_1: Conventional tillage (CT)	155.62	168.45	172.62	165.56
RT_2: Zero tillage (ZT)	138.79	163.29	182.29	161.45
Mean	147.20	165.87	177.45	
	Mean			
RT_1: Conventional tillage (CT)	153.98	166.31	171.64	163.98
RT_2: Zero tillage (ZT)	137.81	162.73	179.14	159.89
Mean	145.89	164.52	175.39	

	2016-17		**2017-18**		**Mean**	
	SEm±	**CD (P=0.05)**	**SEm±**	**CD (P=0.05)**	**SEm±**	**CD (P=0.05)**
Comparison of two residue management at same levels of tillage	4.72	10.89	5.29	12.20	4.98	11.49
Comparison of two tillage at same levels of residue management	4.98	15.47	5.55	17.19	5.25	16.31

Tillage \ Residue Management	RR_1: RDF + No residue	RR_2: RDF + Residue mulching (3 t ha^{-1})	RR_3: RDF + Residue mulching (6 t ha^{-1})	Mean
	Number of grains cob^{-1}			
	2016-17			
RT_1: Conventional tillage (CT)	523.33	589.44	593.22	568.67
RT_2: Zero tillage (ZT)	500.22	580.50	604.67	561.80
Mean	511.77	584.97	598.94	
	2017-18			
RT_1: Conventional tillage (CT)	553.67	584.33	608.17	582.06
RT_2: Zero tillage (ZT)	508.49	582.63	612.02	567.71
Mean	531.08	583.48	610.09	
	Mean			
RT_1: Conventional tillage (CT)	538.50	586.89	600.69	575.36
RT_2: Zero tillage (ZT)	504.36	581.56	608.34	564.75
Mean	521.43	584.23	604.52	

	2016-17		**2017-18**		**Mean**	
	SEm±	**CD (P=0.05)**	**SEm±**	**CD (P=0.05)**	**SEm±**	**CD (P=0.05)**
Comparison of two residue management at same levels of tillage	6.47	14.93	11.10	25.59	8.42	19.44
Comparison of two tillage at same levels of residue management	10.44	39.58	12.56	40.99	11.20	39.76

Similar results were found by Sayre *et al*. (2005), Verhulst *et al*. (2011) and Jat *et al*. (2013). Residue mulch provided favourable soil moisture and temperature conditions for better crop growth resulting in highest yield parameters (Parihar *et al*., 2016). Kumar and Angadi (2014) also reported that significantly higher cob weight (166.10 g) and 100-seed weight (27.52 g) were recorded with mulching as compared to no mulching. Yield attributing characters differed significantly due to the application of straw mulch and antitranspirant (Brahma *et al*., 2007).

The interaction between zero tillage (ZT) with RDF + residue mulching (6 t ha^{-1}) registered significantly highest weight of grains cob^{-1} and number of grains cob^{-1} as compared to other interactions. However, it was at par to interactions of conventional tillage (CT) with RDF + residue mulching (6 t ha^{-1}), conventional tillage (CT) with RDF + residue mulching (3 t ha^{-1}) and zero tillage (ZT) with RDF + residue mulching (3 t ha^{-1}). This might be due to increased availability of major plant nutrients in zero tillage with residue mulching that resulted in better growth and development of yield attributes. These results are in agreement with the findings of Kobayashi *et al*. (2010) and Kaur and Mahal (2016).

4.2.2.4 Grain yield (t ha^{-1})

The data regarding grain yield of maize as influenced by tillage practices in maize, residue management in maize and residual of nitrogen management in rice are presented in Table 4.39. The findings revealed that the effect of tillage practices in maize and residual of nitrogen management in rice did not have significant influence on grain yield of maize during both the years and on mean basis. However, RT_1 – conventional tillage (CT) and RN_1 – LCC based (100 % RDN) obtained higher grain yield of maize in comparison to their respective treatments throughout both the years and on mean basis.

Among the treatment of residue management in maize, the grain yield was significantly higher under treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) as compared to treatment RR_2 – RDF + residue mulching (3 t ha^{-1}) and RR_1 – RDF + no residue during both the years and on mean basis.

Table 4.39: Grain and stover yields and harvest index of maize as influenced by tillage, residue and residual of nitrogen management

Treatment	Grain yield (t ha^{-1})			Stover yield (t ha^{-1})			Harvest index (%)		
	2016-17	**2017-18**	**Mean**	**2016-17**	**2017-18**	**Mean**	**2016-17**	**2017-18**	**Mean**
Tillage									
RT_1: Conventional tillage (CT)	6.65	6.76	6.70	10.21	10.26	10.24	39.37	39.63	39.50
RT_2: Zero tillage (ZT)	6.54	6.60	6.57	10.15	10.17	10.16	38.99	39.24	39.12
SEm±	0.07	0.08	0.08	0.17	0.15	0.18	1.27	1.22	1.24
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Residue management									
RR_1: RDF + No residue	5.58	5.66	5.62	9.77	9.79	9.78	36.32	36.65	36.49
RR_2: RDF + Residue mulching (3 t ha^{-1})	6.91	6.98	6.94	10.10	10.14	10.12	40.63	40.77	40.70
RR_3: RDF + Residue mulching (6 t ha^{-1})	7.30	7.40	7.35	10.69	10.71	10.70	40.60	40.87	40.74
SEm±	0.09	0.08	0.08	0.15	0.16	0.15	1.21	1.15	1.18
CD (P=0.05)	0.29	0.26	0.25	0.49	0.53	0.50	NS	NS	NS
Residual of nitrogen management									
RN_1: LCC based (100 % RDN)	6.66	6.72	6.69	10.25	10.30	10.27	39.24	39.41	39.33
RN_2: LCC based (75 % RDN)	6.53	6.63	6.58	10.11	10.13	10.12	39.12	39.46	39.29
SEm±	0.07	0.08	0.07	0.12	0.12	0.10	0.89	0.88	0.89
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	S	S	S	NS	NS	NS	NS	NS	NS

Table 4.40: Interaction effect of tillage and residue management on grain and stover yields of maize

Residue Management / Tillage	RR_1: RDF + No residue	RR_2: RDF + Residue mulching (3 t ha^{-1})	RR_3: RDF + Residue mulching (6 t ha^{-1})	Mean
	Grain yield (t ha^{-1})			
	2016 -17			
RT_1: Conventional tillage (CT)	5.84	6.92	7.19	6.65
RT_2: Zero tillage (ZT)	5.31	6.89	7.41	6.54
Mean	5.58	6.91	7.30	
	2017-18			
RT_1: Conventional tillage (CT)	5.94	6.98	7.34	6.76
RT_2: Zero tillage (ZT)	5.37	6.97	7.46	6.60
Mean	5.66	6.98	7.40	
	Mean			
RT_1: Conventional tillage (CT)	5.89	6.95	7.27	6.70
RT_2: Zero tillage (ZT)	5.34	6.93	7.44	6.57
Mean	5.62	6.94	7.35	

	2016-17		2017-18		Mean	
	SEm±	**CD (P=0.05)**	**SEm±**	**CD (P=0.05)**	**SEm±**	**CD (P=0.05)**
Comparison of two residue management at same levels of tillage	0.18	0.41	0.16	0.36	0.15	0.35
Comparison of two tillage at same levels of residue management	0.18	0.54	0.17	0.56	0.16	0.52

Residue Management / Tillage	RR_1: RDF + No residue	RR_2: RDF + Residue mulching (3 t ha^{-1})	RR_3: RDF + Residue mulching (6 t ha^{-1})	Mean
	Stover yield (t ha^{-1})			
	2016-17			
RT_1: Conventional tillage (CT)	9.92	10.22	10.55	10.21
RT_2: Zero tillage (ZT)	9.35	9.94	11.17	10.15
Mean	9.63	10.08	10.84	
	2017-18			
RT_1: Conventional tillage (CT)	9.97	10.24	10.58	10.26
RT_2: Zero tillage (ZT)	9.39	9.96	11.19	10.18
Mean	9.68	10.10	10.89	
	Mean			
RT_1: Conventional tillage (CT)	9.94	10.23	10.54	10.24
RT_2: Zero tillage (ZT)	9.37	9.95	11.18	10.17
Mean	9.66	10.09	10.86	

	2016-17		2017-18		Mean	
	SEm±	**CD (P=0.05)**	**SEm±**	**CD (P=0.05)**	**SEm±**	**CD (P=0.05)**
Comparison of two residue management at same levels of tillage	0.30	0.68	0.29	0.67	0.30	0.69
Comparison of two tillage at same levels of residue management	0.34	1.13	0.31	0.95	0.31	0.96

The interaction between tillage practices in maize and residue management in maize had significant effect on grain yield of maize during both the years and on mean basis (Table 4.40). The interaction between RT_2 – zero tillage (ZT) with RR_3 – RDF + residue mulching (6 t ha^{-1}) produced significantly higher grain yield of maize as compared to other interactions. However, it was statistically similar to interactions of RT_1 – conventional tillage (CT) with RR_3 – RDF + residue mulching (6 t ha^{-1}), RT_1 – conventional tillage (CT) with RR_2 – RDF + residue mulching (3 t ha^{-1}) and RT_2 – zero tillage (ZT) with RR_2 – RDF + residue mulching (3 t ha^{-1}) throughout both the years and on mean basis.

4.2.2.5 Stover yield (t ha^{-1})

The data on stover yield of maize as influenced by tillage practices in maize, residue management in maize and residual of nitrogen management in rice are presented in Table 4.39.

The findings indicated that the effect of tillage practices in maize and residual of nitrogen management in rice did not have significant influence on stover yield of maize, however, RT_1 – conventional tillage (CT) and RN_1 – LCC based (100 % RDN) obtained higher stover yield of maize in comparison to their respective treatments during both the years and on mean basis.

Among the treatments of residue management in maize, the stover yield was significantly treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) as compared to treatment RR_2 – RDF + residue mulching (3 t ha^{-1}) and RR_1 – RDF + no residue during both the years and on mean basis.

The interaction between tillage practices in maize and residue management in maize had significant influence on stover yield of maize during both the years and on mean basis (Table 4.40). The interaction between RT_2 – zero tillage (ZT) with RR_3 – RDF + residue mulching (6 t ha^{-1}) produced significantly higher stover yield of maize as compared to other interactions. However, it was at par to interactions of RT_1 – conventional tillage (CT) with RR_3 – RDF + residue mulching (6 t ha^{-1}), RT_1 – conventional tillage (CT) with RR_2 – RDF + residue mulching (3 t ha^{-1}) and RT_2 – zero tillage (ZT) with RR_2 – RDF + residue mulching (3 t ha^{-1}) throughout both the years and on mean basis.

4.2.2.6 Harvest index (%)

The data related to harvest index of maize as influenced by tillage practices in maize, residue management in maize and residual of nitrogen management in rice has been presented in Table 4.39.

The findings revealed that the effect of tillage practices in maize, residue management in maize and residual of nitrogen management in rice as well their interactions failed to give significant influence on harvest index of maize throughout both the years and on mean basis.

Discussion on grain and stover yields of maize

The effect of tillage practices in maize failed to give significant influence on grain and stover yields of maize. Less soil disturbance under zero tilled soil would have increased the microbial population and organic biomass which might have increased the yield which compensated by compensating the fast growth of crop at the end. Ramesh *et al*. (2016) also reported that tillage methods (conventional tillage and zero tillage) did not show any significant results on yield of maize.

As regards to residue management in maize, significantly higher grain and stover yields were obtained under R_3 – RDF + residue mulching (6 t ha^{-1}) as compared to RDF + residue mulching (3 t ha^{-1}) and RDF + no residue. This might be due to less competition of the weeds with the crop plants for growth and yield attributes factors and hence there was increased availability of nutrients, moisture, CO_2 and sun light to the crop plants. Optimum availability of resources for the growth might have helped to the plants to express their growth and yield parameters to the fullest extent under the mulches. These results were in conformity with the finding of Sharma *et al*. (2008). Singh *et al*. (2011) also noted that mulching recorded higher maize yield as compared to control. Similarly, Uwah and Iwo (2011) reported that dry stover and grain yields of maize were recorded significantly higher with straw mulch @ 6 t ha^{-1} compared to unmulched control plot.

The interaction between zero tillage (ZT) with RDF + residue mulching (6 t ha^{-1}) produced significantly highest grain and stover yields of maize as compared to other interactions. However, it was at par to interactions of conventional tillage

(CT) with RDF + residue mulching (6 t ha^{-1}), conventional tillage (CT) with RDF + residue mulching (3 t ha^{-1}) and zero tillage (ZT) with RDF + residue mulching (3 t ha^{-1}) due to higher weight of grains cob^{-1} and number of grains cob^{-1} which in turn resulted in higher grain and straw yields of maize. Similar results were reported by Bhattacharya *et al*. (2012) and Sarwar *et al*. (2013).

4.2.3 Studies on weeds

The weed growth was measured in terms of density and dry weight of weeds and the data was transformed through square root method before analysis of variance of original values.

4.2.3.1 Total weed density (No. m^{-2})

The data on total weed density recorded at 30 and 60 DAS as influenced by tillage practices in maize, residue management in maize and residual of nitrogen management in rice are presented in Table 4.41.

Between the tillage practices in maize, except at 60 DAS, significantly lower total weed density at 30 DAS was recorded under RT_1 – conventional tillage (CT) as compared to RT_2 – zero tillage (ZT) throughout both the years and on mean basis.

Among the treatments of residue management in maize, except at 60 DAS, treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) registered significantly lower total weed density at 30 DAS as compared to treatment RR_2 – RDF + residue mulching (3 t ha^{-1}) and RR_1 – RDF + no residue during both the years and on mean basis.

Whereas, effect of residual of nitrogen management in rice and interactions of different treatments did not have significant impact on total weed density at 30 and 60 DAS during both the years and on mean basis.

4.2.3.2 Density of different weed species (No. m^{-2})

The data related to density of different weed species recorded at 30 and 60 DAS as influenced by tillage practices in maize, residue management in maize and residual of nitrogen management in rice are presented in Table 4.42 and Table 4.43, respectively.

Table 4.41: Effect of tillage, residue and residual of nitrogen management on total weed density at 30 and 60 DAS in maize

Treatment	Total weed density (No. m^{-2})					
	30 DAS			60 DAS		
	2016-17	2017-18	Mean	2016-17	2017-18	Mean
Tillage						
RT_1: Conventional tillage (CT)	7.15	7.96	7.56	8.43	8.59	8.51
	(50.96)	(63.22)	(57.09)	(70.82)	(73.56)	(72.19)
RT_2: Zero tillage (ZT)	9.11	9.82	9.47	8.77	9.07	8.92
	(83.91)	(97.48)	(90.69)	(76.97)	(82.13)	(79.55)
SEm±	0.21	0.23	0.22	0.25	0.27	0.26
CD (P=0.05)	1.26	1.40	1.33			
Residue management						
RR_1: RDF + No residue	9.11	9.99	9.55	8.95	9.14	9.04
	(84.60)	(101.09)	(92.85)	(79.98)	(83.18)	(81.58)
RR_2: RDF + Residue mulching (3 t ha^{-1})	7.98	8.81	8.39	9.62	8.81	8.72
	(64.08)	(77.96)	(71.02)	(73.99)	(77.28)	(75.63)
RR_3: RDF + Residue mulching (6 t ha^{-1})	7.32	7.87	7.60	8.24	8.55	8.39
	(53.61)	(62.00)	(57.81)	(67.72)	(73.09)	(70.40)
SEm±	0.24	0.31	0.26	0.23	0.21	0.15
CD (P=0.05)	0.80	1.02	0.83			
Residual of nitrogen management						
RN_1: LCC based (100 % RDN)	8.28	9.00	8.64	8.46	8.71	8.58
	(69.72)	(82.25)	(75.98)	(76.42)	(80.05)	(78.24)
RN_2: LCC based (75 % RDN)	7.99	8.78	8.39	8.75	8.96	8.86
	(65.14)	(78.45)	(71.80)	(71.37)	(75.64)	(73.51)
SEm±	0.15	0.17	0.16	0.10	0.16	0.12
CD (P=0.05)	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS

***Original data are given in parenthesis**

Table 4.42: Effect of tillage, residue and residual of nitrogen management on density of different weed species at 30 DAS in maize

Treatment	Weed density (No. m^{-2})																	
	Eleusine indica			*Digiteria sanguinalis*			*Echinochloa colona*			*Cyperus rotundus*			*Alternanthera philoxeroides*			Others		
	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean
Tillage																		
RT_1: Conventional tillage (CT)	3.4 (10.9)	3.6 (12.7)	3.5 (11.8)	3.2 (10.0)	3.5 (12.0)	3.4 (11.0)	2.9 (7.8)	3.5 (11.6)	3.2 (9.7)	3.1 (9.3)	3.8 (14.2)	3.5 (11.7)	2.5 (6.0)	2.6 (6.1)	2.5 (6.0)	2.7 (7.0)	2.7 (6.6)	2.7 (6.8)
RT_2: Zero tillage (ZT)	4.3 (18.5)	4.6 (21.4)	4.5 (20.0)	4.3 (18.1)	4.6 (21.2)	4.4 (19.7)	3.8 (14.4)	4.2 (17.4)	4.0 (15.9)	4.0 (15.9)	4.5 (19.6)	4.2 (17.7)	2.9 (7.9)	3.3 (10.6)	3.1 (9.3)	3.1 (9.0)	2.8 (7.3)	2.9 (8.1)
SEm±	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0
CD (P=0.05)	0.7	0.8	0.7	0.8	0.7	0.8	0.5	0.6	0.6	0.6	0.5	0.6	0.4	0.5	0.4	0.3	0.1	0.22
Residue management																		
RR_1: RDF + No residue	4.3 (18.8)	4.7 (22.1)	4.5 (20.5)	4.3 (18.4)	4.6 (21.5)	4.4 (20.0)	3.8 (14.5)	4.3 (18.5)	4.1 (16.5)	3.9 (15.1)	4.7 (21.4)	4.3 (18.3)	3.1 (8.9)	3.2 (10.3)	3.1 (9.6)	3.1 (8.9)	2.8 (7.3)	2.9 (8.1)
RR_2: RDF + Residue mulching (3 t ha^{-1})	3.8 (14.1)	4.1 (16.8)	3.9 (15.5)	3.6 (12.9)	4.0 (16.0)	3.8 (14.5)	3.2 (10.2)	3.7 (13.6)	3.5 (11.9)	3.5 (12.4)	4.1 (16.3)	3.8 (14.3)	2.7 (6.9)	2.9 (8.2)	2.8 (7.6)	2.8 (7.6)	2.7 (6.9)	2.8 (7.3)
RR_3: RDF + Residue mulching (6 t ha^{-1})	3.4 (11.2)	3.6 (12.3)	3.5 (11.7)	3.3 (10.9)	3.5 (12.2)	3.4 (11.5)	3.0 (8.8)	3.4 (11.5)	3.2 (10.1)	3.2 (10.3)	3.6 (12.8)	3.4 (11.6)	2.3 (5.0)	2.6 (6.6)	2.5 (5.8)	2.8 (7.5)	2.7 (6.6)	2.7 (7.0)
SEm±	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0
CD (P=0.05)	0.4	0.5	0.4	0.5	0.5	0.4	0.3	0.4	0.3	0.4	0.3	0.4	0.4	0.3	0.3	0.2	0.1	0.1
Residual of nitrogen management																		
RN_1: LCC based (100 % RDN)	3.91 (15.3)	4.1 (17.2)	4.0 (16.2)	3.7 (14.2)	4.1 (17.1)	3.9 (15.6)	3.4 (11.6)	3.9 (15.2)	3.7 (13.4)	3.7 (13.3)	4.2 (17.2)	3.9 (15.3)	2.7 (7.1)	3.0 (8.7)	2.9 (7.9)	2.9 (8.2)	2.7 (7.0)	2.8 (7.6)
RN_2: LCC based (75 % RDN)	3.76 (14.1)	4.1 (17.0)	3.9 (15.5)	3.7 (13.9)	4.0 (16.1)	3.9 (15.0)	3.3 (10.8)	3.7 (13.8)	3.5 (12.3)	3.4 (11.8)	4.1 (16.6)	3.8 (14.2)	2.7 (6.7)	2.9 (8.1)	2.8 (7.4)	2.9 (7.8)	2.7 (6.9)	2.8 (7.4)
SEm±	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

***Original data are given in parenthesis**

Table 4.43: Effect of tillage, residue and residual of nitrogen management on density of different weed species at 60 DAS in maize

Treatment	Weed density (No. m^{-2})																	
	Eleusine indica			*Digiteria sanguinalis*			*Echinochloa colona*			*Cyperus rotundus*			*Alternanthera philoxeroides*			Others		
	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean
Tillage																		
RT_1: Conventional tillage (CT)	3.6 (12.9)	3.3 (10.2)	3.5 (11.6)	3.6 (12.8)	3.5 (11.7)	3.6 (12.3)	3.6 (12.4)	4.0 (15.7)	3.8 (14.0)	3.8 (14.0)	3.8 (14.3)	3.8 (14.1)	3.2 (9.7)	3.3 (10.3)	3.3 (10.0)	3.1 (9.1)	3.4 (11.3)	3.3 (10.2)
RT_2: Zero tillage (ZT)	3.7 (13.8)	3.5 (12.2)	3.6 (13.0)	3.7 (13.1)	3.6 (12.9)	3.7 (13.0)	3.7 (13.5)	4.1 (16.6)	3.9 (15.1)	3.9 (15.0)	4.0 (15.5)	4.0 (15.2)	3.4 (10.9)	3.6 (12.7)	3.6 (11.8)	3.4 (10.8)	3.6 (12.2)	3.5 (11.5)
SEm±	0.3	0.3	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Residue management																		
RR_1: RDF + No residue	3.8 (14.2)	3.5 (12.8)	3.6 (13.5)	3.8 (14.5)	3.8 (13.9)	3.8 (14.2)	3.8 (14.1)	4.2 (17.5)	4.0 (15.8)	4.0 (15.6)	4.0 (15.4)	4.0 (15.5)	3.4 (11.2)	3.6 (12.7)	3.6 (11.9)	3.3 (10.5)	3.5 (12.1)	3.4 (11.3)
RR_2: RDF + Residue mulching (3 t ha^{-1})	3.7 (13.5)	3.4 (11.0)	3.6 (12.3)	3.7 (13.1)	3.5 (11.7)	3.6 (12.4)	3.7 (13.0)	4.1 (16.0)	3.9 (14.5)	3.9 (14.6)	3.9 (15.1)	3.9 (14.9)	3.2 (10.0)	3.5 (11.7)	3.5 (10.9)	3.2 (9.8)	3.5 (11.8)	3.3 (10.8)
RR_3: RDF + Residue mulching (6 t ha^{-1})	3.5 (12.3)	3.4 (9.9)	3.4 (11.1)	3.4 (11.3)	3.4 (11.4)	3.4 (11.4)	3.5 (11.7)	3.9 (15.0)	3.7 (13.3)	3.7 (13.3)	3.8 (14.1)	3.8 (13.7)	3.2 (9.7)	3.2 (10.1)	3.2 (9.9)	3.2 (9.5)	3.5 (11.4)	3.3 (10.5)
SEm±	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Residual of nitrogen management																		
RN_1: LCC based (100 % RDN)	3.8 (14.0)	3.4 (11.5)	3.6 (12.8)	3.7 (13.2)	3.6 (12.8)	3.7 (13.0)	3.7 (13.5)	4.1 (16.5)	3.9 (15.0)	3.9 (14.8)	4.0 (15.4)	3.9 (15.1)	3.2 (10.7)	3.4 (12.0)	3.4 (11.4)	3.2 (10.1)	3.5 (11.9)	3.3 (10.7)
RN_2: LCC based (75 % RDN)	3.6 (12.6)	3.4 (11.0)	3.5 (11.8)	3.6 (12.6)	3.5 (11.8)	3.5 (12.2)	3.6 (12.4)	4.0 (15.9)	3.8 (14.1)	3.8 (14.2)	3.9 (14.4)	3.8 (14.3)	3.3 (9.8)	3.5 (11.0)	3.5 (10.4)	3.3 (9.7)	3.5 (11.6)	3.4 (10.7)
SEm±	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

***Original data are given in parenthesis.**

As regard to the tillage practices in maize, except at 60 DAS, treatment RT_1 – conventional tillage (CT) recorded significantly lower density of *Eleusine indica, Digitaria sanguinalis, Echinochloa colona, Cyperus rotundus Alternanthera philoxeroides* and other weeds in maize at 30 DAS as compared to RT_2 – zero tillage (ZT) during both the years and on mean basis.

Among the residue management in maize, except at 60 DAS, significantly lower density of *Eleusine indica, Digitaria sanguinalis, Echinochloa colona, Cyperus rotundus Alternanthera philoxeroides* and other weeds in maize at 30 DAS were registered under treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) as compared to treatments RR_2 – RDF + residue mulching (3 t ha^{-1}) and RR_1 – RDF + no residue throughout both the years and on mean basis.

The results revealed that effect of residual of nitrogen management in rice as well as interaction effect of different treatments remained unaffected with respect to density of different weed species at 30 and 60 DAS during both the years and on mean basis.

4.2.3.3 Total weed dry weight (g m^{-2})

The data on total weed dry weight presented in Table 4.44 reveals that between tillage practices in maize, except at 60 DAS, RT_1 – conventional tillage (CT) recorded significantly lower total weed dry weight at 30 DAS as compared to RT_2 – zero tillage (ZT) during both the years and on mean basis.

Among the residue management in maize, except at 60 DAS, significantly lower total weed dry weight at 30 DAS was recorded under treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) as compared to treatments RR_2 – RDF + residue mulching (3 t ha^{-1}) and RR_1 – RDF + no residue during both the years and on mean basis.

The effect of residual of nitrogen management in rice and interaction effect of different treatments were found non - significant on total weed dry weight at 30 and 60 DAS during both the years and on mean basis.

Table 4.44: Effect of tillage, residue and residual of nitrogen management on total weed dry weight at 30 and 60 DAS in maize

Treatment	Total weed dry weight (g m^{-2})					
	30 DAS			60 DAS		
	2016-17	2017-18	Mean	2016-17	2017-18	Mean
Tillage in maize						
RT_1: Conventional tillage (CT)	2.82 (7.48)	2.89 (7.88)	2.86 (7.68)	5.27 (27.34)	5.29 (27.40)	5.28 (27.37)
RT_2: Zero tillage (ZT)	3.13 (9.30)	3.23 (9.97)	3.18 (9.64)	5.74 (32.47)	5.83 (33.59)	5.78 (33.03)
SEm±	0.02	0.02	0.02	0.15	0.13	0.14
CD (P=0.05)	0.12	0.13	0.12	NS	NS	NS
Residue management						
RR_1: RDF + No residue	3.13 (9.33)	3.25 (10.09)	3.19 (9.71)	5.74 (32.53)	5.80 (33.27)	5.77 (32.90)
RR_2: RDF + Residue mulching (3 t ha^{-1})	2.96 (8.31)	3.02 (8.69)	2.99 (8.50)	5.49 (29.68)	5.53 (30.15)	5.51 (29.91)
RR_3: RDF + Residue mulching (6 t ha^{-1})	2.83 (7.53)	2.91 (8.00)	2.87 (7.77)	5.29 (27.50)	5.34 (28.08)	5.31 (27.79)
SEm±	0.02	0.02	0.02	0.14	0.13	0.13
CD (P=0.05)	0.08	0.05	0.06	NS	NS	NS
Residual of nitrogen management						
RN_1: LCC based (100 % RDN)	2.99 (8.48)	3.08 (9.01)	3.03 (8.75)	5.52 (29.98)	5.57 (30.66)	5.54 (30.32)
RN_2: LCC based (75 % RDN)	2.96 (8.30)	3.05 (8.84)	3.00 (8.57)	5.50 (29.82)	5.54 (30.33)	5.52 (30.08)
SEm±	0.05	0.04	0.04	0.10	0.10	0.10
CD (P=0.05)	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS

***Original data are given in parenthesis**

4.2.3.3 Dry weight of different weed species (g m^{-2})

Regarding data on dry weight of different weeds species recorded at 30 and 60 DAS as influenced by tillage practices in maize, residue management in maize and residual of nitrogen management in rice are presented in Table 4.45 and Table 4.46, respectively.

In case of the tillage practices in maize, except at 60 DAS, significantly lower dry weight of *Eleusine indica, Digitaria sanguinalis, Echinochloa colona, Cyperus rotundus Alternanthera philoxeroides* and other weeds in maize at 30 were noted under RT_1 – conventional tillage (CT) as compared to RT_2 – zero tillage (ZT) during both the years and on mean basis.

Among the residue management in maize, except at 60 DAS, treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) recorded significantly lower dry weight of *Eleusine indica, Digitaria sanguinalis, Echinochloa colona, Cyperus rotundus Alternanthera philoxeroides* and other weeds in maize at 30 DAS as compared to treatments RR_2 – RDF + residue mulching (3 t ha^{-1}) and RR_1 – RDF + no residue during both the years and on mean basis.

The effect of residual of nitrogen management in rice and interaction effect of different treatments remained unaffected with respect to dry weight of different weed species at 30 and 60 DAS during both the years and on mean basis.

Discussion on weeds

Between the tillage practices in maize, significantly lower total and species wise density and dry weight of weeds were recorded under conventional tillage (CT) as compared to zero tillage (ZT). This might be due to the existing vegetation was controlled by preparatory cultivation in conventional tillage and higher weed seed bank in zero tillage. Similar results were reported by Pradeep *et al*. (2002), Sharma and Gautam (2012) and Stanzen *et al*. (2016). Singh *et al.* (2008) and Walia *et al*. (2009) also noted that more number of weeds and weed dry matter under conservation tillage than conventional tillage.

Table 4.45: Effect of tillage, residue and residual of nitrogen management on dry weight of different weed species at 30 DAS in maize

Treatment	Weed dry weight (g m^{-2})																	
	Eleusine indica			*Digiteria sanguinalis*			*Echinochloa colona*			*Cyperus rotundus*			*Alternanthera philoxeroides*			Others		
	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean
Tillage																		
RT_1: Conventional tillage (CT)	1.51 (1.77)	1.52 (1.83)	1.52 (1.80)	1.34 (1.29)	1.38 (1.41)	1.36 (1.35)	1.35 (1.33)	1.42 (1.51)	1.38 (1.42)	1.23 (1.01)	1.24 (1.05)	1.23 (1.03)	1.24 (1.03)	1.26 (1.09)	1.25 (1.06)	1.24 (1.05)	1.22 (1.00)	1.23 (1.02)
RT_2: Zero tillage (ZT)	1.69 (2.37)	1.72 (2.47)	1.71 (2.42)	1.55 (1.92)	1.57 (1.97)	1.56 (1.94)	1.44 (1.58)	1.56 (1.93)	1.50 (1.76)	1.29 (1.16)	1.31 (1.21)	1.30 (1.19)	1.27 (1.10)	1.33 (1.28)	1.30 (1.19)	1.29 (1.16)	1.27 (1.11)	1.28 (1.13)
SEm±	0.03	0.04	0.03	0.03	0.03	0.03	0.01	0.02	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.00	0.00
CD (P=0.05)	0.17	0.18	0.18	0.19	0.18	0.19	0.06	0.07	0.07	0.06	0.05	0.06	0.01	0.07	0.04	0.03	0.01	0.02
Residue management																		
RR_1: RDF + No residue	1.67 (2.31)	1.71 (2.43)	1.69 (2.37)	1.52 (1.85)	1.59 (2.06)	1.56 (1.95)	1.42 (1.53)	1.54 (1.87)	1.48 (1.70)	1.36 (1.35)	1.37 (1.37)	1.36 (1.36)	1.28 (1.13)	1.34 (1.30)	1.31 (1.21)	1.28 (1.15)	1.26 (1.09)	1.27 (1.12)
RR_2: RDF + Residue mulching (3 t ha^{-1})	1.59 (2.04)	1.60 (2.06)	1.59 (2.05)	1.42 (1.54)	1.45 (1.62)	1.44 (1.58)	1.40 (1.48)	1.48 (1.69)	1.44 (1.58)	1.26 (1.08)	1.26 (1.10)	1.26 (1.09)	1.25 (1.07)	1.29 (1.17)	1.27 (1.12)	1.27 (1.11)	1.25 (1.05)	1.26 (1.08)
RR_3: RDF + Residue mulching (6 t ha^{-1})	1.54 (1.87)	1.56 (1.95)	1.55 (1.91)	1.38 (1.43)	1.39 (1.41)	1.38 (1.42)	1.37 (1.37)	1.45 (1.60)	1.41 (1.48)	1.15 (0.82)	1.19 (0.93)	1.17 (0.87)	1.23 (1.01)	1.26 (1.09)	1.24 (1.05)	1.24 (1.04)	1.23 (1.02)	1.24 (1.03)
SEm±	0.03	0.04	0.03	0.03	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.00	0.01
CD (P=0.05)	0.09	0.10	0.09	0.10	0.10	0.10	0.03	0.04	0.04	0.04	0.03	0.04	0.02	0.05	0.03	0.04	0.02	0.03
Residual of nitrogen management																		
RN_1: LCC based (100 % RDN)	1.61 (2.10)	1.63 (2.17)	1.62 (2.13)	1.45 (1.63)	1.48 (1.72)	1.47 (1.68)	1.40 (1.47)	1.49 (1.73)	1.45 (1.60)	1.26 (1.09)	1.28 (1.14)	1.27 (1.11)	1.25 (1.07)	1.30 (1.19)	1.28 (1.13)	2.94 (1.12)	2.74 (1.05)	2.84 (1.09)
RN_2: LCC based (75 % RDN)	1.59 (2.05)	1.62 (2.13)	1.60 (2.09)	1.44 (1.58)	1.46 (1.65)	1.45 (1.62)	1.39 (1.44)	1.48 (1.71)	1.44 (1.58)	1.25 (1.08)	1.27 (1.12)	1.26 (1.10)	1.25 (1.06)	1.29 (1.17)	1.27 (1.12)	2.88 (1.09)	2.72 (1.05)	2.80 (1.07)
SEm±	0.02	0.01	0.02	0.02	0.03	0.02	0.02	0.01	0.01	0.01	0.02	0.01	0.00	0.01	0.01	0.01	0.00	0.00
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

***Original data are given in parenthesis**

Table 4.46: Effect of tillage, residue and residual of nitrogen management on dry weight of different weed species at 60 DAS in maize

Treatment	Weed dry weight (g m^{-2})																	
	Eleusine indica			*Digiteria sanguinalis*			*Echinochloa colona*			*Cyperus rotundus*			*Alternanthera philoxeroides*			Others		
	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean
Tillage																		
RT_1: Conventional tillage (CT)	2.42 (5.36)	2.44 (5.48)	2.43 (5.42)	2.28 (4.73)	2.34 (4.98)	2.31 (4.85)	2.19 (4.30)	2.09 (3.86)	2.14 (4.08)	1.97 (3.39)	1.91 (3.16)	1.94 (3.28)	2.59 (6.21)	2.61 (6.30)	2.60 (6.25)	1.96 (3.35)	2.03 (3.62)	1.99 (3.49)
RT_2: Zero tillage (ZT)	2.66 (6.56)	2.69 (6.75)	2.67 (6.65)	2.45 (5.51)	2.66 (6.59)	2.55 (6.05)	2.37 (5.13)	2.27 (4.69)	2.32 (4.91)	2.13 (4.03)	2.09 (3.89)	2.11 (3.96)	2.73 (6.96)	2.77 (7.21)	2.75 (7.09)	2.18 (4.27)	2.23 (4.47)	2.20 (4.37)
SEm±	0.06	0.05	0.06	0.06	0.07	0.06	0.05	0.05	0.05	0.02	0.02	0.02	0.07	0.07	0.07	0.05	0.06	0.06
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Residue management																		
RR_1: RDF + No residue	2.58 (6.20)	2.65 (6.53)	2.61 (6.36)	2.47 (5.63)	2.59 (6.26)	2.53 (5.94)	2.34 (5.00)	2.29 (4.75)	2.31 (4.87)	2.17 (4.23)	2.12 (4.01)	2.15 (4.12)	2.79 (7.30)	2.81 (7.41)	2.80 (7.35)	2.16 (4.18)	2.19 (4.32)	2.17 (4.25)
RR_2: RDF + Residue mulching 3 t ha^{-1})	2.53 (5.92)	2.54 (5.97)	2.53 (5.94)	2.33 (4.93)	2.48 (5.67)	2.40 (5.30)	2.30 (4.79)	2.18 (4.27)	2.24 (4.53)	2.08 (3.84)	2.01 (3.53)	2.04 (3.68)	2.65 (6.54)	2.69 (6.75)	2.67 (6.64)	2.04 (3.67)	2.11 (3.96)	2.07 (3.81)
RR_3: RDF + Residue mulching (6 t ha^{-1})	2.50 (5.76)	2.52 (5.87)	2.51 (5.82)	2.30 (4.80)	2.43 (5.42)	2.36 (5.11)	2.21 (4.37)	2.07 (3.81)	2.14 (4.09)	1.89 (3.07)	1.88 (3.03)	1.88 (3.05)	2.53 (5.92)	2.57 (6.11)	2.55 (6.01)	2.02 (3.58)	2.08 (3.85)	2.05 (3.72)
SEm±	0.06	0.05	0.05	0.06	0.05	0.05	0.05	0.04	0.05	0.03	0.02	0.02	0.06	0.06	0.06	0.05	0.07	0.06
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Residual of nitrogen management																		
RN_1: LCC based (100 % RDN)	2.56 (6.06)	2.58 (6.16)	2.57 (6.11)	2.37 (5.12)	2.50 (5.80)	2.44 (5.46)	2.29 (4.74)	2.19 (4.31)	2.24 (4.53)	2.06 (3.77)	2.01 (3.55)	2.03 (3.66)	2.65 (6.51)	2.70 (6.79)	2.67 (6.65)	2.06 (3.78)	2.14 (4.05)	2.11 (3.92)
RN_2: LCC based (75 % RDN)	2.52 (5.86)	2.56 (6.08)	2.54 (5.97)	2.36 (5.11)	2.49 (5.77)	2.43 (5.44)	2.28 (4.70)	2.17 (4.23)	2.22 (4.47)	2.03 (3.65)	1.99 (3.50)	2.01 (3.58)	2.67 (6.66)	2.68 (6.72)	2.68 (6.69)	2.08 (3.84)	2.12 (4.03)	2.10 (3.94)
SEm±	0.04	0.04	0.04	0.04	0.03	0.04	0.04	0.03	0.04	0.02	0.01	0.02	0.05	0.05	0.05	0.04	0.04	0.04
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

***Original data are given in parenthesis**

Carter *et al*. (2002) observed that significantly higher number of annuals (18.5 m^{-2}), broad leaved weeds (13.6 m^{-2}) and grasses (5.6 m^{-2}) were recorded in no tillage maize plot compared to tilled maize plot (0.8, 1.5 and 0.2 m^{-2}, annuals, broad leaved and grasses respectively). Kumar and Angadi (2014) reported that significantly higher total dry weight of weeds was recorded in zero tillage plots as compared to conventional tillage practices.

Among the residue management in maize, significantly lower total and species wise density and dry weight of weeds were recorded under RDF + residue mulching (6 t ha^{-1}) as compared to other treatments. This might be due to crop residue mulching on the soil surface can suppress weed seedling emergence, delay the time of emergence, and allow the crop to gain an advantage over weeds . Uwah and Iwo (2011) reported that the unmulched plots had the highest weed infestation and total weed dry matter yield. Crop residue mulching may alter the frequency and distribution of weeds and may hamper the emergence and growth of weeds (Essien, *et al*., 2009). Bahar (2013) reported that straw mulching recorded significantly lower total weed density (13.1 m^{-2}) and total weed dry weight (7.8 g m^{-2}) as compared to no mulching practice (16.2 m^{-2} and 10.8 g m^{-2} total weed density and total weed dry weight, respectively. Density, dry weight, index and persistency index of weed were lower under mulched plot (7.5 m^{-2}. 4.4 g m^{-2}, 20.6 and 11.6 %), respectively due to mulch restricted the weed growth and significantly lowered the weed parameters under mulching (Choudhary and Kumar, 2014). These finding was in agreement with Amini *et al*. (2014).

4.2.4 Chemical studies

4.2.4.1 N, P and K content (%) in grain and stover

The data on N, P and K content in grain and stover of maize as influenced by tillage practices in maize, residue management in maize and residual of nitrogen management in rice are presented in Table 4.47 and Table 4.48, respectively.

The findings revealed that the effect of tillage practices in maize, residue management in maize and residual of nitrogen management in rice as well as their interactions did not show any significant influence on N, P and K content in grain and stover of maize during both the years and on mean basis.

Table 4.47: Nutrient content in grain of maize as influenced by tillage, residue and residual of nitrogen management

Treatment	N content in grain (%)			P content in grain (%)			K content in grain (%)		
	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean
Tillage									
RT_1: Conventional tillage (CT)	1.20	1.22	1.21	0.39	0.40	0.40	0.35	0.33	0.34
RT_2: Zero tillage (ZT)	1.19	1.20	1.20	0.40	0.41	0.40	0.33	0.31	0.32
SEm±	0.02	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Residue management									
RR_1: RDF + No residue	1.17	1.20	1.19	0.38	0.39	0.39	0.32	0.31	0.32
RR_2: RDF + Residue mulching (3 t ha^{-1})	1.20	1.21	1.21	0.39	0.41	0.40	0.33	0.32	0.32
RR_3: RDF + Residue mulching (6 t ha^{-1})	1.21	1.22	1.22	0.41	0.42	0.42	0.36	0.34	0.35
SEm±	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Residual of nitrogen management									
RN_1: LCC based (100 % RDN)	1.19	1.20	1.20	0.38	0.40	0.39	0.33	0.32	0.33
RN_2: LCC based (75 % RDN)	1.20	1.22	1.21	0.40	0.41	0.41	0.34	0.33	0.33
SEm±	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 4.48: Nutrient content in stover of maize as influenced by tillage, residue and residual of nitrogen management

Treatment	N content in straw (%)			P content in straw (%)			K content in straw (%)		
	2016-17	**2017-18**	**Mean**	**2016-17**	**2017-18**	**Mean**	**2016-17**	**2017-18**	**Mean**
Tillage									
RT_1: Conventional tillage (CT)	0.76	0.75	0.76	0.25	0.26	0.26	1.15	1.16	1.15
RT_2: Zero tillage (ZT)	0.75	0.74	0.75	0.24	0.25	0.24	1.13	1.15	1.14
SEm±	0.02	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.02
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Residue management									
RR_1: RDF + No residue	0.74	0.73	0.73	0.23	0.24	0.24	1.12	1.13	1.13
RR_2: RDF + Residue mulching (3 t ha^{-1})	0.76	0.75	0.75	0.25	0.26	0.25	1.14	1.15	1.15
RR_3: RDF + Residue mulching (6 t ha^{-1})	0.77	0.76	0.77	0.26	0.27	0.26	1.16	1.18	1.17
SEm±	0.02	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.02
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Residual of nitrogen management									
RN_1: LCC based (100 % RDN)	0.75	0.74	0.75	0.24	0.25	0.25	1.14	1.14	1.14
RN_2: LCC based (75 % RDN)	0.76	0.75	0.76	0.25	0.26	0.26	1.15	1.16	1.15
SEm±	0.02	0.02	0.02	0.00	0.00	0.00	0.02	0.01	0.02
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS

4.2.4.2 N, P and K uptake (kg ha^{-1}) by maize

The data related to N, P and K uptake by maize as influenced by tillage practices in maize, residue management in maize and residual of nitrogen management in rice are given in Table 4.49.

The findings indicated that the effect of tillage practices in maize and residual of nitrogen management in rice did not have significant impact on N, P and K uptake by maize during both the years and on mean basis. However, RT_1 – conventional tillage (CT) and RN_1 – LCC based (100 % RDN) recorded higher N, P and K uptake by maize in comparison to their respective treatments during both the years and on mean basis.

In case of the residue management in maize, treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) recorded significantly higher N, P and K uptake by maize as compared to treatment RR_2 – RDF + residue mulching (3 t ha^{-1}) and RR_1 – RDF + no residue during both the years and on mean basis.

The interaction among tillage practices in maize, residue management in maize and residual of nitrogen management in rice were found non – significant with respect to N, P and K uptake by maize during both the years and on mean basis.

Discussion on nutrient uptake of maize

The effect of tillage practices in maize and residual of nitrogen management in rice did not have significant impact on N, P and K uptake by maize might be due to the effect of uniform number of cobs as well as grain and straw yields in between the tested treatments. The results were in concordance with the findings of Nadiger (2011).

As regards to the residue management in maize, significantly higher N, P and K uptake by maize were recorded under RDF + residue mulching (6 t ha^{-1}) as compared to RDF + residue mulching (3 t ha^{-1}) and RDF + no residue which might be due to higher concentration of N, P and K in maize crop along with higher yield ultimately leads to higher uptake of nutrients (N, P and K), as uptake is derived by multiplication of nutrient concentration in grain and stover with respective yields.

Table 4.49: N, P and K uptake by maize (grain and stover) as influenced by tillage, residue and residual of nitrogen management

Treatment	N uptake (kg ha^{-1})			P uptake (kg ha^{-1})			K uptake (kg ha^{-1})		
	2016-17	**2017-18**	**Mean**	**2016-17**	**2017-18**	**Mean**	**2016-17**	**2017-18**	**Mean**
Tillage									
RT_1: Conventional tillage (CT)	158.32	160.11	159.22	52.36	54.71	53.54	141.19	141.33	141.26
RT_2: Zero tillage (ZT)	154.36	154.76	154.56	50.48	52.28	51.38	136.83	137.61	137.22
SEm±	5.21	5.79	5.50	1.72	1.78	1.75	4.60	4.35	4.47
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Residue management									
RR_1: RDF + No residue	137.69	139.89	138.79	44.37	46.24	45.30	128.13	128.69	128.41
RR_2: RDF + Residue mulching (3 t ha^{-1})	160.13	160.40	160.27	52.16	54.49	53.32	138.50	138.90	138.70
RR_3: RDF + Residue mulching (6 t ha^{-1})	171.21	172.01	171.61	57.73	59.75	58.74	150.39	150.82	150.61
SEm±	3.28	3.34	3.31	1.63	1.65	1.62	3.94	4.57	4.12
CD (P=0.05)	10.70	10.91	10.80	5.30	5.37	5.29	12.85	14.89	13.45
Residual of nitrogen management									
RN_1: LCC based (100 % RDN)	154.37	155.60	154.99	50.03	52.44	51.23	137.35	137.48	137.42
RN_2: LCC based (75 % RDN)	158.31	159.27	158.79	52.81	54.55	53.68	140.66	141.46	141.06
SEm±	4.12	4.09	3.84	1.29	1.31	1.28	3.31	2.79	2.87
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS

Singh *et al*. (1991) also noted higher nutrient uptake of N, P and K as an effect of mulching in winter maize. Nitrogen uptake was significantly higher with paddy straw and paddy husk mulching as compared to no mulch and improved the nitrogen use efficiency (Chakraborty *et al*., 2010). Shaheen *et al*. (2010) also concluded that mulching gave statistically superior over no mulch with respect to total N and P uptake. Similar results were reported by Rahman *et al*. (2005), Kachroo and Dixit (2005) and Pervaiz *et al*. (2009).

4.2.4.3 Partial factor productivity (kg kg^{-1}) and Production efficiency (kg ha^{-1} day^{-1})

The data regarding partial factor productivity of nitrogen, phosphorus and potassium in maize and production efficiency of maize as influenced by tillage practices in maize, residue management in maize and residual of nitrogen management in rice are presented in Table 4.50.

The effect of tillage practices in maize and residual of nitrogen management in rice failed to give significant influence on partial factor productivity of nitrogen, phosphorus and potassium in maize as well as production efficiency of maize throughout both the years and on mean basis. However, RT_1 – conventional tillage (CT) and RN_1 – LCC based (100 % RDN) recorded higher partial factor productivity of nitrogen, phosphorus and potassium in maize as well as production efficiency of maize in comparison to their respective treatments throughout both the years and on mean basis.

Among the residue management in maize, treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) recorded higher partial factor productivity of nitrogen, phosphorus and potassium in maize as well as production efficiency of maize as compared to treatment RR_1 – RDF + no residue, but it was at par to treatment RR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis.

The interaction effect of the tillage practices in maize, residue management in maize and residual of nitrogen management in rice remained unaffected with respect to partial factor productivity of nitrogen, phosphorus and potassium in maize as well as production efficiency of maize during both the years and on mean basis.

Table 4.50: Partial factor productivity and production efficiency of maize as influenced by tillage, residue and residual of nitrogen management

Treatment	Partial factor productivity (kg kg^{-1})									Production efficiency (kg ha^{-1} day^{-1})		
	Nitrogen			Phosphorus			Potassium					
	2016-17	**2017-18**	**Mean**	**2016-17**	**2017-18**	**Mean**	**2016-17**	**2017-18**	**Mean**	**2016-17**	**2017-18**	**Mean**
Tillage												
RT_1: Conventional tillage (CT)	20.65	20.72	20.69	21.55	21.62	21.58	80.83	81.07	80.95	64.14	64.33	64.24
RT_2: Zero tillage (ZT)	20.18	20.24	20.21	21.06	21.12	21.09	78.97	79.21	79.09	62.67	62.86	62.77
SEm±	0.41	0.45	0.43	0.44	0.47	0.45	1.76	1.83	1.80	1.49	1.54	1.52
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Residue management												
RR_1: RDF + No residue	17.28	17.34	17.31	18.03	18.10	18.06	67.63	67.87	67.75	53.67	53.86	53.76
RR_2: RDF + Residue mulching (3 t ha^{-1})	21.33	21.39	21.36	22.26	22.32	22.29	83.47	83.71	83.59	66.24	66.43	66.34
RR_3: RDF + Residue mulching (6 t ha^{-1})	22.64	22.70	22.67	23.63	23.69	23.66	88.60	88.84	88.72	70.31	70.50	70.41
SEm±	0.43	0.48	0.45	0.48	0.50	0.49	1.87	1.92	1.89	1.50	1.56	1.53
CD (P=0.05)	1.40	1.57	1.48	1.56	1.63	1.60	6.09	6.26	6.18	4.89	5.09	4.99
Residual of nitrogen management												
RN_1: LCC based (100 % RDN)	20.55	20.61	20.58	21.44	21.51	21.48	80.42	80.66	80.54	62.99	63.18	63.09
RN_2: LCC based (75 % RDN)	20.28	20.35	20.32	21.17	21.23	21.20	79.38	79.62	79.50	63.82	64.01	63.92
SEm±	0.32	0.37	0.34	0.36	0.39	0.38	1.46	1.53	1.50	1.14	1.16	1.15
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Discussion on partial factor productivity and production efficiency

Among the residue management in maize, significantly higher partial factor productivity of nitrogen, phosphorus, potassium and production efficiency were registered significantly under RDF + residue mulching (6 t ha^{-1}) as compared to treatment RDF + no residue, but it was at par to treatment RDF + residue mulching (3 t ha^{-1}). This might be due to higher leaf area index (LAI) and crop growth rate (CGR) as well as higher yield attributes and yields of maize. Pierre *et al*. (2008) also reported that PFP of N, P and K decreased with increasing application rates of crop residue.

4.2.4.4 Protein content in grain (%), protein yield (kg ha^{-1}) and protein Productivity (kg ha^{-1} day^{-1})

The data on protein content in grain, protein yield and protein productivity of maize as influenced by tillage practices in maize, residue management in maize and residual of nitrogen management in rice are presented in Table 4.51.

The results revealed that the effect of tillage practices in maize and residual of nitrogen management in rice did not have significant impact on protein content in grain, protein yield and protein productivity of maize throughout both the years and on mean basis. However, RT_1 – conventional tillage (CT) and RN_1 – LCC based (100 % RDN) recorded higher protein content, protein yield and protein productivity of maize in comparison to their respective treatments during both the years and on mean basis.

Among the residue management in maize, the significantly higher protein yield and protein productivity of maize were registered under treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) as compared to treatment RR_2 – RDF + residue mulching (3 t ha^{-1}) and RR_1 – RDF + no residue, whereas protein content in grain of maize was noted non – significantly during both the years and on mean basis .

The interaction among the tillage practices in maize, residue management in maize and residual of nitrogen management in rice were found non-significantly with respect to protein content in grain, protein yield and protein productivity of maize during both the years and on mean basis.

Table 4.51: Protein content in grain, protein yield and protein productivity of maize as influenced by tillage, residue and residual of nitrogen management

Treatment	Protein content in grain (%)			Protein yield (kg ha^{-1})			Protein productivity (kg ha^{-1} day^{-1})		
	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean
Tillage									
RT_1: Conventional tillage (CT)	7.51	7.57	7.54	507.99	513.52	510.75	4.84	4.89	4.86
RT_2: Zero tillage (ZT)	7.44	7.47	7.45	490.00	493.68	491.84	4.67	4.70	4.68
SEm±	0.11	0.17	0.14	9.65	8.05	8.84	0.09	0.07	0.08
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Residue management									
RR_1: RDF + No residue	7.32	7.46	7.39	413.49	423.82	418.66	3.94	4.04	3.99
RR_2: RDF + Residue mulching (3 t ha^{-1})	7.53	7.54	7.53	524.40	526.81	525.60	4.99	5.02	5.01
RR_3: RDF + Residue mulching (6 t ha^{-1})	7.57	7.57	7.57	559.10	560.16	559.63	5.32	5.33	5.33
SEm±	0.10	0.16	0.13	9.92	9.05	9.46	0.09	0.08	0.09
CD (P=0.05)	NS	NS	NS	32.36	29.51	30.85	0.30	0.27	0.29
Residual of nitrogen management									
RN_1: LCC based (100 % RDN)	7.51	7.53	7.52	504.19	506.36	505.28	4.80	4.82	4.81
RN_2: LCC based (75 % RDN)	7.44	7.52	7.48	493.80	500.83	497.32	4.70	4.77	4.74
SEm±	0.09	0.13	0.11	7.96	6.67	7.31	0.07	0.06	0.07
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS

Discussion on protein yield and protein productivity

As regards to the residue management in maize, significantly higher protein yield and protein productivity of maize were registered under RDF + residue mulching (6 t ha^{-1}) as compared to RDF + residue mulching (3 t ha^{-1}) and RDF + no residue. This might be due to more production of photosynthates in leaves and uptake of nutrient from soil and more availability of soil moisture under residue mulch, which kept proper water balance in the plant system, which might have resulted into efficient biochemical processes involved in the biosynthesis of protein content. Similar results were reported by Andrija *et al*. (2009) and Zamir *et al.* (2013).

4.2.4.5 Carbon pools in soil

The data regarding total and soil organic carbon, water soluble carbon (WSC), acid hydrolysable carbon (AHC), permanganate oxidizable carbon (POSC), microbial biomass carbon (MBC) and readily mineralizable carbon (RMC) in soil after the harvest of maize as affected by tillage practices in maize, residue management in maize and residual of nitrogen management in rice are presented in Table 4.52 and Table 4.53.

Between the tillage practices in maize, significantly higher value of total and soil organic carbon, water soluble carbon, permanganate oxidizable carbon, microbial biomass carbon and readily mineralizable carbon in soil after the harvest of maize were recorded under RT_2 – zero tillage (ZT) as compared to RT_1 – conventional tillage (CT) during both the years and on mean basis.

Among the residue management in maize, significantly higher value of water soluble carbon and acid hydrolysable carbon in soil after the harvest of maize were recorded under treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) as compared to treatment RR_1 – RDF + no residue, but it was at par to treatment R_2 – RDF + residue mulching (3 t ha^{-1}), whereas treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) noted significantly higher total and soil organic carbon, permanganate oxidizable carbon, microbial biomass carbon and readily mineralizable carbon in soil after the harvest of maize as compared to other treatments throughout both the years and on mean basis.

Table 4.52: Total and soil organic carbon, water soluble carbon and acid hydrolysable carbon in soil after the harvest of maize as influenced by tillage, residues and residual of nitrogen management

Treatment	Total organic carbon (g kg^{-1} soil)			Soil organic carbon (g kg^{-1} soil)			WSC (mg kg^{-1} soil)			AHC (mg kg^{-1} soil)		
	2016	**2017**	**Mean**	**2016**	**2017**	**Mean**	**2016**	**2017**	**Mean**	**2016**	**2017**	**Mean**
Tillage												
RT_1: Conventional tillage (CT)	6.82	6.84	6.83	5.56	5.57	5.56	54.57	56.50	55.54	462.51	464.15	463.33
RT_2: Zero tillage (ZT)	7.62	7.78	7.70	6.25	6.38	6.32	70.01	71.87	70.94	513.49	517.48	515.48
SEm±	0.13	0.13	0.13	0.11	0.09	0.10	1.17	1.21	1.19	9.37	9.43	9.40
CD (P=0.05)	0.77	0.79	0.78	0.69	0.55	0.61	7.11	7.34	7.22	NS	NS	NS
Residue management												
RR_1: RDF + No residue	6.19	6.21	6.20	5.52	5.52	5.52	59.53	61.38	60.45	464.36	467.61	465.99
RR_2: RDF + Residue mulching (3 t ha^{-1})	7.38	7.51	7.45	5.88	5.98	5.93	62.44	64.63	63.53	491.64	494.46	493.05
RR_3: RDF + Residue mulching (6 t ha^{-1})	8.08	8.21	8.15	6.32	6.43	6.37	64.91	66.55	65.73	508.00	510.37	509.19
SEm±	0.14	0.14	0.14	0.10	0.13	0.12	1.15	1.17	1.16	10.03	10.16	10.10
CD (P=0.05)	0.44	0.46	0.45	0.34	0.44	0.43	3.75	3.83	3.79	32.73	33.14	32.93
Nitrogen management												
RN_1: LCC based (100 % RDN)	7.24	7.36	7.30	5.98	6.01	6.00	62.71	64.63	63.67	496.31	498.73	497.52
RN_2: LCC based (75 % RDN)	7.19	7.25	7.22	5.83	5.94	5.88	61.88	63.74	62.81	479.69	482.90	481.30
SEm±	0.10	0.11	0.10	0.09	0.09	0.09	1.00	1.02	1.01	7.02	7.02	7.02
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

WSC, water soluble carbon; AHC, acid hydrolysable carbon;

Table 4.53: KMnO4 extractable carbon, microbial biomass carbon and readily mineralizable carbon in soil after the harvest of maize as influenced by tillage, residues and residual of nitrogen, management

Treatment	POSC (mg kg^{-1} soil)			MBC (mg kg^{-1} soil)			RMC (mg kg^{-1} soil)		
	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean
Tillage									
RT_1: Conventional tillage (CT)	336.87	340.25	338.56	247.88	258.92	253.40	136.39	138.46	137.43
RT_2: Zero tillage (ZT)	394.40	396.30	395.35	267.99	279.62	273.80	147.96	156.41	152.18
SEm±	8.41	7.80	8.11	3.23	3.30	3.17	1.80	2.63	2.22
CD (P=0.05)	51.17	47.48	49.32	19.68	20.08	19.31	10.96	16.02	13.49
Residue management									
RR_1: RDF + No residue	329.39	332.64	331.02	251.64	258.63	255.13	137.18	142.13	139.66
RR_2: RDF + Residue mulching (3 t ha^{-1})	359.23	362.90	361.06	253.56	267.25	260.40	141.32	144.82	143.07
RR_3: RDF + Residue mulching (6 t ha^{-1})	408.28	409.29	408.79	268.61	281.94	275.27	148.02	155.34	151.68
SEm±	8.24	11.95	9.81	3.37	3.47	3.61	1.84	2.41	2.11
CD (P=0.05)	26.87	38.97	31.98	11.01	11.31	11.76	6.01	7.85	6.88
Nitrogen management									
RN_1: LCC based (100 % RDN)	372.30	372.88	372.59	259.86	270.35	265.11	143.63	148.40	146.02
RN_2: LCC based (75 % RDN)	358.97	363.67	361.32	256.00	268.19	262.10	140.72	146.47	143.59
SEm±	7.03	6.15	6.38	2.88	3.00	2.69	1.59	2.37	1.95
CD (P=0.05)	NS	NS	NS	8.78	8.94	8.86	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS

POSC, KMnO4 extractable carbon; MBC, microbial biomass carbon; RMC, Readily mineralizable carbon

The effect of residual of nitrogen management in rice and interaction effect of different treatments remained unaffected with respect to water soluble carbon, acid hydrolysable carbon, permanganate oxidizable carbon, microbial biomass carbon and readily mineralizable carbon in soil after the harvest of maize during both the years and on mean basis.

Discussion on carbon pools in soil

Between the tillage practices in maize, significantly higher value of total and soil organic carbon, water soluble carbon, permanganate oxidizable carbon, microbial biomass carbon and readily mineralizable carbon in soil after the harvest of maize were recorded under zero tillage (ZT) as compared to conventional tillage (CT). Higher carbon pools under zero tillage might have led to the prevention of loss of carbon by gaseous emissions. The amount of biomass returned to soil was proportional to the increase in soil carbon content. Similar results were reported by Campbell *et al.* (1996) and Six *et al*. (2000). Higher microbial biomass C, dissolved organic C, and particulate organic C at the 0 – 5 cm depth under NT compared to CT reflected the impact of tillage practice (Sainju *et al*., 2008, Lewis *et al*., 2011 and Kahlon *et al*., 2013). The results obtained were in agreement with the earlier investigations reporting higher levels of $KMnO_4$-C under zero tillage (Weil *et a*l., 2003 and Chen *et al.,* 2009). Similarly, Li *et al*. (2007) also found that total organic C content in the surface layer (0–10 cm) was significantly increased under NT with residue mulch in northern China. Bhattacharyya *et al*. (2012b) also reported conventional tillage system increased rate of soil organic matter decomposition and organic carbon oxidation compared to ZT system resulting leading to less labile C pool in 0-15 cm depth of soil.

Among the residue management in maize, significantly higher value of total and soil organic carbon, water soluble carbon and acid hydrolysable carbon in soil were recorded under RDF + residue mulching (6 t ha^{-1}) as compared to RDF + no residue, but it was at par to RDF + residue mulching (3 t ha^{-1}), whereas RDF + residue mulching (6 t ha^{-1}) noted significantly higher permanganate oxidizable carbon, microbial biomass carbon and readily mineralizable carbon in soil as compared to other treatments. This might be due to crop residues provide substrate for soil microorganisms and contribute to accumulation of labile carbon. Alam *et* *al*. (2014) also reported that crop residue retained on the soil decays slowly and therefore plays an important role in the accumulation of organic matter in the surface soil. Application of mulch improved the carbon pools and the soil content of microbial carbon, showing the importance of the used of mulch in enhancing soil fertility (Pankhurst *et al*. 2002 and Nie *et al*. 2007).

4.2.4.6 Soil nitrogen pools

The data related to total nitrogen, available nitrogen, microbial biomass nitrogen, ammonical nitrogen and nitrate nitrogen in soil after the harvest of maize as affected by tillage practices in maize, residue management in maize and residual of nitrogen management in rice are presented in Table 4.54.

Ag regards to the tillage practices in maize, significantly higher value of total nitrogen, available nitrogen, microbial biomass nitrogen, ammonical nitrogen and nitrate nitrogen in soil after the harvest of maize were recorded under RT_2 – zero tillage (ZT) as compared to TR_1 – conventional tillage (CT) during both the years and on mean basis.

Among the residue management in maize, treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) recorded significantly higher value of total nitrogen and available nitrogen in soil after the harvest of maize as compared to treatment RR_1 – RDF + no residue, but it was at par to treatment RR_2 – RDF + residue mulching (3 t ha^{-1}), whereas significantly higher value of microbial biomass nitrogen, ammonical nitrogen and nitrate nitrogen in soil after the harvest of maize were noted under treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) as compared to other treatments throughout both the years and on mean basis.

The effect of residual of nitrogen management in rice and interaction effect of different treatments were found non - significant with respect to total nitrogen, available nitrogen, microbial biomass nitrogen, ammonical nitrogen and nitrate nitrogen in soil after the harvest of maize during both the years and on mean basis.

Table 4.54: Nitrogen pools of soil after the harvest of maize as influenced by tillage, residue and residual of nitrogen management

Treatment	Nitrogen pools of soil														
	Total Nitrogen (mg kg^{-1} soil)			Available Nitrogen (kg ha^{-1})			Microbial biomass nitrogen (mg kg^{-1} soil)			Ammonical nitrogen (mg kg^{-1} soil)			Nitrate nitrogen (mg kg^{-1} soil)		
	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean
Tillage															
RT_1: Conventional tillage (CT)	679.06	685.97	682.52	290.65	298.05	294.35	28.37	29.47	28.92	10.36	10.89	10.63	20.67	23.93	22.30
RT_2: Zero tillage (ZT)	720.05	736.41	728.23	322.72	330.78	326.75	32.75	32.82	32.79	12.49	12.57	12.53	26.03	28.29	27.16
SEm±	6.72	8.25	7.48	5.08	4.67	4.86	0.55	0.52	0.54	0.27	0.27	0.27	0.58	0.65	0.61
CD (P=0.05)	40.91	50.18	45.50	30.91	28.43	29.58	3.37	3.19	3.27	1.67	1.65	1.66	3.51	3.96	3.73
Residue management															
RR_1: RDF + No residue	656.89	664.20	660.54	288.01	302.88	295.45	28.27	28.21	28.24	10.87	10.88	10.88	21.82	24.63	23.23
RR_2: RDF + Residue mulching (3 t ha^{-1})	712.63	718.52	715.57	305.34	313.92	309.63	29.97	31.25	30.61	11.16	11.60	11.38	23.12	25.11	24.11
RR_3: RDF + Residue mulching (6 t ha^{-1})	729.14	750.87	740.01	326.70	326.45	326.58	33.45	33.97	33.71	12.25	12.57	12.41	25.12	27.59	26.36
SEm±	8.41	10.72	9.48	7.19	5.49	6.23	0.59	0.62	0.60	0.29	0.30	0.29	0.58	0.65	0.62
CD (P=0.05)	27.44	34.96	30.92	23.44	17.91	20.30	1.91	2.03	1.95	0.93	0.96	0.95	1.89	2.13	2.01
Residual of nitrogen management															
RN_1: LCC based (100 % RDN)	709.33	714.26	711.79	311.78	316.73	314.26	30.95	31.84	31.40	11.60	11.96	11.78	23.72	26.24	24.98
RN_2: LCC based (75 % RDN)	689.79	708.13	698.96	301.59	312.10	306.85	30.17	30.45	30.31	11.25	11.50	11.38	22.99	25.99	24.49
SEm±	6.72	7.34	6.98	4.51	3.83	4.13	0.43	0.48	0.44	0.19	0.19	0.17	0.41	0.46	0.43
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

4.2.4.7 Available phosphorus and potassium in soil (kg ha^{-1})

The data regarding available phosphorus and potassium in soil after the harvest of maize as influenced by tillage practices in maize, residue management in maize and residual of nitrogen management in rice are presented in Table 4.55.

As regards to tillage practices in maize, treatment RT_2 – zero tillage (ZT) recorded significantly higher available phosphorus and potassium in soil after the harvest of maize in comparison to RT_1 – conventional tillage (CT)during both the years and on mean basis.

Among the residue management in maize, treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) recorded significantly higher value of available phosphorus in soil after the harvest of maize as compared to treatment RR_1 – RDF + no residue, but it was at par to RR_2 – RDF + residue mulching (3 t ha^{-1}), whereas available potassium in soil was recorded significantly higher under treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) as compared to other treatments during during both the years and on mean basis.

The effect of residual of nitrogen management in rice and interaction effect of different treatments were found non - significant with respect to available phosphorus and potassium in soil after the harvest of maize throughout both the years and on mean basis.

Discussion on nitrogen pools, available phosphorus and potassium in soil

Between the tillage practices in maize, significantly higher value of total nitrogen, available nitrogen, microbial biomass nitrogen, ammonical nitrogen, nitrate nitrogen, available phosphorus and potassium in soil were recorded under zero tillage (ZT) as compared to conventional tillage (CT). The intensive tillage accelerated organic matter decomposition and decreased immobilization of mineral nitrogen by soil microorganisms (Follett and Schimel, 1989). Alam *et al.* (2014) observed that the zero tillage recorded significantly higher total nitrogen content in soil as compared to conventional tillage and minimum tillage. Xu et al. (2007) reported that soil nitrogen and microbial biomass nitrogen were recorded higher under no – tillage than under conventional tillage.

Table 4.55: Available phosphorus and potassium in soil after the harvest of maize as influenced by tillage, residue and residual of nitrogen management

Treatment	Available phosphorus (kg ha^{-1})			Available potassium (kg ha^{-1})		
	2016-17	**2017-18**	**Mean**	**2016-17**	**2017-18**	**Mean**
Tillage						
RT_1: Conventional tillage (CT)	22.50	23.43	22.96	176.60	178.75	177.67
RT_2: Zero tillage (ZT)	24.72	25.65	25.18	195.52	197.69	196.61
SEm±	0.36	0.35	0.35	3.01	3.00	3.00
CD (P=0.05)	2.17	2.15	2.16	18.32	18.23	18.28
Residue management						
RR_1: RDF + No residue	22.53	23.59	23.06	179.16	182.61	180.89
RR_2: RDF + Residue mulching (3 t ha^{-1})	23.52	24.40	23.96	183.37	184.19	183.78
RR_3: RDF + Residue mulching (6 t ha^{-1})	24.77	25.63	25.20	195.65	197.86	196.75
SEm±	0.41	0.42	0.42	3.43	3.50	3.46
CD (P=0.05)	1.34	1.37	1.36	11.18	11.40	11.28
Residual of nitrogen management						
RN_1: LCC based (100 % RDN)	23.85	24.84	24.35	187.60	189.48	188.54
RN_2: LCC based (75 % RDN)	23.36	24.23	23.80	184.52	186.96	185.74
SEm±	0.29	0.29	0.29	2.41	2.35	2.37
CD (P=0.05)	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS

Grant and Lafond (1994) also observed that total nitrogen in the top soil (depth 0 – 15 cm) was higher under no – tillage and reduced tillage than under conventional tillage.

Among the residue management in maize, RDF + residue mulching (6 t ha^{-1}) recorded significantly higher value of total nitrogen and available nitrogen in soil as compared to RDF + no residue, but it was at par to RDF + residue mulching (3 t ha^{-1}), whereas significantly higher value of microbial biomass nitrogen and available potassium in soil were noted under treatment RDF + residue mulching (6 t ha^{-1}) as compared to other treatments. This might be due to the incorporation of crop residues enhance soil microbes that catalyze the conversion of organically bound nitrogen to inorganic form and increased the mineralization and build-up of available nitrogen (Lopez *et al*., 2011). Residue mulch had led to the increase in available nitrogen in soil and microbial activity which is clear indication of an improvement in soil health on long term basis (Nie *et al*., 2007). Prasad *et al*. (2010) also reported increase in available K in soil due to addition of crop residues. Higher concentration of soil available N and K was recorded under mulching as compared to no mulch was reported by Shylla *et al.* (2016).

4.2.5 Economics

4.2.5.1 Cost of cultivation (× 10^3 ₹ ha^{-1})

The data on cost of cultivation of maize as influenced by tillage practices in maize, residue management in maize and residual of nitrogen management in rice are presented in Table 4.56.

Between the tillage practices in maize, RT_1 – conventional tillage (CT) recorded highest cost of cultivation and the lowest cost of cultivation was recorded under RT_2 – zero tillage (ZT) throughout both the years and on mean basis.

Among the residue management in maize, treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) recorded highest cost of cultivation and the lowest cost of cultivation was noted under treatment RR_1 – RDF + no residue during both the years and on mean basis.

The cost of cultivation was calculated similar in between residual of nitrogen management in rice treatments throughout both the years and on mean basis.

4.2.5.2 Gross return (× 10^3 ₹ ha^{-1})

The data pertaining to gross return of maize as influenced by tillage practices in maize, residue management in maize and residual of nitrogen management in rice are presented in Table 4.56.

The effect of tillage practices in maize and residual of nitrogen management in rice failed give to significant influence with respect to gross return of maize throughout both the years and on mean basis.

Among the residue management in maize, significantly higher gross return of maize was recorded under treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) as compared to treatment RR_1 – RDF + no residue, but it was at par to treatment RR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis.

The interaction between tillage practices in maize and residue management in maize had significant effect on gross return of maize during both the years and on mean basis (Table 4.57). The interaction between RT_2 – zero tillage (ZT) with RR_3 – RDF + residue mulching (6 t ha^{-1}) obtained significantly higher gross return of maize as compared to other interactions. However, it was statistically similar to interactions of RT_1 – conventional tillage (CT) with RR_3 – RDF + residue mulching (6 t ha^{-1}), RT_1 – conventional tillage (CT) with RR_2 – RDF + :residue mulching (3 t ha^{-1})" and RT_2 – zero tillage (ZT) with RR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis.

4.2.5.3 Net return (× 10^3 ₹ ha^{-1}) and benefit cost ratio

The data regarding net return and benefit cost ratio of maize as affected by tillage practices in maize, residue management in maize and nitrogen management in rice are presented in Table 4.56.

The findings revealed that the effect of tillage practices in maize and residual of nitrogen management in rice remained unaffected with respect to net return and benefit cost ratio of maize during both the years and on mean basis.

Table 4.56: Economics of maize as influenced by tillage, residue and residual of nitrogen management

Treatment	Cost of cultivation (× 10^3 ₹ ha^{-1})			Gross return (× 10^3 ₹ ha^{-1})			Net return (× 10^3 ₹ ha^{-1})			Benefit cost ratio		
	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean
Tillage												
RT_1: Conventional tillage (CT)	41	43	42	92	97	95	51	55	53	2.26	2.28	2.27
RT_2: Zero tillage (ZT)	38	40	39	90	95	93	52	55	54	2.37	2.36	2.36
SEm±	-	-	-	1	1	1	1	1	1	0.05	0.05	0.05
CD (P=0.05)	-	-	-	NS	NS	NS	NS	NS	NS	NS	NS	NS
Residue management												
RR_1: RDF + No residue	38	40	39	77	82	79	39	42	40	2.00	2.06	2.03
RR_2: RDF + Residue mulching (3 t ha^{-1})	39	41	40	95	100	98	56	59	58	2.42	2.43	2.43
RR_3: RDF + Residue mulching (6 t ha^{-1})	40	43	42	101	107	104	60	63	62	2.51	2.47	2.49
SEm±	-	-	-	1	1	1	1	1	1	0.05	0.05	0.05
CD (P=0.05)	-	-	-	4	4	3	4	4	3	0.15	0.15	0.15
Residual of nitrogen management												
RN_1: LCC based (100 % RDN)	39	41	40	92	97	94	53	55	54	2.33	2.34	2.34
RN_2: LCC based (75 % RDN)	39	41	40	90	96	93	51	54	53	2.29	2.31	2.30
SEm±	-	-	-	1	1	1	1	1	1	0.04	0.04	0.04
CD (P=0.05)	-	-	-	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	-	-	-	NS	NS	NS	NS	NS	NS	NS	NS	NS

MSP: maize - ₹ 1365 q-1 (2016-17) and ₹ 1425 q-1(2017-18)

Table 4.57: Interaction effect of tillage and residue management on gross and net return of maize

Tillage \ Residue Management	RR_1: RDF + No residue	RR_2: RDF + Residue mulching (3 t ha^{-1})	RR_3: RDF + Residue mulching (6 t ha^{-1})	Mean
	Gross return (× 10^3 ₹ ha^{-1})			
	2016 -17			
RT_1: Conventional tillage (CT)	81	95	99	92
RT_2: Zero tillage (ZT)	73	95	102	90
Mean	77	95	101	
	2017-18			
RT_1: Conventional tillage (CT)	86	101	106	97
RT_2: Zero tillage (ZT)	77	100	107	95
Mean	82	100	107	
	Mean			
RT_1: Conventional tillage (CT)	83	98	102	95
RT_2: Zero tillage (ZT)	75	98	105	93
Mean	79	98	104	

	2016-17 SEm±	2016-17 CD (P=0.05)	2017-18 SEm±	2017-18 CD (P=0.05)	Mean SEm±	Mean CD (P=0.05)
Comparison of two residue management at same levels of tillage	2	5	2	5	2	5
Comparison of two tillage at same levels of residue management	2	7	2	8	2	8

Tillage	RR_1	RR_2	RR_3	Mean
	Net return (× 10^3 ₹ ha^{-1})			
	2016-17			
RT_1: Conventional tillage (CT)	41	55	58	51
RT_2: Zero tillage (ZT)	36	57	63	52
Mean	39	56	60	
	2017-18			
T_1: Conventional tillage (CT)	45	58	61	55
T_2: Zero tillage (ZT)	39	60	65	55
Mean	42	59	63	
	Mean			
RT_1: Conventional tillage (CT)	43	56	60	53
RT_2: Zero tillage (ZT)	38	59	64	54
Mean	40	58	62	

	2016-17 SEm±	2016-17 CD (P=0.05)	2017-18 SEm±	2017-18 CD (P=0.05)	Mean SEm±	Mean CD (P=0.05)
Comparison of two residue management at same levels of tillage	2	5	2	5	2	5
Comparison of two tillage at same levels of residue management	2	8	2	8	2	8

MSP: maize - ₹ 1365 q-1 (2016-17) and ₹ 1425 q-1(2017-18)

Among the residue management in maize, treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) recorded significantly higher net return and benefit cost ratio of rice as compared to treatment RR_2 – RDF + residue mulching (3 t ha^{-1}) and RR_1 – RDF + no residue throughout both the years and on mean basis.

The interaction between tillage practices in maize and residue management in maize had significant effect on net return of maize during both the years and on mean basis (Table 4.57). The interaction between RT_2 – zero tillage (ZT) with RR_3 – RDF + residue mulching (6 t ha^{-1}) obtained significantly higher net return of maize as compared to other interactions. However, it was statistically similar to interactions of RT_1 – conventional tillage (CT) with RR_3 – RDF + residue mulching (6 t ha^{-1}), RT_1 – conventional tillage (CT) with RR_2 – RDF + residue mulching (3 t ha^{-1}) and RT_2 – zero tillage (ZT) with RR_2 – RDF + residue mulching (3 t ha^{-1}) throughout both the years and on mean basis.

Discussion on economics of maize

Among the residue management in maize, RDF + residue mulching (6 t ha^{-1}) recorded significantly higher gross return as compared to RDF + no residue, but it was comparable to RDF + residue mulching (3 t ha^{-1}), whereas significantly higher net return and benefit cost ratio of rice were recoded under RDF + residue mulching (6 t ha^{-1}) as compared to other treatments due to higher grain and straw yields of maize. These results are in agreement with the findings of Kumar (2005), Singh *et al*. (2015) and Sharma *et al.* (2011). Meena and Singh (2013) also noted that the highest net return and benefit: cost ratio were recorded for rice residue mulch treatment followed by rice residue incorporation treatment . Sharma *et al.* (2008) also reported that straw mulching recorded higher B: C ratio (1.11) followed by soil mulch (1.05), polythene mulch (1.04) and no mulch (0.71).

4.2.6 Energetics

4.2.6.1 Input energy (× 10^3 MJ ha^{-1})

The data on input energy of maize as influenced by tillage practices in maize, residue management in maize and residual of nitrogen management in rice are presented in Table 4.58.

Between tillage practices in maize, RT_1 – conventional tillage (CT) recorded highest input energy of maize and the lowest input energy of maize was noted under RT_2 – zero tillage (ZT) during both the years and on mean basis.

In case of residue management in maize, treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) recorded highest input energy of maize, whereas the lowest input energy of maize was registered under treatment RR_1 – RDF + no residue during both the years and on mean basis.

The input energy of maize was recorded similar in between residual of nitrogen management in rice treatments during both the years and on mean basis.

4.2.6.2 Output energy (× 10^3 MJ ha^{-1})

The data pertaining to output energy of maize as influenced by tillage practices in rice, residual of residues in maize and nitrogen management in rice are presented in Table 4.58.

The findings indicated that the effect of tillage practices in maize and residual of nitrogen management in rice as well as interactions of different treatments did not have significant impact on output energy of maize during both the years and on mean basis.

In case of residue management in maize, treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) recorded significantly higher output energy of maize as compared to treatment RR_2 – RDF + residue mulching (3 t ha^{-1}) and RR_1 – RDF + no residue during both the years and on mean basis.

4.2.6.3 Net energy (× 10^3 MJ ha^{-1}), energy use efficiency and energy productivity (kg MJ^{-1})

The data on net energy, energy use efficiency and energy productivity of maize as influenced by tillage practices in maize, residue management in maize and residual of nitrogen management in rice are presented in Table 4.58 and Table 4.59.

Among the residue management in maize, treatment RR_1 – RDF + no residue obtained significantly higher net energy, energy use efficiency and energy productivity of maize as compared to treatment RR_2 – RDF + residue mulching (3 t ha^{-1}) and RR_3 – RDF + residue mulching (6 t ha^{-1}) during both the years and on mean basis.

Table 4.58: Input and output energy, net energy, energy use efficiency and energy profitability of maize as influenced by tillage, residue and residual of nitrogen management

Treatment	Energy input (× 10^3 MJ ha^{-1})			Energy output (× 10^3 MJ ha^{-1})			Net energy (× 10^3 MJ ha^{-1})			Energy use efficiency		
	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean
Tillage												
RT_1: Conventional tillage (CT)	59.35	59.01	59.18	225.43	227.59	226.51	166.08	168.58	167.33	5.30	5.43	5.37
RT_2: Zero tillage (ZT)	55.42	55.09	55.25	223.06	224.09	223.58	167.64	169.00	168.32	5.93	6.01	5.97
SEm±	-	-	-	3.24	3.45	3.32	3.24	3.45	3.32	0.11	0.15	0.13
CD (P=0.05)	-	-	-	NS	NS	NS	NS	NS	NS	NS	NS	NS
Residue management												
RR_1: RDF + No residue	19.88	19.55	19.72	204.05	205.55	204.80	184.17	186.00	185.08	10.34	10.58	10.46
RR_2: RDF + Residue mulching (3 t ha^{-1})	57.38	57.05	57.22	227.73	229.27	228.50	170.34	172.21	171.28	3.97	4.02	4.00
RR_3: RDF + Residue mulching (6 t ha^{-1})	94.88	94.55	94.72	240.95	242.71	241.83	146.07	148.16	147.11	2.54	2.57	2.56
SEm±	-	-	-	2.88	2.80	2.58	2.88	2.80	2.58	0.10	0.13	0.11
CD (P=0.05)	-	-	-	9.39	9.12	8.41	9.39	9.12	8.41	0.33	0.41	0.34
Residual of nitrogen management												
RN_1: LCC based (100 % RDN)	57.38	57.05	57.22	226.02	227.49	226.75	168.63	170.44	169.54	5.68	5.77	5.72
RN_2: LCC based (75 % RDN)	57.38	57.05	57.22	222.47	224.19	223.33	165.09	167.14	166.11	5.55	5.68	5.62
SEm±	-	-	-	2.44	2.54	2.23	2.44	2.54	2.23	0.08	0.10	0.08
CD (P=0.05)	-	-	-	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	-	-	-	NS	NS	NS	NS	NS	NS	NS	NS	NS

None of the treatments of tillage practices in maize and residual of nitrogen management in rice as well as interaction effect of different treatments had significant influence on net energy, energy use efficiency and energy productivity of maize during both the years and on mean basis.

4.2.6.4 Specific energy (MJ kg^{-1}), energy intensity in economic term (MJ ₹$^{-1}$) and energy intensity in physical term (MJ kg^{-1})

The data on specific energy, energy intensity in economics term and energy intensity in physical term of maize as influenced by tillage practices in maize, residue management in maize and residual of nitrogen management in rice are presented in Table 4.59.

Among the residue management in maize, treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) recorded significantly higher energy intensity in economics term of maize than treatment RR_1 – RDF + no residue, but it was at par to treatment RR_2 – RDF + residue mulching (3 t ha^{-1}), whereas specific energy and energy intensity in physical term of maize was significant higher under treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) as compared to other treatments during both the years and on mean basis.

None of the treatments of tillage practices in maize and residual of nitrogen management in rice as well as interaction effect of different treatments had significant influence on specific energy, energy intensity in economics term and energy intensity in physical term of maize during both the years and on mean basis.

Discussion on energetics of maize

Among the residue management in maize, significantly higher output energy, specific energy, energy intensity in economic term and energy intensity in physical term were recoded under RDF + residue mulching (6 t ha^{-1}) as compared to RDF + residue mulching (3 t ha^{-1}) and RDF + no residue due to higher grain and straw yields, whereas, significantly higher net energy, energy use efficiency, energy, energy profitability and energy productivity were noted under RDF + no residue , owing to less input energy required above treatments. Similar results were reported by Prasad *et al*. (2014).

Table 4.59: Energy productivity, specific energy, energy intensity in economic and physical term of maize as influenced by tillage, residue and residual of nitrogen management

Treatment	Energy productivity (kg MJ^{-1})			Specific energy (MJ kg^{-1})			Energy intensity in economic term (MJ $₹^{-1}$)			Energy intensity in physical term (MJ kg^{-1})		
	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean
Tillage in maize												
RT_1: Conventional tillage (CT)	0.153	0.157	0.155	8.61	8.42	8.52	5.17	5.18	5.18	3.45	3.40	3.42
RT_2: Zero tillage (ZT)	0.167	0.171	0.169	7.98	7.87	7.92	5.42	5.38	5.40	3.19	3.15	3.17
SEm±	0.002	0.002	0.002	0.09	0.10	0.10	0.08	0.08	0.08	0.05	0.03	0.04
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Residue management												
RR_1: RDF + No residue	0.282	0.291	0.286	3.57	3.46	3.51	5.04	5.02	5.03	1.30	1.27	1.28
RR_2: RDF + Residue mulching (3 t ha^{-1})	0.121	0.122	0.121	8.32	8.19	8.26	5.39	5.37	5.38	3.38	3.34	3.36
RR_3: RDF + Residue mulching (6 t ha^{-1})	0.077	0.078	0.078	13.01	12.78	12.89	5.47	5.45	5.46	5.28	5.22	5.25
SEm±	0.003	0.003	0.003	0.09	0.08	0.08	0.07	0.07	0.06	0.04	0.04	0.04
CD (P=0.05)	0.009	0.010	0.009	0.29	0.25	0.25	0.22	0.22	0.20	0.14	0.12	0.12
Residual of nitrogen management												
RN_1: LCC based (100 % RDN)	0.162	0.165	0.163	8.23	8.09	8.16	5.34	5.32	5.33	3.30	3.25	3.27
RN_2: LCC based (75 % RDN)	0.158	0.163	0.160	8.37	8.20	8.28	5.26	5.24	5.25	3.34	3.30	3.32
SEm±	0.003	0.003	0.003	0.08	0.08	0.08	0.06	0.06	0.05	0.03	0.03	0.03
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

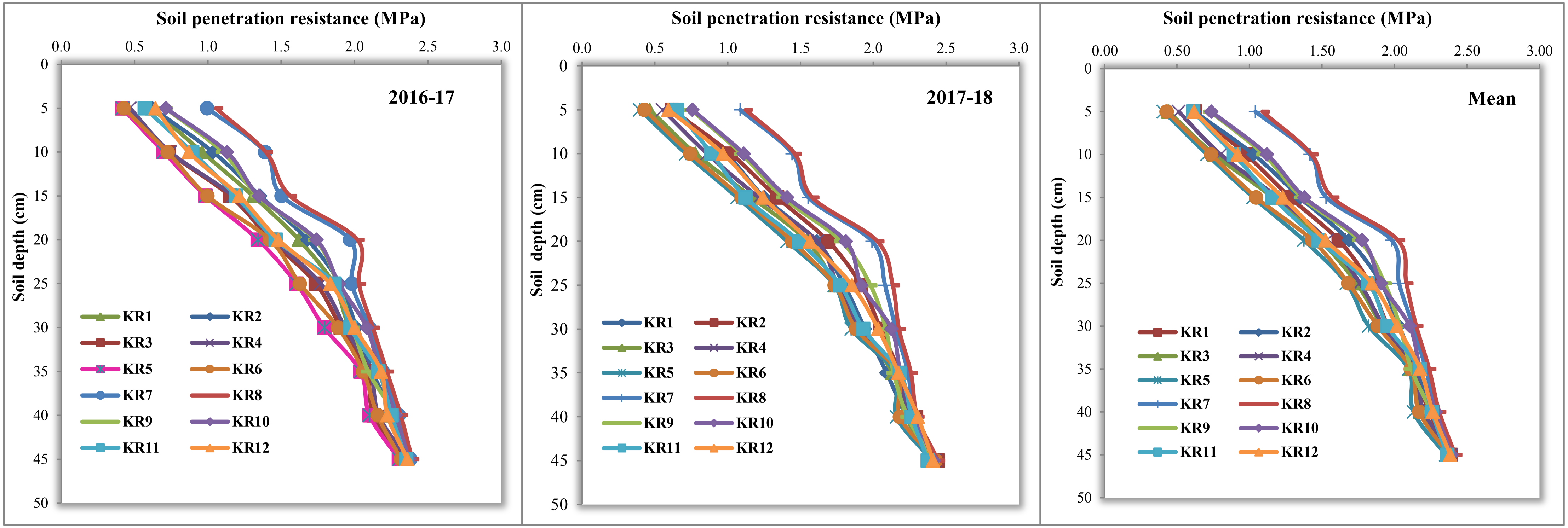
4.3 System

4.3.1 Soil penetration resistance (MPa)

The data on soil penetration resistance (SPR) measured at 0-5, 5-10, 10-15, 15-20, 20-25, 25-30, 30-35, 35-40 and 40-45 cm in soil depth as influenced by different treatment combinations of rice – maize cropping system are depicted in Fig 4.9. Among the different treatment combinations of rice – maize cropping system, soil penetration resistance was recorded lowest at 0-5, 5-10, 10-15, 15-20, 20-25, 25-30, 30-35, 35-40 and 40-45 cm in soil depth under KR_5 - [{CT + residual of RM (6 t ha^{-1})+ LCC 100 %} – {CT + RM (6 t ha^{-1}) + residual of LCC 100 %}] followed by KR_6 - [{CT + residual of RM (6 t ha^{-1})+ LCC 75 %} – {CT + RM (6 t ha^{-1}) + residual of LCC 75 %}], KR_3 - [{CT + residual of RM (3 t ha^{-1})+ LCC 100 %} – {CT + RM (3 t ha^{-1}) + residual of LCC 100 %}] and KR_4 - [{CT + residual of RM (3 t ha^{-1})+ LCC 75 %} – {CT + RM (3 t ha^{-1}) + residual of LCC 75 %}] during both the years and on mean basis.

4.3.3 Rice equivalent yield and system productivity (t ha^{-1})

The data pertaining to rice equivalent yield and system productivity as affected by different treatment combinations of rice – maize cropping system are presented in Table 4.60. As regards to system analysis of rice – maize cropping system, rice equivalent yield was recorded highest under KR_{11} – [{ZT + residual of RM (6 t ha^{-1}) + LCC 100 %} – {ZT + RM (6 t ha^{-1}) + residual of LCC 100 %) followed by KR_{12} – [{ZT + residual of RM (6 t ha^{-1}) + LCC 75 %} – {ZT + RM (6 t ha^{-1}) + residual of LCC 75 %), KR_5 - [{CT + residual of RM (6 t ha^{-1})+ LCC 100 %} – {CT + RM (6 t ha^{-1}) + Residual of LCC 100 %}] and KR_6 - [{CT + residual of RM (6 t ha^{-1})+ LCC 75 %} – {CT + RM (6 t ha^{-1}) + residual of LCC 75 %}] during both the years and on mean basis. Whereas, system productivity was recorded highest under KR_5 - [{CT + residual of RM (6 t ha^{-1}) + LCC 100 %} – {CT + RM (6 t ha^{-1}) + Residual of LCC 100 %}] followed by KR_6 - [{CT + residual of RM (6 t ha^{-1})+ LCC 75 %} – {CT + RM (6 t ha^{-1}) + residual of LCC 75 %}], KR_3 - [{CT + residual of RM (3 t ha^{-1})+ LCC 100 %} – {CT + RM (3 t ha^{-1}) + residual of LCC 100 %}] and KR_{11} – [{ZT + residual of RM (6 t ha^{-1}) + LCC 100 %} – {ZT + RM (6 t ha^{-1}) + residual of LCC 100 %) during both the years and on mean basis.



4.9: Soil penetration resistance (SPR) in soil as influenced by different treatments of rice – maize cropping system (2016-17, 2017-18 and mean)

KR$_1$: CT + residual of NR + LCC 100 % - CT + NR + residual of LCC 100% , **KR$_2$:** CT + residual of NR + LCC 75% - CT + NR + residual of LCC 75 %, **KR$_3$:** CT + residual of RM (3 t ha^{-1})+ LCC 100% - CT + RM (3 t ha^{-1}) + residual of LCC 100 %, **KR$_4$:** CT + residual of RM (3 t ha^{-1})+ LCC 75% - CT + RM (3 t ha^{-1}) + residual of LCC 5 % , **KR$_5$:** CT + residual of RM (6 t ha^{-1})+ LCC 100% - CT + RM (6 t ha^{-1}) + residual of LCC Based (RDN 100 %), **KR$_6$:** CT + residual of residue mulching (6 t ha^{-1})+ LCC based (RDN 75%) - CT + residue mulching (6 t ha^{-1}) + residual of LCC Based (RDN 75 %), **KR$_7$:** ZT + residual of no residue + LCC based 100% - ZT + NR + residual of LCC 100 % , **KR$_8$:** ZT + residual of NR + LCC 75% - ZT + NR + residual of LCC 75 %, **KR$_9$:** ZT + residual of RM (3 t ha^{-1})+ LCC 100% - ZT + RM (3 t ha^{-1}) + residual of LCC 100 % , **KR$_{10}$:** ZT + residual of RM (3 t ha^{-1}) + LCC 75% - ZT + RM (3 t ha^{-1}) + residual of LCC 75 %, **KR$_{11}$:** ZT + residual of RM (6 t ha^{-1})+ LCC 100% - ZT + RM (6 t ha^{-1}) + residual of LCC 100 % , **KR$_{12}$:** ZT + residual of RM (6 t ha^{-1})+ LCC 75% - ZT + RM (6 t ha^{-1}) + residual of LCC 75 % .

Table 4.60: Rice equivalent yield and productivity of system as influenced by different treatments of rice – maize cropping system

Treatment combination	Rice equivalent yield (t ha^{-1})			System productivity (t ha^{-1})		
Rice – Maize	**2016-17**	**2017-18**	**Mean**	**2016-17**	**2017-18**	**Mean**
KR_1	5.53	5.50	5.52	11.44	11.45	11.44
KR_2	5.46	5.42	5.44	10.29	10.37	10.33
KR_3	6.52	6.47	6.50	12.80	12.85	12.83
KR_4	6.41	6.37	6.39	12.45	12.50	12.48
KR_5	6.84	6.79	6.81	13.04	13.15	13.10
KR_6	6.76	6.72	6.74	12.95	13.07	13.01
KR_7	5.02	4.99	5.00	10.38	10.47	10.42
KR_8	4.92	4.89	4.90	9.55	9.50	9.53
KR_9	6.50	6.46	6.48	12.01	12.17	12.09
KR_{10}	6.40	6.35	6.38	11.80	11.66	11.73
KR_{11}	6.92	6.87	6.90	12.75	12.75	12.75
KR_{12}	6.90	6.85	6.87	12.51	12.62	12.57

KR_1: CT + residual of NR + LCC 100 % - CT + NR + residual of LCC 100% , **KR_2:** CT + residual of NR + LCC 75% - CT + NR + residual of LCC 75 %, **KR_3:** CT + residual of RM (3 t ha^{-1})+ LCC 100% - CT + RM (3 t ha^{-1}) + residual of LCC 100 %, **KR_4:** CT + residual of RM (3 t ha^{-1})+ LCC 75% - CT + RM (3 t ha^{-1}) + residual of LCC 5 % , **KR_5:** CT + residual of RM (6 t ha^{-1})+ LCC 100% - CT + RM (6 t ha^{-1}) + residual of LCC Based (RDN 100 %), **KR_6:** CT + residual of residue mulching (6 t ha^{-1})+ LCC based (RDN 75%) - CT + residue mulching (6 t ha^{-1}) + residual of LCC Based (RDN 75 %), **KR_7:** ZT + residual of no residue + LCC based 100% - ZT + NR + residual of LCC 100 % , **KR_8:** ZT + residual of NR + LCC 75% - ZT + NR + residual of LCC 75 %, **KR_9:** ZT + residual of RM (3 t ha^{-1})+ LCC 100% - ZT + RM (3 t ha^{-1}) + residual of LCC 100 % , **KR_{10}:** ZT + residual of RM (3 t ha^{-1}) + LCC 75% - ZT + RM (3 t ha^{-1}) + residual of LCC 75 %, **KR_{11}:** ZT + residual of RM (6 t ha^{-1})+ LCC 100% - ZT + RM (6 t ha^{-1}) + residual of LCC 100 % , **KR_{12}:** ZT + residual of RM (6 t ha^{-1})+ LCC 75% - ZT + RM (6 t ha^{-1}) + residual of LCC 75 % .

4.3.4 Net return (× 10^3 ₹ ha^{-1}) and benefit cost ratio

The data related to net return and benefit cost ratio of system as influenced by different treatment combinations of rice – maize cropping system are presented in Table 4.61. The results revealed that net return of system was recorded under KR_{11} – [{ZT + residual of RM (6 t ha^{-1}) + LCC 100 %} – {ZT + RM (6 t ha^{-1}) + residual of LCC 100 %) followed by KR_{12} – [{ZT + residual of RM (6 t ha^{-1}) + LCC 75 %} – {ZT + RM (6 t ha^{-1}) + residual of LCC 75 %), KR_5 - [{CT + residual of RM (6 t ha^{-1})+ LCC 100 %} – {CT + RM (6 t ha^{-1}) + Residual of LCC 100 %}] and KR_6 - [{CT + residual of RM (6 t ha^{-1})+ LCC 75 %} – {CT + RM (6 t ha^{-1}) + residual of LCC 75 %}], whereas, benefit cost ratio of system was recorded highest under KR_{11} – [{ZT + residual of RM (6 t ha^{-1}) + LCC 100 %} – {ZT + RM (6 t ha^{-1}) + residual of LCC 100 %) followed by KR_{12} – [{ZT + residual of RM (6 t ha^{-1}) + LCC 75 %} – {ZT + RM (6 t ha^{-1}) + residual of LCC 75 %), KR_9 – [{ZT + residual of RM (3 t ha^{-1})+ LCC 100 %} – {ZT + RM (3 t ha^{-1}) + residual of LCC 100 %}] and KR_5 - [{CT + residual of RM (6 t ha^{-1})+ LCC 100 %} – {CT + RM (6 t ha^{-1}) + Residual of LCC 100 %}] during both the years and on mean basis.

4.3.5 Net energy (× 10^3 MJ ha^{-1}) and energy use efficiency

The data on net energy and energy use efficiency of system as affected by different treatment combinations of rice – maize cropping system are presented in Table 4.61. Among the different treatment combinations of rice – maize cropping system, net return of system was recorded highest under KR_1 - [{CT + residual of NR+ LCC 100 %} – {CT + NR + residual of LCC 100 %}] followed by KR_3 - [{CT + residual of RM (3 t ha^{-1})+ LCC 100 %} – {CT + RM (3 t ha^{-1}) + residual of LCC 100 %}], KR_4 – [{CT + residual of RM (3 t ha^{-1})+ LCC 75 %} – {CT + RM (3 t ha^{-1}) + residual of LCC 75 %}] and KR_7 - [{ZT + residual of NR+ LCC 100 %} – {ZT + NR + residual of LCC 100 %}] during both the years and on mean basis. But energy use efficiency of system was registered highest under KR_7 - [{ZT + residual of NR+ LCC 100 %} – {ZT + NR + residual of LCC 100 %}] followed by KR_8 - [{ZT + residual of NR+ LCC 75 %} – {ZT + NR + residual of LCC 75%}], KR_1 - [{CT + residual of NR+ LCC 100 %} – {CT + NR + residual of LCC 100 %}] and KR_2 - [{CT + residual of NR+ LCC 75 %} – {CT + NR + residual of LCC 75 %}] during both the years and on mean basis.

Table 4.61: Net return, benefit cost ratio, net energy and energy use efficiency of system as influenced by different treatments of rice – maize cropping system

Treatment combination	Net return (× 10^3 ₹ ha^{-1})			Benefit cost ratio			Net energy (× 10^3 MJ ha^{-1})			Energy use efficiency		
Rice – Maize	**2016-17**	**2017-18**	**Mean**	**2016-17**	**2017-18**	**Mean**	**2016-17**	**2017-18**	**Mean**	**2016-17**	**2017-18**	**Mean**
KR_1	93.95	100.35	97.15	2.21	2.25	2.23	354.54	360.76	357.65	11.01	11.13	11.07
KR_2	74.94	83.73	79.34	1.97	2.05	2.01	328.38	331.40	329.89	10.62	10.92	10.77
KR_3	112.65	120.41	116.53	2.44	2.47	2.45	344.83	349.04	346.94	5.74	5.78	5.76
KR_4	107.64	115.08	111.36	2.38	2.41	2.39	336.39	337.03	336.71	5.67	5.64	5.66
KR_5	113.98	123.29	118.63	2.44	2.47	2.45	312.38	321.89	317.14	3.85	3.90	3.87
KR_6	112.97	122.19	117.58	2.43	2.46	2.45	314.28	319.22	316.75	3.84	3.87	3.86
KR_7	84.23	91.10	87.66	2.19	2.23	2.21	332.02	332.82	332.42	11.90	11.99	11.94
KR_8	71.96	76.20	74.08	2.02	2.03	2.03	306.89	308.16	307.53	11.56	11.88	11.72
KR_9	107.27	115.79	111.53	2.50	2.53	2.51	324.62	332.18	328.40	5.86	5.99	5.93
KR_{10}	104.11	108.13	106.12	2.46	2.43	2.44	321.45	325.89	323.67	5.73	5.83	5.78
KR_{11}	117.69	123.19	120.44	2.62	2.59	2.60	315.26	317.83	316.54	3.99	4.04	4.02
KR_{12}	114.20	121.39	117.80	2.58	2.57	2.57	305.89	311.01	308.45	3.91	3.96	3.93

KR_1: CT + residual of NR + LCC 100 % - CT + NR + residual of LCC 100% , **KR_2:** CT + residual of NR + LCC 75% - CT + NR + residual of LCC 75 %, **KR_3:** CT + residual of RM (3 t ha^{-1})+ LCC 100% - CT + RM (3 t ha^{-1}) + residual of LCC 100 %, **KR_4:** CT + residual of RM (3 t ha^{-1})+ LCC 75% - CT + RM (3 t ha^{-1}) + residual of LCC 5 % , **KR_5:** CT + residual of RM (6 t ha^{-1})+ LCC 100% - CT + RM (6 t ha^{-1}) + residual of LCC Based (RDN 100 %), **KR_6:** CT + residual of residue mulching (6 t ha^{-1})+ LCC based (RDN 75%) - CT + residue mulching (6 t ha^{-1}) + residual of LCC Based (RDN 75 %), **KR_7:** ZT + residual of no residue + LCC based 100% - ZT + NR + residual of LCC 100 % , **KR_8:** ZT + residual of NR + LCC 75% - ZT + NR + residual of LCC 75 %, **KR_9:** ZT + residual of RM (3 t ha^{-1})+ LCC 100% - ZT + RM (3 t ha^{-1}) + residual of LCC 100 % , **KR_{10}:** ZT + residual of RM (3 t ha^{-1}) + LCC 75% - ZT + RM (3 t ha^{-1}) + residual of LCC 75 %, **KR_{11}:** ZT + residual of RM (6 t ha^{-1})+ LCC 100% - ZT + RM (6 t ha^{-1}) + residual of LCC 100 % , **KR_{12}:** ZT + residual of RM (6 t ha^{-1})+ LCC 75% - ZT + RM (6 t ha^{-1}) + residual of LCC 75 % .

Fig 4.10: General view of performance of rice crop during *kharif* 2017

Fig 4.11: Treatment wise vies of rice field at physiological maturity stage

Fig 4.12: General view of performance of maize crop during *rabi* 2017-18

CHAPTER – V
SUMMARY AND CONCLUSIONS

Rice-Rice is the most important cropping system of Eastern India, yet its continuous practicing has generated a number of ecological and other second generation problems like low input use efficiency, nutrient deficiencies, lowering of ground water table and weed problems as well as deteriorate the soil quality. Thus, its elements have given thrust to search for alternate cropping systems. Maize can be an important crop to diversify the rice-rice cropping system, as it has higher yield potential than any cereal crop and wide adaptability to wide range of environment. Conservation agriculture systems have gained importance to make farming more profitable by cutting down the variable cost and tillage practices plays major role in accomplishing the sustainability in crop productivity and soil fertility.

Keeping these points in view, field experiments were conducted during 2016-17 and 2017-18 at Research Farm of ICAR- National Rice Research Institute, Cuttack (Odisha). In *kharif* season, the field experiment was laid out in split-split plot design with three replications. The treatment consisted of two tillage practices in rice *viz.*, KT_1 – conventional tillage (CT) and KT_2 – zero tillage (ZT) in main – plot, three residual of residues in maize *viz.*, KR_1 – RDF + no residue, KR_2 – RDF + residue mulching (3 t ha^{-1}) and KR_3 – RDF + residue mulching (6 t ha^{-1}) in sub - plot and two nitrogen management in rice *viz.*, KN_1 – LCC based (100 % RDN) and KN_2 – LCC based (75 % RDN) in sub – sub plot.

In *rabi* season, maize crop was grown in the same set of layout following the above design and replications. The treatment consisted of two tillage practices in maize viz., RT_1 – conventional tillage (CT) and RT_2 – zero tillage (ZT) in main – plot, three residue management in maize *viz.*, RR_1 – RDF + no residue, RR_2 – RDF + residue mulching (3 t ha^{-1}) and RR_3 – RDF + residue mulching (6 t ha^{-1}) in sub - plot and two residual of nitrogen management in rice *viz.*, RN_1 – LCC based (100 % RDN) and RN_2 – LCC based (75 % RDN) in sub – sub plot.

This experiment is on-going since past three years at Division of Crop Production, ICAR – National Rice Research Institute, Cuttack (Odisha).

The salient findings of various observations in rice – maize cropping system are summarized as follows:

5.1 Rice

5.1.1 Pre - harvest observations

- The effect of tillage practices in rice, residual of residues and nitrogen management as well as their interactions did not have significant influence on plant population at 30 DAS during both the years and on mean basis.
- At 60, 90, 120 DAS and at harvest, significantly taller plants were recorded with KT_1 – conventional tillage (CT) in comparison to KT_2 – zero tillage (CT) during both the years and on mean basis. Among the residual of residues in maize, at 60, 90, 120 DAS and at harvest, significantly tallest plants were recorded under treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) which was at par to treatment KR_2 – RDF + "residue mulching (3 t ha^{-1}) during both the years and on mean basis. As regards to nitrogen management in rice, at 60, 90, 120 DAS and at harvest, treatment KN_1 – LCC based (100 % RDN) registered significantly taller plants as compared to treatment KN_2 – LCC based (75 % RDN) during both the years and on mean basis.
- At 60, 90, 120 DAS and at harvest, significantly higher dry matter accumulation was obtained under KT_1 – conventional tillage (CT) "as compared to KT_2 – zero tillage (ZT) during both the years and on mean basis. Among the residual of residues in maize, at 60, 90, 120 DAS and at harvest, significantly the highest dry matter accumulation was recorded under treatment KR_3 –RDF + residue mulching (6 t ha^{-1}) which was at par to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis. With respect to nitrogen management in rice, at 60, 90, 120 DAS and at harvest, significantly higher dry matter accumulation was obtained under treatment KN_1 – LCC based (100 %

RDN) as compared to treatment KN_2 – LCC based (75 % RDN) during both the years and on mean basis.

- At 60, 90 and 120 DAS, significantly higher leaf area index was recorded under KT_1 – conventional tillage (CT) than KT_2 – zero tillage (ZT) during both the years and on mean basis. Among the residual of residues in maize, at 60, 90 and 120 DAS, treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) gave significantly the higher leaf area index as compared to treatment KR_1 – RDF + no residue, but it was comparable to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis. With respect to nitrogen management in rice, at 60, 90 and 120 DAS, significantly higher leaf area index was recorded under treatment KN_1 – LCC based (100 % RDN) as compared to treatment KN_2 – LCC based (75 % RDN) during both the years and on mean basis.
- At 30 – 60, 60 – 90, 90 – 120 DAS and 120 DAS – at harvest, treatment KT_1 – conventional tillage (CT) gave significantly higher crop growth rate as compared to KT_2 – zero tillage (ZT) during both the years and on mean basis. With respect to residual of residues in maize, at 30 – 60, 60 – 90, 90 – 120 DAS and 120 DAS – at harvest, significantly highest crop growth rate was recorded under treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) which was at par to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis. As regards to nitrogen management in rice, at 30 – 60, 60 – 90, 90 – 120 DAS and 120 DAS – at harvest, the crop growth rate was recorded significantly higher under treatment KN_1 – LCC based (100 % RDN) as compared to treatment KN_2 – LCC based (75 % RDN) during both the years and on mean basis.
- The effect of tillage practices in rice, residual of residues in maize and nitrogen management in rice as well as their interactions did not have significant impact on relative growth rate of rice at 0 – 30, 30 – 60, 60 – 90, 90 – 120 DAS and 120 DAS – at harvest during both the years and on mean basis.
- The tillage practices in rice and residual of residues in maize did not have significant impact on SPAD value of rice at 30, 60, 90 and 120 DAS

during both the years and on mean basis. As regards to nitrogen management in rice, at 60, 90 and 120 DAS, significantly higher SPAD value was registered under treatment KN_1 – LCC based (100 % RDN) as compared to treatment KN_2 – LCC based (75 % RDN) during both the years and on mean basis.

5.1.2 Post-harvest observations

- Effective tillers m^{-2} of rice was significantly higher under KT_1 – conventional tillage (CT) as compared to KT_2 – zero tillage (ZT) during the both years and on mean basis. Among the residual of residues in maize, treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) registered significantly highest number of effective tillers of rice which was at par to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) during the both years and on mean basis. As regards to nitrogen management in rice, treatment KN_1 – LCC based (100 % RDN) showed significantly higher number of tillers of rice as compared to treatment KN_2 – LCC based (75 % RDN) during both the years and on mean basis. The interaction between KR_3 – RDF + residue mulching (6 t ha^{-1}) with KN_1 – LCC based (100 % RDN) showed significantly higher number of effective tillers as compared to others. However, it was statistically similar to interactions of KR_2 – RDF + residue mulching (3 t ha^{-1}) with KN_1 – LCC based (100 % RDN), KR_3 – RDF + residue mulching (6 t ha^{-1}) with KN_2 – LCC based (75 % RDN) and KR_2 – RDF + residue mulching (3 t ha^{-1}) with KN_2 – LCC based (75 % RDN) during both the years and on mean basis.
- The panicle weight was registered significantly higher under KT_1 – conventional tillage (CT) as compared to KT_2 – zero tillage (ZT) during both the years and on mean basis. Among the residual of residues in maize, treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) registered significantly higher panicle weight of rice as compared to treatment KR_1 – RDF + no residue, however, it was at par to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis. Treatment KN_1 – LCC based (100 % RDN) showed significantly higher

panicle weight of rice as compared to treatment KN_2 – LCC based (75 % RDN) during both the years and on mean basis.

- The effect of tillage practices in rice, residual of residues in maize and nitrogen management in rice as well as their interactions did not have significant impact on panicle length and test weight of rice during both the years and on mean basis.
- The total number of grains panicle^{-1} of rice was recorded significantly higher under KT_1 – conventional tillage (CT) in comparison to KT_2 – zero tillage (ZT) during both the years and on mean basis. Among the residual of residues in maize, significantly maximum total number of grains panicle^{-1} of rice was noted under treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) which was at par to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}), whereas significantly minimum total number of grains panicle^{-1} was noted under treatment KR_1 – RDF + no residue during both the years and on mean basis. As regards to the nitrogen management in rice, significantly maximum total number of grains panicle^{-1} of rice was recorded under treatment KN_1 – LCC based (100 % RDN) as compared to treatment KN_2 – LCC based (75 % RDN) during both the years and on mean basis.
- Significantly higher number of filled grains panicle^{-1} of rice was registered under KT_1 – conventional tillage (CT) than KT_2 – zero tillage (ZT) during both the years and on mean basis. Among the residual of residues in maize, treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) noted significantly highest number of filled grains panicle^{-1} which was at comparable to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis. Treatment KN_1 – LCC based (100 % RDN) showed significantly higher number of filled grains panicle^{-1} of rice as compared to treatment KN_2 – LCC based (75 % RDN) during both the years and on mean basis. Interaction between KR_3 – RDF + residue mulching (6 t ha^{-1}) with KN_1 – LCC based (100 % RDN) showed significantly maximum number of filled grains panicle^{-1} of rice as compared to other interactions during both the years and on mean basis.

However, it was at par to interactions of KR_2 – RDF + residue mulching (3 t ha^{-1}) with KN_1 – LCC based (100 % RDN), KR_3 – RDF + residue mulching (6 t ha^{-1}) with KN_2 – LCC based (75 % RDN) and KR_2 – RDF + residue mulching (3 t ha^{-1}) with KN_2 – LCC based (75 % RDN) during both the years and on mean basis.

- The effect of tillage practices in rice, residual of residues in maize and nitrogen management in rice as well as their interactions did not have significant impact on number of unfilled grains $panicle^{-1}$ and sterility percentage of rice during both the years and on mean basis.
- The grain yield of rice was significantly higher under KT_1 – conventional tillage (CT) in comparison to KT_2 – zero tillage (ZT) during both the years and on mean basis. Among the residual of residues in maize, significantly higher grain yield of rice was registered under treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) as compared to treatment KR_1 – RDF + no residue, but it was comparable to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis. Regarding nitrogen management in rice, treatment KN_1 – LCC based (100 % RDN) registered significantly higher grain yield of rice as compared to treatment KN_2 – LCC based (75 % RDN) during both the years and on mean basis. Interaction between KR_3 – RDF + residue mulching (6 t ha^{-1}) with KN_1 – LCC based (100 % RDN) produced significantly higher grain yield of rice as compared to other interactions, but it was comparable to interactions of KR_2 – RDF + residue mulching (3 t ha^{-1}) with KN_1 – LCC based (100 % RDN), KR_3 – RDF + residue mulching (6 t ha^{-1}) with KN_2 – LCC based (75 % RDN) and KR_2 – RDF + residue mulching (3 t ha^{-1}) with KN_2 – LCC based (75 % RDN) during both the years and on mean basis.
- Straw yield of rice was recorded significantly higher under KT_1 – conventional tillage (CT) as compared to KT_2 – zero tillage (ZT) during both the years and on mean basis. Among the residual of residues in maize, significantly higher straw yield of rice was recorded under treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) as compared to treatment KR_1 – RDF + no residue, but it was statistically similar to

treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis. Regarding nitrogen management in rice, treatment KN_1 – LCC based (100 % RDN) showed significantly higher straw yield of rice in comparison to treatment KN_2 – LCC based (75 % RDN) during both the years and on mean basis. Interaction between KR_3 – RDF + residue mulching (6 t ha^{-1}) with KN_1 – LCC based (100 % RDN) produced significantly higher straw yield of rice as compared to other interactions, but it was at par to interactions of KR_2 – RDF + residue mulching (3 t ha^{-1}) with KN_1 – LCC based (100 % RDN), KR_3 – RDF + residue mulching (6 t ha^{-1}) with KN_2 – LCC based (75 % RDN) and KR_2 – RDF + residue mulching (3 t ha^{-1}) with KN_2 – LCC based (75 % RDN) during both the years and on mean basis.

- The effect of tillage practices in rice, residual of residues in maize and nitrogen management in rice as well as their interactions did not have significant effect on harvest index of rice during both the years and on mean basis.

5.1.3 Studies on weeds

- At 25 and 50 DAS, significantly lower total weed density and dry weight were recorded under KT_1 – conventional tillage (CT) in comparison to KT_2 – zero tillage (ZT) during both the years and on mean basis.
- The significantly lower density and dry weight of *Echinochloa colona*, *Digitaria sanguinalis*, *Cyperus iria* and other weeds at 25 and 50 DAS and *Ludwigia parviflora* at 50 DAS were recorded under KT_1 – conventional tillage (CT) than KT_2 – zero tillage (ZT) during both the years and on mean basis.

5.1.4 Chemical studies

- The effect of tillage practices in rice, residual of residues in maize and nitrogen management in rice as well as their interactions did not show any significant influence on N, P and K content in grain and straw of rice during both the years and on mean basis.
- N, P and K uptake by rice were recorded significantly higher under T_1 – conventional tillage (CT) as compared to KT_2 – zero tillage (ZT) during

both the years and on mean basis. In case of residual of residues in maize, treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) registered significantly higher N, P and K uptake by rice as compared to treatment KR_1 – RDF + no residue, but it was at par to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis. Between nitrogen management in rice, treatment KN_1 – LCC based (100 % RDN) gave significantly higher N, P and K uptake by rice as compared to treatment KN_2 – LCC based (75 % RDN) during both the years and on mean basis.

- Significantly higher production efficiency was recorded under KT_1 – conventional tillage (CT) as compared to KT_2 – zero tillage (ZT) during both the years and on mean basis. In case of residual of residues in maize, treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) registered significantly highest partial factor productivity of nitrogen, phosphorus and potassium as well as production efficiency of rice which was at par to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis. Treatment KN_2 – LCC based (75 % RDN) obtained significantly higher partial factor productivity of nitrogen in rice as compared to treatment KN_1 – LCC based (100 % RDN), whereas significantly higher partial factor productivity of phosphorus and potassium as well as production efficiency of rice was recorded under treatment KN_1 – LCC based (100 % RDN) as compared to treatment KN_2 – LCC based (75 % RDN) during both the years and on mean basis. Interaction between KR_3 – RDF + residue mulching (6 t ha^{-1}) with KN_2 – LCC based (75 % RDN) gave significantly higher partial factor productivity of nitrogen as compared to other interactions during both the years and on mean basis. However, it was comparable to interaction between KR_2 – RDF + residue mulching (3 t ha^{-1}) with KN_2 – LCC based (75 % RDN) and significantly lowest partial factor productivity of nitrogen was noted under interaction between KR_1 – RDF + no residue with KN_1 – LCC based (100 % RDN) during both the years and on mean basis.
- Significantly higher total and soil organic carbon, water soluble carbon, permanganate oxidizable carbon, microbial biomass carbon and readily

mineralizable carbon in soil after the harvest of rice were recorded under KT_2 – zero tillage (ZT) as compared to KT_1 – conventional tillage (CT) during both the years and on mean basis. Among the residual of residues in maize, significantly higher total and soil organic carbon, water soluble carbon, acid hydrolysable carbon, permanganate oxidizable carbon, microbial biomass carbon and readily mineralizable carbon in soil after the harvest of rice were recorded under treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) than treatment KR_1 – RDF + no residue, however, it was at par to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) under during both years and on mean basis. Treatment KN_1 – LCC based (100 % RDN) estimated significantly higher microbial biomass carbon as compared to treatment KN_2 – LCC based (75 % RDN) during both the years and on mean basis.

- Significantly higher value of total nitrogen, available nitrogen, microbial biomass nitrogen, ammonical nitrogen and nitrate nitrogen in soil after the harvest of rice were recorded under treatment KT_2 – zero tillage (ZT) as compared to KT_1 – conventional tillage (CT) during both the years and on mean basis. Among residual of residues in rice, treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) showed significantly maximum value of total nitrogen, available nitrogen, microbial biomass nitrogen ammonical nitrogen and nitrate nitrogen in soil after the harvest of rice which was at par to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis. Between nitrogen management in rice, the significantly maximum value of total nitrogen, available nitrogen, microbial biomass nitrogen, ammonical nitrogen and nitrate nitrogen in soil after the harvest of rice were estimated under treatment KN_1 – LCC based (100 % RDN) as compared to treatment KN_2 – LCC based (75 % RDN) during both the years and on mean basis. Interaction between KR_3 – RDF + residue mulching (6 t ha^{-1}) with KN_1 – LCC based (100 % RDN) showed significantly higher value of available nitrogen in soil after the harvest of rice as compared to other interactions, but it was at par to interactions of KR_3 – RDF + residue mulching (6 t ha^{-1}) with KN_2 – LCC based (75 %

RDN), KR_2 – RDF + residue mulching (3 t ha^{-1}) with KN_1 – LCC based (100 % RDN) and KR_1 – RDF + no residue with KN_1 – LCC based (100 % RDN) and significantly minimum value of available nitrogen was noted under interaction of R_1 – RDF + no residue with KN_2 – LCC based (75 % RDN) during both the years and on mean basis.

- Significantly higher value of available phosphorus and potassium in soil after the harvest of rice was observed under KT_2 – zero tillage (ZT) as compared to KT_1 – conventional tillage (CT) during both the years and on mean basis. Among the residual of residues in maize, treatment R_3 – RDF + residue mulching (6 t ha^{-1}) gave significantly higher value of available phosphorus and potassium in soil after the harvest of rice which was at par to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) and significantly higher values of available phosphorus and potassium in soil were estimated under treatment KN_1 – LCC based (100 % RDN) as compared to treatment KN_2 – LCC based (75 % RDN) during both the years and on mean basis.

5.1.5 Economics

- The cost of cultivation was registered the highest under KT_1 –conventional tillage (CT) and the lowest cost of cultivation was recorded under T_2 – zero tillage (ZT) during both the years and on mean basis. In case of nitrogen management in rice, treatment KN_1 – LCC based (100 % RDN) gave the highest cost of cultivation and the lowest cost of cultivation was recorded under treatment KN_2 – LCC based (75 % RDN) during both the years and on mean basis.
- Significantly higher gross return of rice was registered under KT_1 – conventional tillage (CT) as compared to KT_2 – zero tillage (ZT) during both the years and on mean basis. Among the residual of residues in maize, treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) gave significantly higher gross return of rice as compared to treatment KR_1 – RDF + no residue, but it was at par to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis. In case of nitrogen" management in rice, treatment KN_1 – LCC based (100 % RDN) recorded significantly higher gross return of rice as compared to treatment

KN_2 – LCC based (75 % RDN) during both the years and on mean basis. Interaction between KR_3 – RDF + residue mulching (6 t ha^{-1}) with KN_1 – LCC based (100 % RDN) registered significantly higher gross return of rice in comparison to other interactions, but it was comparable to interactions of KR_2 – RDF + residue mulching (3 t ha^{-1}) with KN_1 – LCC based (100 % RDN) and KR_3 – RDF + residue mulching (6 t ha^{-1}) with KN_2 – LCC based (75 % RDN) during both the years and on mean basis.

- Treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) showed significantly higher net return and benefit cost ratio of rice as compared to treatment KR_1 – RDF + no residue, but it was found comparable to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis. Treatment KN_1 – LCC based (100 % RDN) gave significantly higher net return and benefit cost ratio of rice as compared to treatment KN_2 – LCC based (75 % RDN) during both the years and on mean basis. Interaction between KR_3 – RDF + residue mulching (6 t ha^{-1}) with KN_1 – LCC based (100 % RDN) registered significantly higher net return of rice as compared to other interactions, but it was at par to interactions of KR_2 – RDF + residue mulching (3 t ha^{-1}) with KN_1 – LCC based (100 % RDN) and KR_3 – RDF + residue mulching (6 t ha^{-1}) with KN_2 – LCC based (75 % RDN) during both the years and on mean basis.

5.1.6 Energetics

- Treatment KT_1 – conventional tillage (CT) demonstrated the highest input energy of rice and the lowest input energy of rice was recorded under KT_2 – zero tillage (ZT) during both the years and on mean basis. In case of nitrogen management in rice, treatment KN_1 – LCC based (100 % RDN) recorded maximum input energy of rice, whereas the lowest input energy of rice was recorded under treatment KN_2 – LCC based (75 % RDN) during both the years and on mean basis.
- Treatment KT_1 – conventional tillage (CT) showed significantly the highest output energy of rice, whereas the lowest value was noted under KT_2 – zero tillage (ZT) during both the years and on mean basis. In case of residual of residues in maize, treatment KR_3 – RDF + residue mulching (6 t

ha^{-1}) obtained significantly higher output energy of rice as compared to treatment R_1 – RDF + no residue, but it was at par to treatment R_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis. Between nitrogen management in rice, treatment N_1 – LCC based (100 % RDN) gave significantly higher output energy of rice as compared to treatment N_2 – LCC based (75 % RDN) during both the years and on mean basis.

- Treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) obtained significantly highest net energy of rice which was at par to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) and significantly lowest net energy of rice was noted under treatment KR_1 – RDF + no residue during both the years and on mean basis. As regards to the nitrogen management in rice, treatment KN_1 – LCC based (100 % RDN) obtained significantly higher net energy of rice as compared to treatment KN_2 – LCC based (75 % RDN) during both the years and on mean basis.
- Treatment KT_2 – zero tillage (ZT) obtained significantly the highest energy use efficiency and energy profitability of rice as compared to KT_1 – conventional tillage (CT) during both the years and on mean basis. In case of residual of residues in maize, treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) gave significantly higher energy use efficiency and energy profitability of rice than treatment KR_1 – RDF + no residue, but it was at par to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis. As regards to nitrogen management in rice, treatment KN_2 – LCC based (75 % RDN) obtained significantly higher energy use efficiency and energy profitability of rice as compared to treatment KN_1 – LCC based (100 % RDN) during both the years and on mean basis.
- Treatment KT_2 – zero tillage (ZT) registered significantly higher energy productivity of rice as compared to KT_1 – conventional tillage (CT) during both the years and on mean basis. In case of residual of residues in maize, treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) obtained significantly higher energy productivity of rice than treatment KR_1 – RDF + no residue,

but it was comparable to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis. As regards to nitrogen management in rice, treatment KN_2 – LCC based (75 % RDN) obtained significantly higher energy productivity of rice as compared to treatment KN_1 – LCC based (100 % RDN) during both the years and on mean basis.

- Treatment KT_1 – conventional tillage (CT) showed significantly higher specific energy of rice and energy intensity in physical term in comparison to KT_2 – zero tillage (ZT) during both the years and on mean basis. In case of residual of residues in maize, treatment KR_1 – RDF + no residue obtained significantly higher specific energy of rice and energy intensity in physical term in comparison to other treatments during both the years and on mean basis.
- Significantly higher energy intensity in economics term of rice was obtained under treatment KR_3 – RDF + residue mulching (6 t ha^{-1}) as compared to treatment KR_1 – RDF + no residue, but it was at par to treatment KR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis. In case of nitrogen management in rice, treatment KN_1 – LCC based (100 % RDN) gave significantly higher energy intensity in economics term of rice as compared to treatment KN_2 – LCC based (75 % RDN) during both the years and on mean basis.

5.2 Studies on maize (*rabi* 2017-18 and 2017-18)

5.2.1 Pre – harvest observations

- The findings revealed that the effect of tillage practices in maize, residual of nitrogen management in rice as well as interactions among different treatments did not have significant influence on plant height of maize at 30, 60, 90 DAS and at harvest during both the years and on mean basis. Among the residue management in maize, at 60, 90 DAS and at harvest, significantly the taller plants were recorded under treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) in comparison to treatment RR_1 – RDF + no residue, but it was at par to treatment RR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis.

- The effect of tillage practices and residue management in maize and residual of nitrogen management in rice as well as their interactions did not show any significant influence on number of leaves plant^{-1} of maize at 30, 60, 90 DAS and at harvest during both the years and on mean basis.
- The effect of tillage practices in maize, residual of nitrogen management in rice as well as interactions among different treatments failed to give significant influence on dry matter accumulation of maize at 30, 60, 90 DAS and at harvest during both the years and on mean basis. Among the residue management in maize, at 60, 90 DAS and at harvest, the dry matter accumulation of maize was significantly higher under treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) as compared to RR_1 – RDF + no residue, but it was at par to treatment RR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis.
- The effect of tillage practices in maize at 30, 60 and 90 DAS; residue management in maize at 30 DAS and residual of nitrogen management in rice at 30, 60 and 90 DAS as well as their interactions were found non – significant influence on leaf area index of maize during both the years and on mean basis. Among the treatments of residue management in maize, at 60 and 90 DAS, significantly the highest leaf area index of maize was registered under treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) which was at par to treatment RR_2 – RDF + residue mulching (3 t ha^{-1}) and lowest leaf area index of maize was recorded under treatment RR_1 – RDF + no residue during both the years and on mean basis.
- The effect of tillage practices in maize and residual of nitrogen management in rice did not have significant effect on crop growth rate of maize during both the years and on mean basis. As regards to treatments of residue management in maize, the significantly higher crop growth rate was noted under treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) as compared to treatment RR_1 – RDF + no residue, but it was at par to treatment RR_2 – RDF + residue mulching (3 t ha^{-1}) at 30 – 60 DAS and 60 – 90 DAS, whereas at 90 DAS – at harvest, significantly higher crop growth rate of maize was noted under treatment RR_3 – RDF + residue

mulching (6 t ha^{-1}) in comparison to other treatments during both the years and on mean basis.

- The effect of tillage practices in maize, residue management in maize and residual of nitrogen management in rice as well as their interactions failed to give significant influence on relative growth rate of maize at 0 – 30, 30 – 60, 60 – 90 DAS and 90 DAS – at harvest during both the years and on mean basis.
- The effect of tillage practices in maize, residue management in maize and residual of nitrogen management in rice as well as their interactions did not have significant effect on SPAD value of maize at 30, 60 and 90 DAS during both the years and on mean basis.

5.2.1 Post – harvest observations

- The effect of tillage practices in maize, residue management in maize and residual of nitrogen management in rice as well as their interactions failed to give significant influence on number of cobs m^{-2} of maize during both the years and on mean basis.
- Significantly higher values of cob length, cob girth and weight of grains cob^{-1} of maize were noticed under treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) than other treatments during both the years and on mean basis. The interaction between RT_2 – zero tillage (ZT) with RR_3 – RDF + residue mulching (6 t ha^{-1}) registered significantly higher weight of grains cob^{-1} as compared to other interactions, but it was at par to interactions of RT_1 – conventional tillage (CT) with RR_3 – RDF + residue mulching (6 t ha^{-1}), RT_1 – conventional tillage (CT) with RR_2 – RDF + residue mulching (3 t ha^{-1}) and RT_2 – zero tillage (ZT) with RR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis.
- Significantly higher number of grains cob^{-1} of maize was noted under treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) in comparison to others during both the years and on mean basis. The interaction between RT_2 – zero tillage (ZT) with RR_3 – RDF + residue mulching (6 t ha^{-1}) showed significantly higher number of grains cob^{-1} as than other interactions, but it was statistically similar to interactions of RT_1 – conventional tillage (CT)

with RR_3 – RDF + residue mulching (6 t ha^{-1}), RT_1 – conventional tillage (CT) with RR_2 – RDF + residue mulching (3 t ha^{-1}) andRT_2 – zero tillage (ZT) with RR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis.

- The effect of tillage practices in maize and residual of nitrogen management in rice did not have significant influence on grain yield of maize during both the years and on mean basis. Among the treatment of residue management in maize, the grain yield was significantly higher under treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) as compared to treatment RR_2 – RDF + residue mulching (3 t ha^{-1}) and RR_1 – RDF + no residue during both the years and on mean basis. The interaction between RT_2 – zero tillage (ZT) with RR_3 – RDF + residue mulching (6 t ha^{-1}) produced significantly higher grain yield of maize as compared to other interactions. However, it was statistically similar to interactions of RT_1 – conventional tillage (CT) with RR_3 – RDF + residue mulching (6 t ha^{-1}), T_1 – conventional tillage (CT) with RR_2 – RDF + residue mulching (3 t ha^{-1}) and RT_2 – zero tillage (ZT) with RR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis.
- The effect of tillage practices in maize and residual of nitrogen management in rice did not have significant influence on stover yield of maize during both the years and on mean basis. Among the treatments of residue management in maize, the stover yield was significantly higher under treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) in comparison to treatment RR_2 – RDF + residue mulching (3 t ha^{-1}) and RR_1 – RDF + no residue during both the years and on mean basis. The interaction between RT_2 – zero tillage (ZT) with RR_3 – RDF + residue mulching (6 t ha^{-1}) showed significantly higher stover yield of maize as compared to other interactions. However, it was at par to interactions of RT_1 – conventional tillage (CT) with RR_3 – RDF + residue mulching (6 t ha^{-1}), RT_1 – conventional tillage (CT) with RR_2 – RDF + residue mulching (3 t ha^{-1}) and RT_2 – zero tillage (ZT) with RR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis.

- The effect of tillage practices in maize, residue management in maize and residual of nitrogen management in rice as well their interactions failed to give significant impact on harvest index of maize during both the years and on mean basis.

5.2.3 Studies on weeds

- At 30 and 60 DAS, significantly lower total weed density and dry weight were recorded under RT_1 – conventional tillage (CT) as compared to RT_2 – zero tillage (ZT) during both the years and on mean basis. Among the treatments of residue management in maize, at 30 and 60 DAS, treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) gave significantly lower total weed density and dry weight as compared to treatment RR_2 – RDF + residue mulching (3 t ha^{-1}) and RR_1 – RDF + no residue during both the years and on mean basis.
- At 30 and 60 DAS, treatment RT_1 – conventional tillage (CT) showed significantly lower density and dry weight of *Eleusine indica, Digitaria sanguinalis, Echinochloa colona, Cyperus rotundus Alternanthera philoxeroides* and other weeds in maize as compared to RT_2 – zero tillage (ZT) during both the years and on mean basis. Among the residue management in maize, at 30 and 60 DAS, significantly lower density and dry weight of *Eleusine indica, Digitaria sanguinalis, Echinochloa colona, Cyperus rotundus Alternanthera philoxeroides* and other weeds in maize were registered under treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) as compared to treatments RR_2 – RDF + residue mulching (3 t ha^{-1}) and RR_1 – RDF + no residue during both the years and on mean basis.

5.2.4 Chemical studies

- The effect of tillage practices in maize, residue management in maize and residual of nitrogen management in rice as well as their interactions did not show any significant influence on N, P and K content in grain and stover of maize during both the years and on mean basis.
- The effect of tillage practices in maize and residual of nitrogen management in rice did not have significant impact on N, P and K uptake by maize during both the years and on mean basis. In case of the residue

management in maize, treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) gave significantly higher N, P and K uptake by maize as compared to treatment RR_2 – RDF + residue mulching (3 t ha^{-1}) and RR_1 – RDF + no residue during both the years and on mean basis.

- The effect of tillage practices in maize and residual of nitrogen management in rice failed to give significant influence on partial factor productivity of nitrogen, phosphorus and potassium in maize as well as production efficiency of maize during both the years and on mean basis. Among the residue management in maize, treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) showed higher partial factor productivity of nitrogen, phosphorus and potassium in maize as well as production efficiency of maize as compared to treatment RR_1 – RDF + no residue, but it was comparable to treatment RR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis.
- The effect of tillage practices in maize and residual of nitrogen management in rice did not have significant impact on protein content in grain, protein yield and protein productivity of maize during both the years and on mean basis. Among the residue management in maize, the significantly higher protein yield and protein productivity of maize were registered under treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) as compared to treatment RR_2 – RDF + residue mulching (3 t ha^{-1}) and RR_1 – RDF + no residue during both the years and on mean basis.
- Significantly higher values of total and soil organic carbon, water soluble carbon, permanganate oxidizable carbon, microbial biomass carbon and readily mineralizable carbon in soil were recorded under RT_2 – zero tillage (ZT) in comparison to RT_1 – conventional tillage (CT) during both the years and on mean basis. Among the residue management in maize, significantly higher value of water soluble carbon and acid hydrolysable carbon in soil were recorded under treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) as compared to treatment RR_1 – RDF + no residue, but it was statistically similar to treatment RR_2 – RDF + residue mulching (3 t ha^{-1}), whereas treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) noted

significantly higher total and soil organic carbon, permanganate oxidizable carbon, microbial biomass carbon and readily mineralizable carbon in soil in comparison to other treatments during both the years and on mean basis.

- Significantly higher value of total nitrogen, available nitrogen, microbial biomass nitrogen, ammonical and nitrate nitrogen in soil were recorded under RT_2 – zero tillage (ZT) in comparison to RT_1 – conventional tillage (CT). Among the residue management in maize, treatment R_3 – RDF + residue mulching (6 t ha^{-1}) gave significantly higher value of total nitrogen and available nitrogen in soil after the harvest of maize as compared to treatment RR_1 – RDF + no residue, but it was comparable to treatment RR_2 – RDF + residue mulching (3 t ha^{-1}), whereas significantly higher value of microbial biomass nitrogen, ammonical nitrogen and nitrate nitrogen in soil were noted under treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) as compared to other treatments during both the years and on mean basis.
- Treatment RT_2 – zero tillage (ZT) gave significantly higher available phosphorus and potassium in soil after the harvest of maize as compared to RT_1 – conventional tillage (CT) during both the years and on mean basis. Among the residue management in maize, treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) recorded significantly higher value of available phosphorus and potassium in soil as compared to treatment RR_2 – RDF + residue mulching (3 t ha^{-1}) and treatment RR_1 – RDF + no residue during both the years and on mean basis.

5.2.5 Economics

- The cost of cultivation was recorded the highest under RT_1 – conventional tillage (CT) and the lowest cost of cultivation was recorded under RT_2 – zero tillage (ZT) during both the years and on mean basis. Regarding the residue management in maize, treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) registered the highest cost of cultivation and the lowest cost of cultivation was noted under treatment RR_1 – RDF + no residue during both the years and on mean basis.

- The effect of tillage practices in maize and residual of nitrogen management in rice failed give to significant influence with respect to gross return of maize during both the years and on mean basis. Regarding residue management in maize, significantly higher gross return of maize was recorded under treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) as compared to treatment RR_1 – RDF + no residue, but it was comparable to treatment RR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis. The interaction between RT_2 – zero tillage (ZT) with RR_3 – RDF + residue mulching (6 t ha^{-1}) obtained significantly higher gross return of maize as compared to other interactions. However, it was comparable to interactions of RT_1 – conventional tillage (CT) with RR_3 – RDF + residue mulching (6 t ha^{-1}), RT_1 – conventional tillage (CT) with RR_2 – RDF + residue mulching (3 t ha^{-1}) and RT_2 – zero tillage (ZT) with RR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis.
- The effect of tillage practices in maize and residual of nitrogen management in rice remained unaffected with respect to net return and benefit cost ratio of maize during both the years and on mean basis. Among the residue management in maize, treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) registered significantly higher net return and benefit cost ratio of rice as compared to treatment RR_2 – RDF + residue mulching (3 t ha^{-1}) and RR_1 – RDF + no residue during both the years and on mean basis. The interaction between RT_2 – zero tillage (ZT) with RR_3 – RDF + residue mulching (6 t ha^{-1}) obtained significantly higher net return of maize as compared to other interactions. However, it was statistically similar to interactions of RT_1 – conventional tillage (CT) with RR_3 – RDF + residue mulching (6 t ha^{-1}), RT_1 – conventional tillage (CT) with RR_2 – RDF + residue mulching (3 t ha^{-1}) and RT_2 – zero tillage (ZT) with RR_2 – RDF + residue mulching (3 t ha^{-1}) during both the years and on mean basis.

5.2.6 Energetics

- The input energy of maize was recorded highest under RT_1 – conventional tillage (CT) and the lowest input energy of maize was noted under RT_2 – zero tillage (ZT) during both the years and on mean basis. In case of residue management in maize, treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) registered highest input energy of maize, whereas the lowest input energy of maize was noted under treatment RR_1 – RDF + no residue during both the years and on mean basis.
- The effect of tillage practices in maize and residual of nitrogen management in rice as well as interactions of different treatments did not have significant impact on output energy of maize during both the years and on mean basis. Among the residue management in maize, treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) gave significantly higher output energy of maize as compared to treatment RR_2 – RDF + residue mulching (3 t ha^{-1}) and RR_1 – RDF + no residue during both the years and on mean basis.
- Among the residue management in maize, treatment RR_1 – RDF + no residue obtained significantly higher net energy, energy use efficiency, energy profitability and energy productivity of maize as compared to treatment RR_2 – RDF + residue mulching (3 t ha^{-1}) and RR_3 – RDF + residue mulching (6 t ha^{-1}) during both the years and on mean basis. None of the treatments of tillage practices in maize and residual of nitrogen management in rice as well as interaction effect of different treatments had significant influence on these parameters during both the years and on mean basis.
- In case of the residue management in maize, treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) gave significantly higher energy intensity in economics term of maize than treatment RR_1 – RDF + no residue, but it was at par to treatment RR_2 – RDF + residue mulching (3 t ha^{-1}), whereas specific energy and energy intensity in physical term of maize was significantly higher under treatment RR_3 – RDF + residue mulching (6 t ha^{-1}) as compared to other treatments during both the years and on mean

basis. None of the treatments of tillage practices in maize and residual of nitrogen management in rice as well as interaction effect of different treatments had significant influence on these parameters during both the years and on mean basis.

5.3 System

- Soil penetration resistance at 0-5, 5-10, 10-15, 15-20, 20-25, 25-30, 30-35, 35-40 and 40-45 cm in soil depth was recorded the lowest under KR_5 - [{CT + residual of RM (6 t ha^{-1})+ LCC 100 %} – {CT + RM (6 t ha^{-1}) + residual of LCC 100 %}] followed by KR_6 - [{CT + residual of RM (6 t ha^{-1})+ LCC 75 %} – {CT + RM (6 t ha^{-1}) + residual of LCC 75 %}], KR_3 - [{CT + residual of RM (3 t ha^{-1})+ LCC 100 %} – {CT + RM (3 t ha^{-1}) + residual of LCC 100 %}] and KR_4 - [{CT + residual of RM (3 t ha^{-1})+ LCC 75 %} – {CT + RM (3 t ha^{-1}) + residual of LCC 75 %}] during both the years and on mean basis.
- Rice equivalent yield was recorded the highest under KR_{11} – [{ZT + residual of RM (6 t ha^{-1}) + LCC 100 %} – {ZT + RM (6 t ha^{-1}) + residual of LCC 100 %) followed by KR_{12} – [{ZT + residual of RM (6 t ha^{-1}) + LCC 75 %} – {ZT + RM (6 t ha^{-1}) + residual of LCC 75 %), KR_5 - [{CT + residual of RM (6 t ha^{-1})+ LCC 100 %} – {CT + RM (6 t ha^{-1}) + Residual of LCC 100 %}] and KR_6 - [{CT + residual of RM (6 t ha^{-1})+ LCC 75 %} – {CT + RM (6 t ha^{-1}) + residual of LCC 75 %}], whereas system productivity was recorded the highest under KR_5 - [{CT + residual of RM (6 t ha^{-1}) + LCC 100 %} – {CT + RM (6 t ha^{-1}) + Residual of LCC 100 %}] followed by KR_6 - [{CT + residual of RM (6 t ha^{-1})+ LCC 75 %} – {CT + RM (6 t ha^{-1}) + residual of LCC 75 %}], KR_3 - [{CT + residual of RM (3 t ha^{-1})+ LCC 100 %} – {CT + RM (3 t ha^{-1}) + residual of LCC 100 %}] and KR_{11} – [{ZT + residual of RM (6 t ha^{-1}) + LCC 100 %} – {ZT + RM (6 t ha^{-1}) + residual of LCC 100 %) during both the years and on mean basis.
- Net return of system was recorded maximum under KR_{11} – [{ZT + residual of RM (6 t ha^{-1}) + LCC 100 %} – {ZT + RM (6 t ha^{-1}) + residual of LCC 100 %) followed by KR_{12} – [{ZT + residual of RM (6 t ha^{-1}) + LCC 75 %}

– {ZT + RM (6 t ha^{-1}) + residual of LCC 75 %), KR_5 - [{CT + residual of RM (6 t ha^{-1})+ LCC 100 %} – {CT + RM (6 t ha^{-1}) + Residual of LCC 100 %}] and KR_6 - [{CT + residual of RM (6 t ha^{-1})+ LCC 75 %} – {CT + RM (6 t ha^{-1}) + residual of LCC 75 %}], whereas benefit cost ratio of system was recorded the highest under KR_{11} – [{ZT + residual of RM (6 t ha^{-1}) + LCC 100 %} – {ZT + RM (6 t ha^{-1}) + residual of LCC 100 %) followed by KR_{12} – [{ZT + residual of RM (6 t ha^{-1}) + LCC 75 %} – {ZT + RM (6 t ha^{-1}) + residual of LCC 75 %), KR_9 – [{ZT + residual of RM (3 t ha^{-1})+ LCC 100 %} – {ZT + RM (3 t ha^{-1}) + residual of LCC 100 %}] and KR_5 - [{CT + residual of RM (6 t ha^{-1})+ LCC 100 %} – {CT + RM (6 t ha^{-1}) + Residual of LCC 100 %}] during both the years and on mean basis.

- Net energy of system was recorded the highest under KR_1 - [{CT + residual of NR+ LCC 100 %} – {CT + NR + residual of LCC 100 %}] followed by KR_3 - [{CT + residual of RM (3 t ha^{-1})+ LCC 100 %} – {CT + RM (3 t ha^{-1}) + residual of LCC 100 %}], KR_4 – [{CT + residual of RM (3 t ha^{-1})+ LCC 75 %} – {CT + RM (3 t ha^{-1}) + residual of LCC 75 %}] and KR_7 - [{ZT + residual of NR+ LCC 100 %} – {ZT + NR + residual of LCC 100 %}], but energy use efficiency of system was registered the highest under KR_7 - [{ZT + residual of NR+ LCC 100 %} – {ZT + NR + residual of LCC 100 %}] followed by KR_8 - [{ZT + residual of NR+ LCC 75 %} – {ZT + NR + residual of LCC 75%}], KR_1 - [{CT + residual of NR+ LCC 100 %} – {CT + NR + residual of LCC 100 %}] and KR_2 - [{CT + residual of NR+ LCC 75 %} – {CT + NR + residual of LCC 75 %}] during both the years and on mean basis.

CONCLUSION

On the basis of two years experimentation (2016-17 and 2017-18) on "Conservation agriculture based resource management in rice – maize cropping system" conducted at ICAR – National Rice Research Institute, Cuttack, the following conclusions can be drawn:

1. In rice – maize cropping system, during *kharif* season in rice, the effect of tillage, residual of residues and nitrogen management clearly reflects that use

of RDF + residue mulching (6 t ha^{-1}) and LCC based (100 % RDN) registered significantly higher growth parameters (plant height, dry matter accumulation, leaf area index and crop growth rate), yield attributes (effective tillers, panicle weight, total and filled grains $panicle^{-1}$), grain and straw yields, nutrient uptake (N, P and K), partial factor productivity (N, P and K) and production efficiency, carbon pools (water soluble carbon, acid hydrolysable carbon, $KMnO_4$ extractable carbon, microbial biomass carbon and readily mineralizable carbon) and nitrogen pools (total nitrogen, available nitrogen, microbial biomass nitrogen, ammonical and nitrate nitrogen), available P and K in soil, net return, B:C ratio and energetics (net energy and energy intensity in economic term) as compared to their respective treatments. However, these parameters were statistically similar under RDF + residue mulching (3 t ha^{-1}). Regarding tillage practices, conventional tillage proved better in terms of growth parameters, yield attributes, grain and straw yields, nutrient uptake (N, P and K), total and species wise density and dry weight of weeds, net return and energetics (net energy, specific energy and energy intensity in physical term). Whereas, zero tillage recorded higher values of carbon and nitrogen pools, available P and K and energetics (energy use efficiency, energy profitability and productivity) than conventional tillage.

2. During *rabi* season in maize, significantly higher growth parameters (plant height, dry matter accumulation, leaf area index and crop growth rate), yield attributes (length and girth of cob, weight and number of grains cob^{-1}), grain and stover yields, nutrient uptake (N, P and K), partial factor productivity (N, P and K), protein yield and productivity, carbon pools (water soluble carbon, acid hydrolysable carbon, $KMnO_4$ extractable carbon, microbial biomass carbon and readily mineralizable carbon) and nitrogen pools (total nitrogen, available nitrogen, microbial biomass nitrogen, ammonical and nitrate nitrogen), available P and K, net return, B:C ratio and energetics (specific energy, energy intensity in economic and physical term) were recorded under RDF + residue mulching (6 t ha^{-1}) in comparison to other treatments of residue management. Lowest total and species wise density and dry weight of weeds

were also obtained in this treatment. RDF + residue mulching (3 t ha^{-1}) also showed comparable values of growth parameters.

3. In system analysis of rice – maize cropping system, maximum system productivity was recoded under the treatment combination of KR_5 - [{CT + residual of RM (6 t ha^{-1}) + LCC 100} – {CT + RM (6 t ha^{-1}) + Residual of LCC 100 %}] followed by KR_6 - [{CT + residual of RM (6 t ha^{-1})+ LCC 75 %} – {CT + RM (6 t ha^{-1}) + residual of LCC 75 %}], KR_3 - [{CT + residual of RM (3 t ha^{-1})+ LCC 100 %} – {CT + RM (3 t ha^{-1}) + residual of LCC 100 %}] and KR_{11} – [{ZT + residual of RM (6 t ha^{-1}) + LCC 100 %} – {ZT + RM (6 t ha^{-1}) + residual of LCC 100 %). However, highest rice equivalent yield and net return were noted under the treatment combination of KR_{11} – [{ZT + residual of RM (6 t ha^{-1}) + LCC 100 %} – {ZT + RM (6 t ha^{-1}) + residual of LCC 100 %) followed by KR_{12} – [{ZT + residual of RM (6 t ha^{-1}) + LCC 75 %} – {ZT + RM (6 t ha^{-1}) + residual of LCC 75 %), KR_5 - [{CT + residual of RM (6 t ha^{-1})+ LCC 100 %} – {CT + RM (6 t ha^{-1}) + Residual of LCC 100 %}] and KR_6 - [{CT + residual of RM (6 t ha^{-1})+ LCC 75 %} – {CT + RM (6 t ha^{-1}) + residual of LCC 75 %}].

On the basis of two years finding on net income and benefit:cost ratio from the system, it can be recommended that zero tillage in combination to residual effect of RDF + residue mulching (6 t ha^{-1}) in rice and LCC based (100 % RDN) in *kharif* and zero tillage in combination to RDF + residue mulching (6 t ha^{-1}) and residual effect of LCC based (100 % RDN) in maize can be advocated to the farmers of Eastern India.

SUGGESSIONS FOR FUTURE RESEARCH WORK

On the basis of the findings of the present study, the following future line of work is suggested:

- There is need to study the long term impact of conservation agriculture on weed shift and weed dynamics as well as pest incidence.
- There is a need to study the microclimate changes in rice - maize cropping sequence with different conservation tillage practices.

- Soil quality index, greenhouse gas (GHGs) emissions and climate change mitigation potential under conservation agriculture practices need to be quantified.
- This study needs to be continued further with exploring suitable replacement of crops so as to satisfy the basic principle of conservation agriculture.
- Need to study an appropriate rotation period for conservation tillage v/s conventional tillage practices
- There is urgent need to evaluate these management practices under future climatic scenarios and develop climate smart technologies for sustainable food production under different soil types of Eastern India.

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APPENDIX

APPENDIX I: Weekly meteorological data during crop growth period of rice (From 13th June, 2016 to 20th November, 2016)

Week No.	Date	Temperature (°C)		Rain fall (mm)	Relative humidity (%)		Wind velocity (Kmph)	Evaporation (mm)	Sunshine (hours)
		Max.	Min.		I	II			
24	**June 13-19**	33	27	39.6	94.6	71.3	4.6	5.9	1.9
25	**20-26**	33	27	13.1	92.7	74.3	4.5	6.1	8.4
26	**27-03**	30	26	203.7	96.6	86.6	6.0	4.9	4.0
27	**July 04-10**	31	26	147.9	93.6	79.3	6.4	4.2	0.9
28	**11-17**	31	26	44.0	96.4	79.1	3.7	3.3	1.1
29	**18-24**	32	26	17.8	94.9	78.1	4.4	3.9	4.2
30	**25-31**	31	26	45.6	95.7	80.3	3.8	3.6	3.7
31	**Aug 01-07**	29	25	115.0	95.6	85.1	2.4	2.7	0.8
32	**08-14**	30	26	30.6	93.6	82.4	4.4	2.8	3.0
33	**15-21**	31	26	65.0	94.7	68.7	5.1	3.9	2.3
34	**22-28**	31	26	83.3	94.9	72.3	3.2	2.8	5.3
35	**Sept 29-04**	32	26	39.0	94.4	81.7	3.3	3.3	2.2
36	**05-11**	29	25	52.5	94.9	78.0	4.1	2.2	2.3
37	**12-18**	30	26	95.5	94.6	81.0	3.1	2.2	3.8
38	**19-25**	31	26	47.6	94.3	75.9	2.8	3.6	4.8
39	**Oct 26-02**	29	25	90.8	97.4	84.9	2.4	2.3	3.4
40	**03-09**	31	25	28.4	96.0	77.6	2.8	3.9	6.0
41	**10-16**	32	24	2.0	94.4	71.3	2.2	3.8	7.8
42	**17-23**	31	22	0.0	88.3	66.6	1.8	4.2	8.4
43	**24-30**	31	22	3.0	90.1	66.0	3.6	3.8	6.9
44	**Nov 31-06**	30	22	12.7	94.0	63.9	4.7	3.8	6.0
45	**07-13**	29	17	0.0	91.9	39.6	1.6	3.2	7.1
46	**14-20**	29	17	0.0	94.0	42.3	1.6	3.3	8.3

APPENDIX II: Weekly meteorological data during crop growth period of maize (From 20th December, 2016 to 13th Aprill, 2017)

Week No.	Date	Temperature (°C)		Rain fall (mm)	Relative humidity (%)		Wind velocity (Kmph)	Evaporation (mm)	Sunshine (hours)
		Max.	Min.		I	II			
51	**Dec 19-25**	27.2	11.6	0.0	94.7	46.4	1.4	3.0	8.6
52	**26-01**	27.3	14.1	0.0	96.9	53.7	1.4	2.3	6.5
01	**Jan 02-08**	27.1	13.8	0.0	95.0	44.3	1.4	1.9	6.9
02	**09-15**	26.4	13.3	0.0	85.9	45.6	3.3	2.6	7.9
03	**16-22**	27.3	12.5	0.0	91.6	36.3	2.2	2.7	9.0
04	**23-29**	28.5	13.9	0.0	92.6	42.6	2.2	2.8	8.1
05	**Feb 30-05**	28.5	17.2	0.0	93.7	50.9	2.5	3.1	7.2
06	**06-12**	31.1	17.9	0.0	95.6	44.9	2.5	3.4	7.7
07	**13-19**	31.2	17.7	0.0	96.6	43.6	2.3	3.2	8.2
08	**20-26**	31.2	21.4	0.0	90.3	53.3	5.1	4.2	7.5
09	**Mar 27-05**	32.8	20.9	0.0	92.6	52.1	3.9	4.7	7.1
10	**06-12**	30.6	22.7	55.0	93.0	66.7	4.8	3.6	5.1
11	**13-19**	32.4	22.2	0.0	95.3	57.3	4.5	4.4	7.5
12	**20-26**	34.4	22.1	0.0	92.4	54.4	4.8	4.2	8.3
13	**27-02**	34.5	25.1	0.0	94.1	58.3	9.0	4.9	8.0
14	**Apr 03-09**	34.6	26.3	0.0	92.4	44.6	5.3	5.2	6.1
15	**10-16**	35.6	25.2	0.0	92.9	40.1	7.0	5.8	7.4
16	**17-23**	35.1	23.4	0.0	90.9	45.1	9.1	5.2	4.8
17	**24-30**	37.6	26.4	0.0	92.0	43.1	8.2	6.4	7.8

APPENDIX III: Weekly meteorological data during crop growth period of rice (From 20th June, 2017 to 25th November, 2017)

Week No.	Date	Temperature (°C)		Rain fall (mm)	Relative humidity (%)		Wind velocity (Kmph)	Evaporation (mm)	Sunshine (hours)
		Max.	Min.		I	II			
25	**June 19-25**	32.0	26.2	7.0	91.0	76.0	5.2	3.6	2.6
26	**26-02**	29.9	26.2	25.0	94.9	84.6	2.4	1.8	0.1
27	**July 03-09**	31.2	25.5	58.0	94.1	82.9	3.4	2.2	0.2
28	**10-16**	31.7	25.8	60.5	95.9	80.3	2.1	1.5	1.6
29	**17-23**	30.7	26.3	189.0	96.3	83.3	5.3	2.8	0.9
30	**24-30**	30.7	26.8	42.5	94.9	85.3	1.5	2.9	1.8
31	**Aug 31-06**	31.9	26.3	23.0	93.1	86.3	2.6	4.0	4.7
32	**07-13**	33.0	26.5	22.0	89.3	76.6	2.8	5.0	4.8
33	**14-20**	31.2	26.3	37.0	94.1	85.0	2.2	3.4	2.8
34	**21-27**	32.1	26.6	28.0	94.1	81.0	1.5	2.9	4.5
35	**Sept 28-03**	30.5	25.8	121.0	94.9	84.3	1.7	2.1	1.8
36	**04-10**	32.5	27.0	0.0	94.6	66.4	1.0	3.7	5.1
37	**11-17**	34.2	26.4	57.0	91.3	67.4	1.0	3.2	3.8
38	**18-24**	32.2	26.5	14.0	89.0	75.3	1.3	3.1	3.3
39	**25-01**	32.1	26.9	165.0	92.3	77.7	0.5	2.5	2.3
40	**Oct 02-08**	29.8	26.1	0.0	93.4	79.9	1.3	1.5	2.7
41	**09-15**	33.0	26.2	38.0	95.0	73.3	1.1	2.5	4.3
42	**16-22**	31	26	107.0	89.3	77.4	3.1	3.5	3.5
43	**23-29**	32	25	0.0	90.4	61.1	0.5	3.1	6.3
44	**Nov 30-05**	30	21	0.0	88.4	68.7	1.1	3.1	5.1
45	**06-12**	31	21	0.00	94.57	51.00	1.71	2.49	5.87
46	**13-19**	24	21	47.00	86.57	71.71	3.79	1.20	3.23
47	**20-26**	26	17	0.00	90.86	52.86	1.14	1.10	4.89

APPENDIX IV: Weekly meteorological data during crop growth period of maize (From 19th December, 2017 to 15th Aprill, 2018)

Week No.	Date	Temperature (°C)		Rain fall (mm)	Relative humidity (%)		Wind velocity (Kmph)	Evaporation (mm)	Sunshine (hours)
		Max.	Min.		I	II			
51	**Dec 18-24**	26.1	13.0	0.0	96.3	88.3	0.6	1.0	2.9
52	**25-31**	25.9	12.5	0.0	91.9	68.6	0.7	1.0	4.0
1	**Jan 01-07**	25.5	11.7	0.0	94.3	47.1	1.6	1.0	4.5
2	**08-14**	25.8	10.9	0.0	90.3	46.7	0.7	1.4	5.4
3	**15-21**	27.0	10.6	0.0	95.3	36.6	0.6	2.5	6.2
4	**22-28**	28.3	13.4	0.0	94.4	45.4	0.8	1.4	4.6
5	**Feb 29-04**	29.8	13.2	0.0	91.3	58.9	2.2	3.0	7.9
6	**05-11**	30.9	15.4	0.0	88.1	83.7	3.1	2.9	4.1
7	**12-18**	30.3	15.0	0.0	92.6	77.9	4.0	3.0	7.5
8	**19-25**	33.7	15.9	0.0	93.0	64.4	3.8	4.6	7.9
9	**Mar 26-04**	33.2	21.4	0.0	95.7	52.7	4.9	4.9	6.5
10	**05-11**	31.9	21.2	0.0	94.3	54.1	4.9	4.5	6.6
11	**12-18**	32.6	22.5	0.0	94.4	59.4	3.9	4.7	8.1
12	**19-25**	34.9	22.5	0.0	93.7	59.4	7.3	4.7	8.5
13	**26-01**	35.3	25.1	0.0	93.7	58.3	6.2	4.3	7.9
14	**Apr 02-08**	35.2	26.3	32.0	94.7	42.7	6.9	3.7	6.6
15	**09-15**	35.6	26.0	0.0	91.0	31.3	5.5	5.4	7.0

APPENDIX V: Variable and Fixed cost in rice experiment during wet 2016 and 2017 (ha^{-1})

S. No.	Particulars	Input (ha^{-1})	Price (₹)		Total cost (₹ ha^{-1})	
			2016	2017	2016	2017
1.	**Land preparation**					
Variable cost						
A.	**CT (DSR)**					
	a. TwicepPloughing	6 hrs	₹ 600 hrs^{-1}	₹ 600 hrs^{-1}	3600	3600
	b. Rotavator	2.5 hrs	₹ 600 hrs^{-1}	₹ 600 hrs^{-1}	1500	1500
	c. Planking	1.5 hrs	₹ 600 hrs^{-1}	₹ 600 hrs^{-1}	900	900
2.	Weed management					
	a. Pedimethalin	3.33 lit.	₹ 400 lit^{-1}	₹ 400 lit^{-1}	1332	1332
	b. Bispyribac sodium	250 ml	₹ 8.13 ml^{-1}	₹ 8.13 ml^{-1}	2033	2033
	c. Labour for application	2 labour	₹ 300 lbr^{-1}	₹ 320 lbr^{-1}	600	640
	d. Hand weeding	20 labour	₹ 300 lbr^{-1}	₹ 320 lbr^{-1}	6000	6400
	Total variable cost				**15965**	**16405**
B.	**ZT (DSR)**					
	a. Weed management					
	1. Glyphosate	4.87 lit.	₹ 400 lit^{-1}	₹ 400 lit^{-1}	1948	1948
	2. Pedimethalin	3.33 lit.	₹ 400 lit^{-1}	₹ 400 lit^{-1}	1332	1332
	3. Bispyribac sodium	250 ml	₹ 8.13 ml^{-1}	₹ 8.13 ml^{-1}	2033	2033
	4. Labour for application	3 labour	₹ 300 lbr^{-1}	₹ 320 lbr^{-1}	900	960
	5. Hand weeding	25 labour	₹ 300 lbr^{-1}	₹ 320 lbr^{-1}	7500	8000
	Total variable cost				**13713**	**14273**
Fixed cost						
3.	**Seed**	40 kg	₹ 30 kg^{-1}	₹ 30 kg^{-1}	1400	1400
4.	**Seed treatment**					
	a. Azospirillum	100 g	₹ 1 g^{-1}	₹ 1 g^{-1}	100	100
	a. Labour for treatment	1 labour	₹ 300 lbr^{-1}	₹ 320 lbr^{-1}	300	320
5.	**Sowing**					
	a. Seed dril	2.5 hrs	₹ 600 hrs^{-1}	₹ 600 hrs^{-1}	1500	1500
	b. Labour for sowing	1 labour	₹ 300 lbr^{-1}	₹ 320 lbr^{-1}	300	320
6.	Fertilizer					
	a. SSP	250 kg	₹ 8 kg^{-1}	₹ 8 kg^{-1}	2000	2000
	b. MOP	67 kg	₹ 12 kg^{-1}	₹ 12 kg^{-1}	804	804
	c. Labour for application	8 labour	₹ 300 lbr^{-1}	₹ 320 lbr^{-1}	2400	2560
7.	Gap filling	3 labour	₹ 300 lbr^{-1}	₹ 320 lbr^{-1}	900	960
8.	Irrigation					
	a. No. of irrigation	4 irrigation in 2016 and 5 irrigation in 2017	₹ 400	₹ 400	1600	2000
	b. Labour for irrigation	4 labour in 2016 and 5 labour in 2017	₹ 300 lbr^{-1}	₹ 320 lbr^{-1}	1200	1600
9.	Harvesting and post-harvest	15 labour	₹ 300 lbr^{-1}	₹ 320 lbr^{-1}	4500	4800
	Total fixed cost				**17004**	**18364**

APPENDIX VI: Variable cost of nitrogen management in rice experiment during wet 2016 and 2017 (ha^{-1})

S. No.	Particulars	Input (ha^{-1})	Price (₹)		Total cost (₹ ha^{-1})	
			2016	2017	2016	2017
1.	LCC based N (75%)	130 kg Urea	6 ₹ kg^{-1}	6 ₹ kg^{-1}	783	783
2.	LCC based N (100%)	174 kg Urea	6 ₹ kg^{-1}	6 ₹ kg^{-1}	1044	1044

APPENDIX VII: Total cost in rice experiment during wet 2016 and 2017 (ha^{-1})

S. N	Treat.	Fixed Cost (ha^{-1})		Treatments Cost (ha^{-1})						Total cost (ha^{-1})	
				Tillage		Residue management		Nitrogen management			
		2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
1.	$T_1R_1N_1$	17004	18364	15965	16405	-	-	783	783	33752	35552
2.	$T_1R_1N_2$	17004	18364	15965	16405	-	-	1044	1044	34013	35813
3.	$T_1R_2N_1$	17004	18364	15965	16405	-	-	783	783	33752	35552
4.	$T_1R_2N_2$	17004	18364	15965	16405	-	-	1044	1044	34013	35813
5.	$T_1R_3N_1$	17004	18364	15965	16405	-	-	783	783	33752	35552
6.	$T_1R_3N_2$	17004	18364	15965	16405	-	-	1044	1044	34013	35813
7.	$T_2R_1N_1$	17004	18364	13713	14273	-	-	783	783	31500	33420
8.	$T_2R_1N_2$	17004	18364	13713	14273	-	-	1044	1044	31761	33681
9.	$T_2R_2N_1$	17004	18364	13713	14273	-	-	783	783	31500	33420
10.	$T_2R_2N_2$	17004	18364	13713	14273	-	-	1044	1044	31761	33681
11.	$T_2R_3N_1$	17004	18364	13713	14273	-	-	783	783	31500	33420
12.	$T_2R_3N_2$	17004	18364	13713	14273	-	-	1044	1044	31761	33681

APPENDIX VIII: Variable and Fixed cost in maize experiment during dry 2016-17 and 2017-18 (ha^{-1})

S. N.	Particulars	Input (ha^{-1})	Price (₹)		Total cost (₹ ha^{-1})	
			2016-17	2017-18	2016 -17	2017 -18
1.	**Land preparation**					
Variable cost						
A.	**CT (DSR)**					
	a. Twice ploughing	6 hrs	₹ 600 hrs^{-1}	₹ 600 hrs^{-1}	3600	3600
	b. Rotavator	2.5 hrs	₹ 600 hrs^{-1}	₹ 600 hrs^{-1}	1500	1500
	c. Planking	1.5 hrs	₹ 600 hrs^{-1}	₹ 600 hrs^{-1}	900	900
2.	Weed management					
	a. Atrazine	2 kg	₹ 396 kg^{-1}	₹ 396 kg^{-1}	792	792
	c. Labour for application	1 labour	₹ 300 lbr^{-1}	₹ 320 lbr^{-1}	300	320
	d. Hand weeding	10 labour	₹ 300 lbr^{-1}	₹ 320 lbr^{-1}	3000	3200
	Total variable cost				**10092**	**10312**
B.	**ZT (DSR)**					
	a. Weed management					
	1. Glyphosate	4.87 lit.	₹ 400 lit^{-1}	₹ 400 lit^{-1}	1948	1948
	2. Atrazine	2 kg	₹ 396 kg^{-1}	₹ 396 kg^{-1}	792	792
	4. Labour for application	2 labour	₹ 300 lbr^{-1}	₹ 320 lbr^{-1}	600	640
	5. Hand weeding	15 labour	₹ 300 lbr^{-1}	₹ 320 lbr^{-1}	4500	4800
	Total variable cost				**7840**	**8180**
Fixed cost						
3.	**Seed**	20 kg	₹ 350 kg^{-1}	₹ 350 kg^{-1}	7000	7000
4.	**Sowing**					
	b. Labour for sowing	15 labour	₹ 300 lbr^{-1}	₹ 320 lbr^{-1}	4500	4800
6.	**Fertilizer**					
	a. Urea	326 kg	₹ 6 kg^{-1}	₹ 6 kg^{-1}	1956	1956
	b. SSP	313 kg	₹ 8 kg^{-1}	₹ 8 kg^{-1}	2504	2504
	c. MOP	63 kg	₹ 12 kg^{-1}	₹ 12 kg^{-1}	996	996
	c. Labour for application	6 labour	₹ 300 lbr^{-1}	₹ 320 lbr^{-1}	1800	1920
7.	**Gap filling**	3 labour	₹ 300 lbr^{-1}	₹ 320 lbr^{-1}	900	960
8.	**Irrigation**					
	a. No. of irrigation	7 irrigation in 2016-17 and 6 irrigation in 2017-18	₹ 400	₹ 400	2800	2400
	b. Labour for irrigation	7 labour in 2016 and 6 labour in 2017	₹ 300 lbr^{-1}	₹ 320 lbr^{-1}	2100	1920
9.	Harvesting and post-harvest	11 labour	₹ 300 lbr^{-1}	₹ 320 lbr^{-1}	3300	3520
	Total fixed cost				**27856**	**27976**

APPENDIX IX: Variable cost of residue management in maize experiment during dry 2016-17 and 2017-18 (ha^{-1})

S. No.	Particulars	Input (ha^{-1})	Price (₹) 2016-17	Price (₹) 2017-18	Total cost (₹ ha^{-1}) 2016 - 17	Total cost (₹ ha^{-1}) 2017 - 18
1.	No residue	-				
2.	Residue mulching (3 t ha^{-1})	3 t	₹ 600 t^{-1}	₹ 600 t^{-1}	1800	1800
3.	Residue mulching (6 t ha^{-1})	6 t	₹ 600 t^{-1}	₹ 600 t^{-1}	3600	3600

APPENDIX X: Total cost in maize experiment during dry 2016-17 and 2017-18 (ha^{-1})

S. N	Treat.	Fixed Cost (ha^{-1}) 2016-17	Fixed Cost (ha^{-1}) 2017-18	Treatments Cost (ha^{-1}): Tillage 2016 -17	Tillage 2017 -18	Residue management 2016 -17	Residue management 2017 -18	Nitrogen management 2016 - 17	Nitrogen management 2017 - 18	Total cost (ha^{-1}) 2016 - 17	Total cost (ha^{-1}) 2017 - 18
1.	$T_1R_1N_1$	27856	27976	10092	10312	-	-	-	-	37948	38288
2.	$T_1R_1N_2$	27856	27976	10092	10312	-	-	-	-	37948	38288
3.	$T_1R_2N_1$	27856	27976	10092	10312	1800	1800	-	-	39748	40088
4.	$T_1R_2N_2$	27856	27976	10092	10312	1800	1800	-	-	39748	40088
5.	$T_1R_3N_1$	27856	27976	10092	10312	3600	3600	-	-	41548	41888
6.	$T_1R_3N_2$	27856	27976	10092	10312	3600	3600	-	-	41548	41888
7.	$T_2R_1N_1$	27856	27976	7840	8180	-	-	-	-	35696	36156
8.	$T_2R_1N_2$	27856	27976	7840	8180	-	-	-	-	35696	36156
9.	$T_2R_2N_1$	27856	27976	7840	8180	1800	1800	-	-	37496	37956
10.	$T_2R_2N_2$	27856	27976	7840	8180	1800	1800	-	-	37496	37956
11.	$T_2R_3N_1$	27856	27976	7840	8180	3600	3600	-	-	39296	39756
12.	$T_2R_3N_2$	27856	27976	7840	8180	3600	3600	-	-	39296	39756

APPEND XI: Energy equivalent for different inputs and outputs

S.N.	Particulars	Unit	Equivalent energy (MJ)	Reference
1.	Human Labour			
	a. Adult man	MJ h^{-1}	1.96	Mittal and Dhawan (1988)
	b. Adult women	MJ h^{-1}	1.57	Mittal and Dhawan (1988)
2.	Diesel including lube	MJ l^{-1}	56.31	Mittal and Dhawan (1988)
3.	Electricity	KWh	11.93	Mittal and Dhawan (1988)
4.	Chemical and fertilizers			
	a. Nitrogen	MJ kg^{-1}	78.1*	Kitani (1999)
	b. Phosphorous	MJ kg^{-1}	17.4*	Kitani (1999)
	c. Potash	MJ kg^{-1}	13.7*	Kitani (1999)
	d. fungicide	MJ kg^{-1}	99	Strapatsa *et al.* (2006)
	e. Herbicide	MJ kg^{-1} or l^{-1}	254.45	Mittal and Dhawan (1988)
5.	Seed/Grain			
	a. Rice and maize	MJ kg^{-1}	14.7	West and Marland (2002)
6.	Straw/stover			
	a. Rice straw	MJ kg^{-1}	12.5	Kitani (1999)
	b. Maize straw	MJ kg^{-1}	12.5	Mittal *et al.* (1985)

* Production, packing, transportation and application

APPENDIX XII: Variable and Fixed energy input in rice experiment during wet 2016 and 2017 (ha^{-1})

S. No.	Particulars	Input (ha^{-1})	Rate of energy (MJ)	Total energy (MJ ha^{-1})	
				2016	2017
1.	**Land preparation**				
Variable energy					
A.	**CT (DSR)**				
	a. Twice Ploughing	6 hr (5 l hr^{-1})	56.31 litre^{-1}	1689.30	1689.30
	b. Rotavator	2.5 hr (5 l hr^{-1})	56.31 litre^{-1}	703.88	703.88
	c. Planking	1.5 hr (5 l hr^{-1})	56.31 litre^{-1}	422.33	422.33
2.	Weed management				
	a. Pedimethalin	3.33 lit.	254.45 l^{-1}	847.32	847.32
	b. Bispyribac sodium	250 ml	254.45 l^{-1}	63.61	63.61
	c. Labour for application	2 labour	1.96 hr^{-1}	31.36	31.36
	d. Hand weeding	20 labour	1.57 hr^{-1}	251.20	251.20
	Total variable energy			**4009.00**	**4009.00**
B.	**ZT (DSR)**				
	a. Weed management				
	1. Glyphosate	4.87 lit.	254.45 l^{-1}	1239.17	1239.17
	2. Pedimethalin	3.33 lit.	254.45 l^{-1}	847.32	847.32
	3. Bispyribac sodium	250 ml	254.45 l^{-1}	63.61	63.61
	4. Labour for application	3 labour	1.96 hr^{-1}	47.04	47.04
	5. Hand weeding	25 labour	1.57 hr^{-1}	314.00	314.00
	Total variable energy			**2510.84**	**2510.84**
Fixed energy					
3.	**Seed**	40 kg	14.7 kg^{-1}	588.00	588.00
4.	**Seed treatment**				
	a. Azospirillum	100 g	99 kg^{-1}	9.9	9.9
	a. Labour for treatment	1 labour	1.96 hr^{-1}	15.68	15.68
5.	**Sowing**				
	a. Seed dril	2.5 hr (5 l hr^{-1})	56.31 litre^{-1}	703.86	703.86
	b. Labour for sowing	1 labour	1.96 hr^{-1}	15.68	15.68
6.	Fertilizer				
	a. Phosphorous	40 kg	17.4 kg^{-1}	696	696
	b. Potash	40 kg	13.7 kg^{-1}	548	548
	c. Labour for application	8 labour	1.96 hr^{-1}	125.44	125.44
7.	Gap filling	3 labour	1.96 hr^{-1}	47.04	47.04
8.	Irrigation				
	a. Electricity	136 KWh in 2016 and 170 KWh in 2017	11.93 kWh^{-1}	1616.28	2028.10
	b. Labour for irrigation	4 labour in 2016 and 5 labour in 2017	1.96 hr^{-1}	62.72	78.40
9.	harvesting	10 labour	1.57 hr^{-1}	125.60	125.60
10.	post-harvest	5 labour	1.96 hr^{-1}	78.40	78.40
	Total fixed Energy			**4632.60**	**5060.10**

APPENDIX XII: Variable input energy of nitrogen management in rice experiment during wet 2016 and 2017 (ha^{-1})

S. No.	Particulars	Input (ha^{-1})	Rate of energy (MJ)	Total energy (MJ ha^{-1})
1.	LCC based N (75%)	60 kg	78.1 kg^{-1}	4686
2.	LCC based N (100%)	80 kg	78.1 kg^{-1}	6248

APPENDIX XIII: Total input energy in rice experiment during wet 2016 and 2017 (ha^{-1})

S. N	Treat.	Fixed input energy (ha^{-1})		Treatments input energy (ha^{-1})						Total input energy (ha^{-1})	
				Tillage		Residue management		Nitrogen management			
		2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
1.	$T_1R_1N_1$	4632.60	5060.10	4009.00	4009.00	-	-	4686	4686	13327.60	13755.1
2.	$T_1R_1N_2$	4632.60	5060.10	4009.00	4009.00	-	-	6248	6248	14889.60	15317.1
3.	$T_1R_2N_1$	4632.60	5060.10	4009.00	4009.00	-	-	4686	4686	13327.60	13755.1
4.	$T_1R_2N_2$	4632.60	5060.10	4009.00	4009.00	-	-	6248	6248	14889.60	15317.1
5.	$T_1R_3N_1$	4632.60	5060.10	4009.00	4009.00	-	-	4686	4686	13327.60	13755.1
6.	$T_1R_3N_2$	4632.60	5060.10	4009.00	4009.00	-	-	6248	6248	14889.60	15317.1
7.	$T_2R_1N_1$	4632.60	5060.10	2510.84	2510.84	-	-	4686	4686	11829.44	12256.94
8.	$T_2R_1N_2$	4632.60	5060.10	2510.84	2510.84	-	-	6248	6248	13391.44	13818.94
9.	$T_2R_2N_1$	4632.60	5060.10	2510.84	2510.84	-	-	4686	4686	11829.44	12256.94
10	$T_2R_2N_2$	4632.60	5060.10	2510.84	2510.84	-	-	6248	6248	13391.44	13818.94
11	$T_2R_3N_1$	4632.60	5060.10	2510.84	2510.84	-	-	4686	4686	11829.44	12256.94
12	$T_2R_3N_2$	4632.60	5060.10	2510.84	2510.84	-	-	6248	6248	13391.44	13818.94

APPENDIX XIV: Variable and Fixed input energy in maize experiment during dry 2016-17 and 2017-18 (ha^{-1})

S. No.	Particulars	Input (ha^{-1})	Rate of energy (MJ)	Total energy ($MJ\ ha^{-1}$)	
				2016	2017
1.	**Land preparation**				
Variable input energy					
A.	**CT (DSR)**				
	a. Twice ploughing	6 hr (5 l hr^{-1})	56.31 $litre^{-1}$	1689.30	1689.30
	b. Rotavator	2.5 hr (5 l hr^{-1})	56.31 $litre^{-1}$	703.88	703.88
	c. Planking	1.5 hr (5 l hr^{-1})	56.31 $litre^{-1}$	422.33	422.33
2.	Weed management				
	a. Atrazine	2 kg	254.45 kg^{-1}	508.90	508.90
	c. Labour for application	1 labour	1.96 hr^{-1}	15.68	15.68
	d. Hand weeding	10 labour	1.57 hr^{-1}	125.60	125.60
	Total variable input energy			**3465.69**	**3465.69**
B.	**ZT (DSR)**				
	a. Weed management				
	1. Glyphosate	4.87 lit.	254.45 l^{-1}	1239.17	1239.17
	2. Atrazine	2 kg	254.45 kg^{-1}	508.90	508.90
	4. Labour for application	2 labour	1.96 hr^{-1}	31.36	31.36
	5. Hand weeding	15 labour	1.57 hr^{-1}	188.40	188.40
	Total variable input energy			**1967.83**	**1967.83**
Fixed input energy					
3.	**Seed**	20 kg	14.7 kg^{-1}	294.00	294.00
4.	**Sowing**				
	b. Labour for sowing	15 labour	1.57 hr^{-1}	188.40	188.40
6.	**Fertilizer**				
	a. Nitrogen	150 kg	78.1 kg^{-1}	11715	11715
	b. Phosphorous	50 kg	17.4 kg^{-1}	870	870
	c. Potash	50 kg	13.7 kg^{-1}	685	685
	c. Labour for application	6 labour	1.96 hr^{-1}	94.08	94.08
7.	**Gap filling**	3 labour	1.96 hr^{-1}	47.04	47.04
8.	**Irrigation**				
	a. Electricity	237 KWh in 2016-17 and 210 KWh in 2017-18	11.93 kWh^{-1}	2827.41	2505.30
	b. Labour for irrigation	7 labour in 2016 and 6 labour in 2017	1.96 hr^{-1}	109.76	94.08
9.	Harvesting	8 labour	1.57 hr^{-1}	100.48	100.48
10.	Post-harvest	3 labour	1.96 hr^{-1}	47.04	47.04
	Total fixed input energy			**16978.21**	**16640.42**

APPENDIX XV: Variable input energy of residue management in maize experiment during dry 2016-17 and 2017-18 (ha^{-1})

S. No.	Particulars	Input (ha^{-1})	Rate of energy (MJ)	Total energy (MJ ha^{-1})
1.	No residue	-	-	-
2.	Residue mulching (3 t ha^{-1})	3 t	12.5 kg^{-1}	37500
3.	Residue mulching (6 t ha^{-1})	6 t	12.5 kg^{-1}	75000

APPENDIX XVI: Total input energy in maize experiment during wet 2016-17 and 2017-18 (ha^{-1})

S. N	Treat.	Fixed input energy (ha^{-1})		Treatments input energy (ha^{-1})						Total input energy (ha^{-1})	
				Tillage		Residue management		Nitrogen management			
		2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
1.	$T_1R_1N_1$	16978.21	16640.42	3465.69	3465.69	-	-	-	-	20443.9	20106.11
2.	$T_1R_1N_2$	16978.21	16640.42	3465.69	3465.69	-	-	-	-	20443.9	20106.11
3.	$T_1R_2N_1$	16978.21	16640.42	3465.69	3465.69	37500	37500	-	-	57943.9	57606.11
4.	$T_1R_2N_2$	16978.21	16640.42	3465.69	3465.69	37500	37500	-	-	57943.9	57606.11
5.	$T_1R_3N_1$	16978.21	16640.42	3465.69	3465.69	75000	75000	-	-	95443.9	95106.11
6.	$T_1R_3N_2$	16978.21	16640.42	3465.69	3465.69	75000	75000	-	-	95443.9	95106.11
7.	$T_2R_1N_1$	16978.21	16640.42	1967.83	1967.83	-	-	-	-	18946.04	18608.25
8.	$T_2R_1N_2$	16978.21	16640.42	1967.83	1967.83	-	-	-	-	18946.04	18608.25
9.	$T_2R_2N_1$	16978.21	16640.42	1967.83	1967.83	37500	37500	-	-	56446.04	56108.25
10	$T_2R_2N_2$	16978.21	16640.42	1967.83	1967.83	37500	37500	-	-	56446.04	56108.25
11	$T_2R_3N_1$	16978.21	16640.42	1967.83	1967.83	75000	75000	-	-	93946.04	93608.25
12	$T_2R_3N_2$	16978.21	16640.42	1967.83	1967.83	75000	75000	-	-	93946.04	93608.25

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Effect of tillage, residue and residual of nitrogen management on protein yield, factor productivity and nutrient uptake by maize under rice - maize cropping system

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Abstract
Field experiment was conducted on effect of tiilage, residue and residual of nitrogen management practices at Institute Research Farm of ICAR – National Rice Research Institute, Cuttack (Odisha) during the rabi of 2016-17 and 2017-18 years. The experiment was laid out in split – split plot design with three replications. The results revealed that significantly higher nutrient uptake (N, P and K), partial factor productivity (nitrogen, phosphorus and potassium), protein yield and productivity of maize was recorded under treatment R_3 – RDF + residue mulching (6 t ha^{-1}) as compared R_1 – RDF + no residue, but protein content was found non – significant influence by different treatment of maize.

Keywords: Tillage, residue, protein yield, nutrient uptake and maize

Introduction
Rice – maize cropping system has become very dominant alternative for diversification under prevailing rice based cropping system in Asia. The drivers for substituting *Rabi* rice in rice based cropping system by maize comprise better suitability after harvest of long duration rice varieties with higher productive and profitable compared to the other *Rabi* season crops (Ali *et al*., 2009) [1]. Maize is an important cereal crop with various uses and known as 'Queen of Cereals Crop', being C_4 plant, high productive and requires less water, can be grown successfully under limited water resource conditions. Conventional maize planting results in extreme use of energy, which may constitute 25 – 30 per cent of total energy use in rice and maize cultivation (Sidhu *et al*., 2004) [9]. Further, achieving proper tilth for sowing maize after rice takes longer time. Hence, conservation tillage practices such as zero and minimum tillage are gaining more attention in recent years. Adoption of non-till helps in timeliness of sowing each in rotation, and hence leads to increase in productivity (Mohammad, 2009) [6]. The zero tillage for *rabi* maize may also help in advanced sowing, earlier crop emergence, less weed growth and use of residual soil moisture. During dry season in the coastal region temperature during the growth period does not go below 10 ^{0}C. Radiation is excellent and maize being a photo – insensitive crop has better option for adaption in the changing climatic scenario. In India, rice residue is produced huge quantities but farmers have no alternate uses of residue and usually disposed by burning because rice residue is reduce yield of succeeding crop due to poor plant population establishment and increase attack of pest and diseases (Singh *et al*., 2002) [10]. Crop residue is main input source of organic carbon under rice based cropping system and contributed to the increase in soil organic matter concentration, improvement hydrothermal regime and physical condition of soil (Jat *et al*., 2009) [5]. The aim of nutrient management to provide an adequate supply of all essential plant nutrients for a crop growth during the growing season and the amount of any nutrient is limiting at any time which is a potential for loss in crop yield. The LCC is an ideal and inexpensive tool to enhance nitrogen use in rice (Singh and Singh, 2003) [11]. Nitrogen fertilizer management through using LCC shade 3 as a threshold level resulted higher grain yield and enhance nitrogen use efficiency in direct seeded rice in North Western India (Singh *et al*., 2006) [12]. Hence, an investigation was carried out to know the effect of tillage, residue and residual of nitrogen management on protein yield and nutrient uptake by maize under rice – maize cropping system.

Material and Methods

The studies carried out at Institute Research Farm of ICAR – National Rice Research Institute, Cuttack (Odisha) during *rabi* 2016-17 and 2017-18 to know the effect of tillage, residue management and residual effect of nitrogen management in rice based cropping system. The experiment was laid out in split – split plot design with three replications. The experiment site was sandy loam soil in texture with acidic nature, medium available nitrogen, phosphorus and potassium content. The treatment includes, main plot consists of two tillage practices (T_1 – conventional tillage and T_2 – zero tillage), sub plot consists of three residue management [R_1 – RDF + no residue, R_2 – RDF + residue mulching (3 t ha^{-1}) and R_3 – RDF + residue mulching (6 t ha^{-1})] and sub – sub include of two residual of nitrogen management in rice [N_1 – LCC based (100 % RDN) and N_2 – LCC based (75 % RDN)]. The dose of fertilizers *i.e.* 150:50:50 kg ha^{-1} of nitrogen, phosphorus and potassium were applied in maize, respectively. Urea, single super phosphate and muriate of potash (MOP) were calculated and applied treatment wise. Half dose of nitrogen and full dose of phosphorus and potassium were applied as basal. Remaining half nitrogen was top dressed in two equal splits at knee height and tasseling stages. Irrigation was given immediately after sowing for ensure proper germination and plant stand. Irrigation was scheduled on basis of crop water requirement and duration of dry spell or period without rainfall and adequate drainage facility was provided by making drainage channel in the field. Partial factor productivity was obtained by dividing grain yield by the applied nutrient and production efficiency was calculated with the help of standard procedure given by Tomar and Tiwari (1990) [13]. The statistical analysis of data collected on different parameters of rice as described by Gomez and Gomez (1984) [4]. The protein content was computed by multiplying the respective nitrogen content of grain by the constant of 6.25 and then protein yield was worked out using the following formula:

Protein yield (kg ha^{-1}) = Grain yield (q ha^{-1}) × Protein content in grain

Results and discussion

Nutrient uptake (N, P and K)

The findings indicated that the effect of tillage practices in maize and residual of nitrogen management in rice did not have significant impact on N, P and K uptake by maize during 2016-17 and 2017-18 (Table 1). However, T_1 – conventional tillage (CT) and N_1 – LCC based (100 % RDN) recorded higher N, P and K uptake by maize in comparison to their respective treatments during 2016-17 and 2017-18. In case of the residue management in maize, treatment R_3 – RDF + residue mulching (6 t ha^{-1}) recorded significantly higher N, P and K uptake by maize as compared to treatment R_2 – RDF + residue mulching (3 t ha^{-1}) and R_1 – RDF + no residue during 2016-17 an 2017-18. The interaction among tillage practices in maize, residue management in maize and residual of nitrogen management in rice were found non – significant with respect to N, P and K uptake by maize during 2016-17 and 2018-19. This might be due to higher concentration of N, P and K in maize crop along with higher yield ultimately leads to higher uptake of nutrients (N, P and K), as uptake is derived by multiplication of nutrient concentration in grain and stover with respective yields. Singh *et al*. (1991) also noted higher nutrient uptake of N, P and K as an effect of mulching in winter maize. Nitrogen uptake was significantly higher with paddy straw and paddy husk mulching as compared to no mulch and improved the nitrogen use efficiency (Chakraborty *et al*., 2010) [3]. Shaheen *et al*. (2010) [8] also concluded that mulching gave statistically superior over no mulch with respect to total N and P uptake.

Partial factor productivity and production efficiency

The data on partial factor productivity of nitrogen, phosphorus and potassium as well as production efficiency of maize as influenced by tillage, residue management in maize and residual of nitrogen management in rice are presented in Table 2. The effect of tillage practices in maize and residual of nitrogen management in rice failed to give significant influence on partial factor productivity of nitrogen, phosphorus and potassium in maize as well as production efficiency of maize during both the years and on mean basis. However, T_1 – conventional tillage (CT) and N_1 – LCC based (100 % RDN) recorded higher partial factor productivity of nitrogen, phosphorus and potassium in maize as well as production efficiency of maize in comparison to their respective treatments during 2016-17 and 2017-18. Among the residue management in maize, treatment R_3 – RDF + residue mulching (6 t ha^{-1}) recorded higher partial factor productivity of nitrogen, phosphorus and potassium in maize as well as production efficiency of maize as compared to treatment R_1 – RDF + no residue, but it was at par to treatment R_2 – RDF + residue mulching (3 t ha^{-1}) during 2016-17 and 2017-18. The interaction effect of the tillage practices in maize, residue management in maize and residual of nitrogen management in rice remained unaffected with respect to partial factor productivity of nitrogen, phosphorus and potassium in maize as well as production efficiency of maize during 2016-17 and 2017-18. This might be due to higher leaf area index (LAI) and crop growth rate (CGR) as well as higher yield attributes and yields of maize. Pierre *et al*. (2008) [7] also reported that PFP of N, P and K decreased with increasing application rates of crop residue.

Protein content (%), protein yield (kg ha^{-1}) and protein productivity (kg ha^{-1} day^{-1})

The results revealed that the effect of tillage practices in maize and residual of nitrogen management in rice did not have significant impact on protein content in grain, protein yield and protein productivity of maize during 2016-17 and 2017-18 (Table 3). However, T_1 – conventional tillage (CT) and N_1 – LCC based (100 % RDN) recorded higher protein content, protein yield and protein productivity of maize in comparison to their respective treatments during 2016-17 and 2017-18. Among the residue management in maize, the significantly higher protein yield and protein productivity of maize were registered under treatment R_3 – RDF + residue mulching (6 t ha^{-1}) as compared to treatment R_2 – RDF + residue mulching (3 t ha^{-1}) and R_1 – RDF + no residue, whereas protein content in grain of maize was noted non – significantly during 2016-17 and 2017-18. The interaction among the tillage practices in maize, residue management in maize and residual of nitrogen management in rice were found non-significantly with respect to protein content in grain, protein yield and protein productivity of maize during 2016-17 and 2017-18. This might be due to more production of photosynthates in leaves and uptake of nutrient from soil and more availability of soil moisture under residue mulch, which kept proper water balance in the plant system, which might have resulted into efficient biochemical processes involved in the biosynthesis of protein content. Similar results were reported by Andrija *et al*. (2009) [2] and Zamir *et al.* (2013) [14].

Table 1: N, P and K uptake by maize (grain and stover) as influenced by tillage, residue and residual of nitrogen management

Treatment	N uptake (kg ha^{-1})		P uptake (kg ha^{-1})		K uptake (kg ha^{-1})	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Tillage						
RT$_1$: Conventional tillage (CT)	158.32	160.11	52.36	54.71	141.19	141.33
RT$_2$: Zero tillage (ZT)	154.36	154.76	50.48	52.28	136.83	137.61
SEm±	5.21	5.79	1.72	1.78	4.60	4.35
CD (P=0.05)	NS	NS	NS	NS	NS	NS
Residue management						
RR$_1$: RDF + No residue	137.69	139.89	44.37	46.24	128.13	128.69
RR$_2$: RDF + Residue mulching (3 t ha^{-1})	160.13	160.40	52.16	54.49	138.50	138.90
RR$_3$: RDF + Residue mulching (6 t ha^{-1})	171.21	172.01	57.73	59.75	150.39	150.82
SEm±	3.28	3.34	1.63	1.65	3.94	4.57
CD (P=0.05)	10.70	10.91	5.30	5.37	12.85	14.89
Residual of nitrogen management						
RN$_1$: LCC based (100 % RDN)	154.37	155.60	50.03	52.44	137.35	137.48
RN$_2$: LCC based (75 % RDN)	158.31	159.27	52.81	54.55	140.66	141.46
SEm±	4.12	4.09	1.29	1.31	3.31	2.79
CD (P=0.05)	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS

Table 2: Partial factor productivity and production efficiency of maize as influenced by tillage, residue and residual of nitrogen management

Treatment	"Partial factor productivity (kg kg^{-1})"						Production efficiency (kg ha^{-1} day^{-1})	
	Nitrogen		Phosphorus		Potassium			
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Tillage								
RT$_1$: Conventional tillage (CT)	20.65	20.72	21.55	21.62	80.83	81.07	64.14	64.33
RT$_2$: Zero tillage (ZT)	20.18	20.24	21.06	21.12	78.97	79.21	62.67	62.86
SEm±	0.41	0.45	0.44	0.47	1.76	1.83	1.49	1.54
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Residue management								
RR$_1$: RDF + No residue	17.28	17.34	18.03	18.10	67.63	67.87	53.67	53.86
RR$_2$: RDF + Residue mulching (3 t ha^{-1})	21.33	21.39	22.26	22.32	83.47	83.71	66.24	66.43
RR$_3$: RDF + Residue mulching (6 t ha^{-1})	22.64	22.70	23.63	23.69	88.60	88.84	70.31	70.50
SEm±	0.43	0.48	0.48	0.50	1.87	1.92	1.50	1.56
CD (P=0.05)	1.40	1.57	1.56	1.63	6.09	6.26	4.89	5.09
Residual of nitrogen management								
RN$_1$: LCC based (100 % RDN)	20.55	20.61	21.44	21.51	80.42	80.66	62.99	63.18
RN$_2$: LCC based (75 % RDN)	20.28	20.35	21.17	21.23	79.38	79.62	63.82	64.01
SEm±	0.32	0.37	0.36	0.39	1.46	1.53	1.14	1.16
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

Table 3: Protein content in grain, protein yield and protein productivity of maize as influenced by tillage, residue and residual of nitrogen management

Treatment	Protein content in grain (%)		Protein yield (kg ha^{-1})		Protein productivity (kg ha^{-1} day^{-1})	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Tillage						
RT$_1$: Conventional tillage (CT)	7.51	7.57	507.99	513.52	4.84	4.89
RT$_2$: Zero tillage (ZT)	7.44	7.47	490.00	493.68	4.67	4.70
SEm±	0.11	0.17	9.65	8.05	0.09	0.07
CD (P=0.05)	NS	NS	NS	NS	NS	NS
Residue management						
RR$_1$: RDF + No residue	7.32	7.46	413.49	423.82	3.94	4.04
RR$_2$: RDF + Residue mulching (3 t ha^{-1})	7.53	7.54	524.40	526.81	4.99	5.02
RR$_3$: RDF + Residue mulching (6 t ha^{-1})	7.57	7.57	559.10	560.16	5.32	5.33
SEm±	0.10	0.16	9.92	9.05	0.09	0.08
CD (P=0.05)	NS	NS	32.36	29.51	0.30	0.27
Residual of nitrogen management						
RN$_1$: LCC based (100 % RDN)	7.51	7.53	504.19	506.36	4.80	4.82
RN$_2$: LCC based (75 % RDN)	7.44	7.52	493.80	500.83	4.70	4.77
SEm±	0.09	0.13	7.96	6.67	0.07	0.06
CD (P=0.05)	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS

Conclusion

Residue management had positive effect on partial factor productivity, production efficiency, protein yield and productivity of maize as it enhanced protein production of maize. Among the residue management in maize, treatment R_3 – RDF + residue mulching (6 t ha^{-1}) registered significantly higher nutrient uptake, partial factor productivity of nitrogen, phosphorus and potassium, production efficiency, protein yield and protein productivity of maize as compared to other residue management practices.

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