

**EVALUATION OF WATER REGIMES AND
NUTRIENT MANAGEMENT ON RICE-RICE
CROPPING SYSTEM UNDER TRANSPLANTED AND
MODIFIED SYSTEM OF RICE INTENSIFICATION
(MoSRI)**

Ph.D. Thesis

by

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LEKH RAM SAHU

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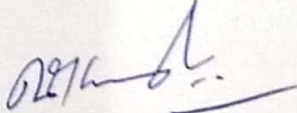
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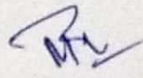
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CERTIFICATE - I

This is to certify that the thesis entitled "**Evaluation of water regimes and nutrient management on rice-rice cropping system under transplanted and modified system of rice intensification (MoSRI)**" 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 **Lekh Ram Sahu** under our guidance and supervision. The subject of the thesis has been approved by Student's Advisory Committee and the Director of Instructions.

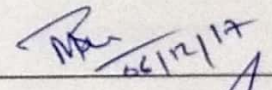
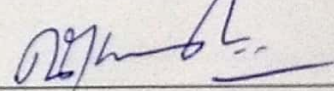
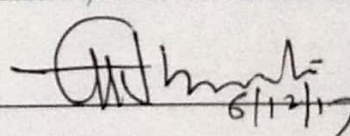
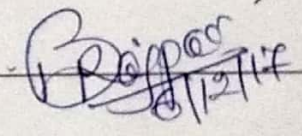
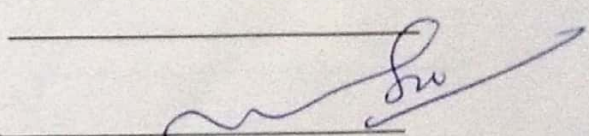
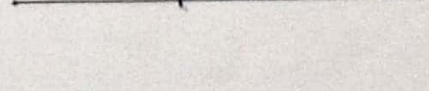
No part of the thesis has been submitted for any other degree or diploma (certificate awarded etc.) or has been published/published part has been fully acknowledged. All the assistance and help received during the course of the investigations have been duly acknowledged by him.


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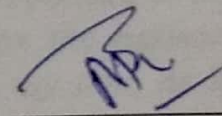
This is to certify that the thesis entitled “**Evaluation of water regimes and nutrient management on rice-rice cropping system under transplanted and modified system of rice intensification (MoSRI)**” submitted by **Lekh Ram Sahu** to the Indira Gandhi Krishi Vishwavidyalaya, Raipur, in partial fulfillment 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.

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Head of the Department

Faculty Dean

Approved/Not approved

Director of Instructions

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LIST OF ABBREVIATIONS

Abbreviations	Description	Abbreviations	Description
%	Per cent	LA	Leaf area
@	At the rate	LAI	Leaf area index
B:C	Benefit : cost	LAD	Leaf area duration
CD	Critical Difference	CGR	Crop growth rate
Day ⁻¹	Per day	RGR	Relative growth rate
t ha ⁻¹	Tonnes per hectare	SPAD	Soil plant analysis development
⁰ C	Degree Celsius	DF	Degree of freedom
DAT	Days after transplanting	SS	Sum of square
<i>et al.</i>	And others/ co-worker	MSS	Mean sum of square
Fig.	Figure	EMS	Error mean sum of square
g	Gram	<i>viz.</i>	Namely
ha	Hectare	₹ ha ⁻¹	Rupees per hectare
ha ⁻¹	Per hectare	<i>PE</i>	Panicle exertion
HI	Harvest index	N	Nitrogen
hr	Hours	P	Phosphorus Potassium
Hill ⁻¹	Per hill	K	Phosphate
<i>i.e.</i>	That is	P ₂ O ₅	Di-potassium oxide
kg	Kilogram	K ₂ O	Organic carbon
Kmph	Kilometer per hour	OC	Per year
cm	Centimeter	yr ⁻¹	Panicle initiation
cm ²	Centimeter square	PI	Per tiller
cm ³	Cubic centimeter	Tiller ⁻¹	Continuous flooding
mm	Milli metre	CF	Alternate wetting and drying
m	Metre	AWD	Perched water tube
max.	Maximum	PWT	Normal transplanting
min.	Minimum	NTP	Modified system of
m ⁻²	Per metre square	MoSRI	rice intensification
MJ	Mega joule		indigenous technology
GJ	Giga joule	ITK	knowledge
No.	Number	WUE	Water use efficiency
NS	Non-significant		
d.f.	Degree of freedom		
etc.	Etcetera		
q	Quintal		
t	tonne		

THESIS ABSTRACT

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- | | |
|---|---|
| a) Title of the Thesis: | Evaluation of water regimes and nutrient management on rice-rice cropping system under transplanted and modified system of rice intensification (MoSRI) |
| b) Full Name of the Student: | Lekh Ram Sahu |
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ABSTRACT

Present investigation entitled **“Evaluation of water regimes and nutrient management on rice-rice cropping system under transplanted and modified system of rice intensification (MoSRI)”** was conducted for consecutive seasons of *kharif* and *rabi* 2015-16 and 2016-17 at the ICAR-Indian Institute of Rice Research, Rajendranagar, Hyderabad (Telangana). The soil of the experimental field was clayey in texture (*Vertisols*) and was near neutral (7.8 ± 0.05) in reaction. The available nitrogen, phosphorus and potassium content were low, high and high, respectively. The climate of the region is semi-arid with an average rainfall of 900 mm year⁻¹. The crop received 331.5, 177.2, 785.9 and 16.4 mm rainfall during crop period of *kharif* 2015, *rabi* 2015-16, *kharif* 2016 and *rabi* 2016-17, respectively. Treatments

comprised of two establishment methods viz. normal transplanting (M_1) and modified system of rice intensification (M_2); three irrigation regimes viz. saturation (I_1), 5 cm water level depletion in perched water tube from soil surface (I_2) and 10 cm water level depletion in perched water tube from soil surface (I_3); and three nutrient levels viz. 100% RDN through inorganic (N_1), 125% RDN through inorganic (N_2) and 50% inorganic + 50% organic (based on % nitrogen content) (N_3). The treatments were replicated thrice. Rice variety 'DRR Dhan 42' was taken as test crop during the course of investigation. Influence of above treatments was studied and their effect on growth behavior and other parameters like yield attributes, yield, soil nutrient availability, nutrient uptake, quality, economics and energetics were assessed and analyzed.

Result of the experiment on growth parameters of rice i.e. number of tillers hill⁻¹, number of leaves hill⁻¹, leaf area, dry matter accumulation, root length and root volume were recorded highest under modified SRI. However, leaf area index and leaf area duration were recorded higher under normal transplanting during both the seasons and years. Days to 50% panicle exertion and days to 50% flowering were longer in normal transplanting over modified SRI. Modified SRI recorded significantly higher yield parameters of rice viz. number of panicles hill⁻¹ (143.48 and 153.94 %, in *kharif* and *rabi* mean respectively), panicle weight, panicle length and grains panicle⁻¹. However, establishment methods showed no significant differences for number of panicles (m⁻²), test weight, sterility percentage and harvest index. Normal transplanting method of establishment managed to produce 9.85 and 8.13 %, increase in grain yield during *kharif* and *rabi* seasons, respectively (mean data) but the differences were non-significant. Similarly, the straw yield was increased by 9.14 and 8.80 %, in *kharif* and *rabi* respectively over modified SRI.

Influence of establishment methods on uptake of N, P and K by both grain and straw; available soil N, P and K in rice after harvest, hulling percentage, milling percentage and head rice recovery in rice was found non-significant. The amount of irrigation water applied was 32.94 and 21.50 %, more in *kharif* and *rabi* season respectively, total water applied (19.88 and 21.20 % higher, in *kharif* and *rabi* mean respectively) and irrigation water productivity (6.74 and 5.56 %, higher in *kharif* and

rabi mean respectively) were found higher under normal transplanting over modified SRI. However, effective rainfall recorded during both the *kharif* seasons of both the years was found higher under modified SRI over normal transplanting.

Modified SRI method of rice establishment recorded lower cost of cultivation, net return (4.90 and 7.95 %, in *kharif* and *rabi* mean respectively) and energy input (4.58 and 4.23 %, in *kharif* and *rabi* mean respectively) as compared to normal transplanting. However, under method of establishments, MoSRI recorded higher value of B:C ratio (2.10 and 1.83 in *kharif* and *rabi* mean respectively) and energy intensity (4.21 and 3.74 MJ ₹⁻¹ in *kharif* and *rabi* mean respectively) were recorded as compared to normal transplanting.

Among water regimes, significantly higher growth parameters of rice *i.e.* number of tillers hill⁻¹, number of leaves hill⁻¹, leaf area, leaf area index, leaf area duration and dry matter accumulation and yield parameters *viz.* number of panicles (in both, m⁻² and hill⁻¹), grains panicle⁻¹ and panicle weight were recorded significantly higher under saturation throughout lifecycle over irrigation at 10 cm water level depletion in perched water tube from soil surface. The days to 50% panicle exertion and days to 50% flowering were longer under saturation throughout lifecycle. However, root length and root volume were recorded significantly superior under 10 cm water level depletion in perched water tube from soil surface at all the growth stages except at 30 DAT. Sterility percentage was lower under saturation throughout lifecycle of crop as compared to other water regimes during both the seasons and years. Water regime of saturation throughout lifecycle of crop produced 12.25 and 14.14 %, higher grain yield during *kharif* and *rabi* (mean data), respectively and 10.48 and 13.96 % higher straw yield over water regime of irrigation at 10 cm water level depletion in perched water tube from soil surface.

Amongst water regimes, the uptake of N and K by grain, straw and total uptake was found significantly higher under saturation throughout lifecycle of crop and was found on par with irrigation at 5 cm water level depletion in perched water tube from soil surface. However uptake of P by grain, straw and total uptake were found on par under different irrigation regimes, Also available soil N, P and K in rice after harvest of each rice crop irrespective of season and

quality parameters (hulling percentage, milling percentage and head rice recovery) during both the *kharif* seasons showed non-significant differences towards water regimes. However, during *rabi* seasons of both the years, significantly higher quality parameters (hulling percentage milling percentage and head rice recovery) were recorded under water regime of saturation throughout lifecycle of crop. Similarly, irrigation water applied was 24.77 and 21.75 %, higher in *kharif* and *rabi* (mean data), respectively and total water applied was 16.58 and 19.86 %, higher in *kharif* and *rabi* (mean data), respectively under saturation throughout lifecycle. With respect to economic returns, water regimes of saturation throughout lifecycle recorded higher cost of cultivation, net return (21.07 and 26.68 %, in *kharif* and *rabi* mean respectively), B:C ratio (10.88 and 10.52 %, in *kharif* and *rabi* mean respectively), energy output : input ratio (14.71 and 2.91 %, in *kharif* and *rabi* mean data), and energy intensity in economic terms (9.07 and 7.75 %, in *kharif* and *rabi* mean data) over water regime of irrigation at 5 cm water level depletion in perched water tube from soil surface during both the seasons and years.

Nutrient levels, did not indicate any significant variation on growth parameters *i.e.* number of leaves hill⁻¹, although numerically higher number of tillers, number of leaves, leaf area, leaf area index, leaf area duration, SPAD value, dry matter accumulation; yield parameters *i.e.* number of panicles (m⁻² and hill⁻¹), panicle length, panicle weight and number of grains panicle⁻¹; grain and straw yield were observed under 125% RDN through inorganic sources at all the observational stages and was followed by 100% RDN through inorganic sources. Also, 125% RDN through inorganic sources gave higher gross return (79,885 and 75,101 ₹ ha⁻¹ in *kharif* and *rabi* mean respectively), net return (44,211 and 37,334 ₹ ha⁻¹ in *kharif* and *rabi* mean respectively), B:C ratio (2.24 and 1.99 in *kharif* and *rabi* mean respectively), gross energy output (158.8 and 158.4 GJ ha⁻¹ in *kharif* and *rabi* mean respectively), net energy output (149.4 and 147.3 GJ ha⁻¹ in *kharif* and *rabi* mean respectively) and energy intensity in economic terms (4.54 and 4.21 MJ ₹⁻¹ in *kharif* and *rabi* mean data) over other nutrient levels.

As regards to interaction effect between establishment methods, irrigation regimes and nitrogen levels, higher cost of cultivation was recorded under normal transplanting x saturation throughout lifecycle of crop x 50% RDN through inorganic + 50% through organic source. Highest gross return, net return, energy input and energy output was obtained under normal transplanting x saturation throughout lifecycle of crop x 125% RDN through inorganic. However, higher B:C ratio was found under modified SRI x irrigation at 5 cm water level depletion in perched water tube from soil surface x 125% RDN through inorganic.

थीसिस सारांश

ए) थीसिस का शीर्षक	धान—धान फसल पद्धति पर जल स्तर एवं पोषकतत्व प्रबंधन का रोपित एवं धान की सघनीकरण की संशोधित पद्धति के अंतर्गत मूल्यांकन
बी) छात्र का पूरा नाम	लेख राम साहू
सी) प्रमुख विषय	सस्य विज्ञान
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ई) डिग्री से सम्मानित किया जाना है	कृषि में पी एच डी

छात्र के हस्ताक्षर

प्रमुख सलाहकार के हस्ताक्षर

तारीख

विभागाध्यक्ष के हस्ताक्षर

सारांश

वर्तमान शोधकार्य शीर्षक “धान—धान फसल पद्धति पर जल स्तर एवं पोषकतत्व प्रबंधन का रोपित एवं धान की सघनीकरण की संशोधित पद्धति के अंतर्गत मूल्यांकन” पर वर्ष २०१५-१६ एवं २०१६-१७ को लगातार खरीफ एवं रबी मौसम में भारतीय कृषि अनुसंधान संस्थान — भारतीय चावल अनुसंधान संस्थान राजेंद्र नगर, हैदराबाद में आयोजित किया गया । प्रायोगिक क्षेत्र की मृदा प्रकृति में चिकनी (वर्टिसोल) तथा प्रतिक्रिया में लगभग उदासीन था । उपलब्ध नत्रजन, स्फुर तथा पोटैश की मात्रा क्रमशः कम, अधिक तथा अधिक था । क्षेत्र की जलवायु अर्ध शुष्क तथा औसत वर्षा १०० मि. मी. प्रतिवर्ष है । फसल अवधि के दौरान खरीफ २०१५, रबी २०१५-१६, खरीफ २०१६ तथा रबी २०१६-१७ में फसल को क्रमशः १३१.५, १७७.२, ७८५.६ तथा १६.४ मि. मी. वर्षा की प्राप्ति हुई । उपचार में दो स्थापना विधियों यथा: सामान्य रोपण (वि. १) तथा धान की सघनीकरण की संशोधित पद्धति (वि. २); तीन जल स्तर नियम

यथा: संतृप्त (सिं. १), मृदा सतह से खड़ी जल ट्यूब में ५ से मी जल स्तर अवक्षय (सिं. २) तथा मृदा सतह से खड़ी जल ट्यूब में १० से मी जल स्तर अवक्षय (सिं. ३); तथा तीन पोषकतत्त्व स्तर यथा: पोषक तत्व की अनुशंसित खुराक का १०० प्रतिशत अकार्बनिक के द्वारा (मा. १), पोषक तत्व की अनुशंसित खुराक का १२५ प्रतिशत अकार्बनिक के द्वारा (मा. २) तथा पोषक तत्व ५० प्रतिशत अकार्बनिक के द्वारा ५० प्रतिशत अकार्बनिक (मा. ३) सम्मिलित थे । परिक्षण के दौरान धान की 'डी आर आर धान ४२' किस्म को परिक्षण फसल के रूप में उपयोग किया गया । वृद्धि आचरण तथा अन्य मापदंड जैसे उत्पादन लक्षण, उपज, मृदा पोषक तत्व उपलब्धता, पोषक तत्त्व, अंतर्ग्रहण, गुणवत्ता मापदंड, आर्थिक एवं ऊर्जा प्राप्ति पर उल्लेखित उपचारों के प्रभाव का अध्ययन किया गया और उनका आकलन कर उसका विश्लेषण किया गया ।

परीक्षण से प्राप्त वृद्धि कारकों के मापदंड जोकि हैं, कल्लो की संख्या प्रति पौधस्थान, पत्ती की संख्या प्रति पौधस्थान, पर्ण क्षेत्र, शुष्क भार संचयन, जड़ की लम्बाई तथा जड़ के आयतन के मान, धान की सघनीकरण की संशोधित पद्धति में अधिकतम पायी गयी । यद्यपि, पर्ण क्षेत्र सूचकांक एवं पर्ण क्षेत्र अवधि के मान सामान्य रोपण के अंतर्गत दोनों मौसमों एवं सालों में सामान्य रोपण में दर्ज किया गया । साथ ही ५० प्रतिशत बालि निकलने की अवस्था के दिनों तथा ५० प्रतिशत पुष्प निकलने की अवस्था के दिनों की संख्या सामान्य रोपण विधि में धान की सघनीकरण की संशोधित पद्धति से अधिक अवधि की पायी गयी । धान की सघनीकरण की संशोधित पद्धति के अंतर्गत उपज मापदंडों यथा: बालियों की संख्या प्रति पौध स्थान (143.48 एवं 153.94 प्रतिशत, खरीफ एवं रबी के औसत में क्रमशः), बाली का भार (4.93 एवं 5.02 प्रतिशत, खरीफ एवं रबी के औसत में क्रमशः), बाली की लम्बाई (24.93 एवं 26.20 प्रतिशत, खरीफ एवं रबी के औसत में क्रमशः), तथा अनाज के दानों की संख्या (प्रति बाली) का मान सामान्य रोपण विधि से सार्थक रूप से अधिक पाया गया । यद्यपि, स्थापना विधियों का बालियों की संख्या (प्रति वर्ग मी), परिक्षण भार, बाँझपन की प्रतिशत्ता एवं उपज सूचकांक पर कोई प्रभाव नहीं पाया गया । अनाज तथा पुवाल उत्पादन में फसल स्थापन की सामान्य रोपण विधि (9.85 एवं 8.13 प्रतिशत अनाज में; 9.14 एवं 8.80 प्रतिशत पुवाल में, खरीफ एवं रबी के औसत में क्रमशः) द्वारा धान के सघनीकरण की संशोधित पद्धति के ऊपर दोनों वर्षों की दौरान तथा औसत आधार पर गैर-सार्थक रूप से अधिक पाया गया ।

अनाज एवं पुवाल तथा पौधे द्वारा कुल नत्रजन स्फुर तथा पोटाश के अंतर्ग्रहण, मृदा में पोषक तत्वों उपलब्धता, छिलका उतारने की प्रतिशत्ता, गहनता की प्रतिशत्ता एवं पूर्ण

चौवल की प्राप्ति का मान दोनों मौसमों एवं वर्षों में गैर-सार्थक पाया गया । सामान्य रोपण विधि में सिंचाई द्वारा जल का प्रयोग (32.94 एवं 21.50 प्रतिशत, खरीफ एवं रबी के औसत में क्रमशः), कुल जल प्रयोग (19.88 एवं 21.20 प्रतिशत, खरीफ एवं रबी के औसत में क्रमशः) एवं सिंचाई जल उत्पादकता (6.74 एवं 5.56 प्रतिशत, खरीफ एवं रबी के औसत में क्रमशः) का मान धान की सघनीकरण की संशोधित पद्धति से दोनों मौसम एवं साल में अधिक पाया गया । यद्यपि प्रभावकारी वर्षा का मान दोनों वर्षों के खरीफ मौसम में धान के सघनीकरण की संशोधित पद्धति (8.06 प्रतिशत, खरीफ के औसत में) में सामान्य रोपण विधि से अधिक पाया गया । खेती की कुल लागत (15.35 एवं 4.78 प्रतिशत, खरीफ एवं रबी के औसत में क्रमशः), सकल लाभ (9.97 एवं 11.33 प्रतिशत, खरीफ एवं रबी के औसत में क्रमशः), शुद्ध लाभ (4.90 एवं 7.95 प्रतिशत, खरीफ एवं रबी के औसत में क्रमशः), उर्जा निवेश (4.58 एवं 4.23 प्रतिशत, खरीफ एवं रबी के औसत में क्रमशः), उर्जा उत्पादन (14.20 एवं 13.70 प्रतिशत, खरीफ एवं रबी के औसत में क्रमशः), उर्जा उत्पादन : लागत अनुपात (4.18 एवं 3.70 प्रतिशत, खरीफ एवं रबी के औसत में क्रमशः), उर्जा उत्पादकता (4.05 एवं 2.85 प्रतिशत, खरीफ एवं रबी के औसत में क्रमशः) एवं शुद्ध उर्जा (10.08 एवं 8.62 प्रतिशत, खरीफ एवं रबी के औसत में क्रमशः) का मान सामान्य रोपण में धान के सघनीकरण की संशोधित पद्धति से दोनों वर्षों के दोनों मौसम में अधिक पाया गया । यद्यपि लाभ : लागत अनुपात (5.24 एवं 2.81 प्रतिशत, खरीफ एवं रबी के औसत में क्रमशः) तथा आर्थिक दृष्टि से उर्जा गहनता (4.46 एवं 5.88 प्रतिशत, खरीफ एवं रबी के औसत में क्रमशः) में धान की सघनीकरण की संशोधित पद्धति के अंतर्गत दोनों मौसम एवं वर्षों जांच के दौरान अधिक पाया गया ।

जल स्तर के संबंध में सार्थक रूप से अधिक धान के वृद्धि मापदण्ड जिनमें कल्लों की संख्या प्रति पौध स्थान, पत्तियों की संख्या प्रति पौध स्थान, पर्ण क्षेत्रफल, पर्ण क्षेत्र सुचकांक, वर्ण क्षेत्र अवधि तथा शुष्क भार संचयन एवं उपज मापदण्ड में यथा: बालियों की संख्या { (14.24 एवं 14.28 प्रतिशत, खरीफ एवं रबी के औसत में क्रमशः) प्रति वर्ग मीटर तथा प्रति पौध स्थान}, अनाज की संख्या प्रति बाली (10.08 एवं 11.83 प्रतिशत, खरीफ एवं रबी के औसत में क्रमशः) एवं बाली का भार (10.00 एवं 12.12 प्रतिशत, खरीफ एवं रबी के औसत में क्रमशः) का मान सार्थक रूप से जीवन पर्यन्त संतृप्त फसल उपचार में मृदा सतह से खड़ी जल ट्यूब में 5 सेमी. तथा 10 सेमी. जल स्तर अवक्षय में दोनों मौसम एवं वर्षों में अधिक पाया गया । 50 प्रतिशत बालि निकलने की अवस्था के दिन (1.18 एवं 4.17 प्रतिशत, खरीफ एवं रबी के औसत में क्रमशः) तथा 50 प्रतिशत पुष्प निकलने की अवस्था के दिन (1.23 एवं 3.35 प्रतिशत, खरीफ एवं रबी के औसत में क्रमशः) की संख्या जीवन पर्यंत सन्तृष्ट फसल उपचार में अधिक पाया गया । यद्यपि जड़ की लंबाई तथा जड़ का आयतन का मान मृदा सतह से खड़ी जल ट्यूब

मे 10 सेमी. जल स्तर अवक्षय उपचार में दोनों मौसम एवं दोनों वर्षों के रोपाई के 30 दिन को छोड़कर सभी वृद्धि अवस्था में अधिक पाया गया। बॉछपन की प्रतिशत का मान जीवन पर्यन्त संतृप्त फसल उपचार (14.68 एवं 22.81 प्रतिशत, खरीफ एवं रबी के औसत में क्रमशः) में निम्नतम पाया गया। सार्थक रूप से अधिक अनाज (12.25 एवं 14.14 प्रतिशत, खरीफ एवं रबी के औसत में क्रमशः) एवं पुवाल (10.48 एवं 13.96 प्रतिशत, खरीफ एवं रबी के औसत में क्रमशः) उत्पादन का मान जीवन पर्यन्त संतृप्त फसल उपचार में पाया गया तथा यह मान मृदा सतह से खड़ी जल ट्यूब में 5 सेमी. जल स्तर उपक्षय उपचार में समतुल्य पाया गया।

जल स्तर के संबंध में नत्रजन एवं पोटाश का अनाज (8.72 एवं 12.17 प्रतिशत नत्रजन; 10.29 एवं 14.23 प्रतिशत पोटाश, खरीफ एवं रबी के औसत में क्रमशः), पुवाल (14.93 एवं 19.43 प्रतिशत नत्रजन; 12.20 एवं 18.03 प्रतिशत पोटाश, खरीफ एवं रबी के औसत में क्रमशः) एवं कुल (7.56 एवं 15.66 प्रतिशत नत्रजन; 11.88 एवं 22.40 प्रतिशत पोटाश, खरीफ एवं रबी के औसत में क्रमशः) अर्न्तग्रहण का मान जीवन पर्यन्त संतृप्त फसल उपचार में सार्थक रूप से अधिक पाया गया, साथ ही इसका मान मृदा सतह से खड़ी जल ट्यूब के 5 सेमी. जल स्तर उपचार में समतुल्य पाया गया। स्फुर अर्न्तग्रहण तथा धान फसल के कटाई के बाद मृदा में नत्रजन स्फुर एवं पोटाश की उपलब्धता जल स्तर के सम्बंध में दोनों वर्षों के गैर सार्थक पाया गया। गुणवत्ता मापदण्ड के सम्बंध में दोनों वर्षों के खरीफ मौसम में गैर-सार्थक पाया गया। परन्तु दोनों वर्षों के रबी मौसम में गुणवत्ता मापदण्ड {छिलका उतारने की प्रतिशतता (2.25 प्रतिशत रबी के औसत में), गाहना की प्रतिशतता (2.50 प्रतिशत रबी के औसत में) एवं पूर्ण चावल की प्राप्ति (2.60 प्रतिशत रबी के औसत में)} जीवन पर्यन्त संतृप्त फसल उपचार में सार्थक रूप से अधिक पाया गया। सिंचाई द्वारा जल प्रयोग (24.77 एवं 21.75 प्रतिशत, खरीफ एवं रबी के औसत में क्रमशः) तथा कुल जल के प्रयोग (16.58 एवं 19.86 प्रतिशत, खरीफ एवं रबी के औसत में क्रमशः) कि मात्रा दोनों मौसमों के दोनों वर्षों में उच्चतर मान जीवन पर्यन्त संतृप्त फसल उपचार में पाया गया था। आर्थिक एवं उर्जा प्राप्ति के संबंध में उच्चतम खेती की लागत (2.26 एवं 4.56 प्रतिशत, खरीफ एवं रबी के औसत में क्रमशः), सकल लाभ (12.14 एवं 13.88 प्रतिशत, खरीफ एवं रबी के औसत में क्रमशः), शुद्ध लाभ (21.07 एवं 26.68 प्रतिशत, खरीफ एवं रबी के औसत में क्रमशः), लाभ : लागत अनुपात (10.88 एवं 10.52 प्रतिशत, खरीफ एवं रबी के औसत में क्रमशः), उर्जा निवेश (6.41 एवं 9.38 प्रतिशत, खरीफ एवं रबी के औसत में क्रमशः), उर्जा उत्पादन (11.52 एवं 12.05 प्रतिशत, खरीफ एवं रबी के औसत में क्रमशः), उर्जा उत्पादन : निवेश अनुपात (4.71 एवं 2.91 प्रतिशत, खरीफ एवं रबी के औसत में क्रमशः), उर्जा उत्पादकता (5.19 एवं 2.85 प्रतिशत, खरीफ एवं रबी के औसत में क्रमशः), शुद्ध उर्जा (12.04 एवं 12.35 प्रतिशत, खरीफ एवं रबी के औसत में क्रमशः) एवं आर्थिक स्वरूप में उर्जा गहनता (9.07 एवं 7.75 प्रतिशत, खरीफ एवं रबी के औसत में क्रमशः) के उच्चतम मान की प्राप्ति दोनों मौसमों के दोनों वर्षों में जीवन पर्यन्त संतृप्त फसल उपचार में की गई।

पोषक तत्व के स्तरों के संबंध में वृद्धि कारक मापदंडों जिनमें कल्लो की संख्या प्रति पौध स्थान और शुष्क भार संकलन में सार्थक रूप से, एवं पत्तियों की संख्या प्रति पौध

स्थान, पर्ण क्षेत्र, पर्ण क्षेत्र सुचकांक, पर्ण क्षेत्र अवधि, जड. की लंबाई एवं जड. का आयतन में गैर सार्थक रूप में तथा उपज मापदंडों में बालियों की संख्या (प्रति वर्ग मीटर तथा प्रति पौध स्थान दोनों में), बाली की लंबाई, बाली का वजन तथा बालियों की संख्या एवं अनाज तथा पुवाल की उपज का मान गैर सार्थक रूप से 125 प्रतिशत पोषकतत्व की अनुशंसित मात्रा में दोनों मौसम एवं वर्षों में प्राप्त की गई ।

स्थापना विधि, जल स्तर तथा पोषकतत्व के पारस्परिक प्रभाव के संबंध में खेती की उच्चतम लागत सामान्य रोपण के साथ जीवन पर्यन्त संतृप्त फसल के साथ 50 प्रतिशत अकार्बनिक 50 प्रतिशत कार्बनिक में पाया गया। उच्चतम सकल उत्पाद, शुद्ध लाभ, उर्जा निवेश तथा उर्जा उत्पादन का मान सामान्य रोपण के साथ जीवन पर्यन्त के साथ 125 प्रतिशत पोषक तत्व की अनुशंसित मात्रा में पाया गया है। यद्यपि उच्चतम लाभ : लागत अनुपात तथा आर्थिक स्वरूप में उर्जा गहनता का मान धान की सघनीकरण की संशोधित पद्धति के साथ मृदा सतह से खड़ी जल ट्यूब में 5 सेमी जल स्तर अवक्षय के साथ 125 प्रतिशत पोषक तत्व की अनुशंसित मात्रा में पाया गया है।

CHAPTER-I INTRODUCTION

Annual food grain production has been gradually increasing every year with the estimated global paddy production in 2017 is set at of 758.9 million tonnes (503.8 million tonnes, milled basis) (Anonymous, 2017). Rice is the most important crop of India and occupies an area of 43.85 M ha out of total cropped area of 194.40 M ha (*kharif* and *rabi* both) with an annual production of 104.80 Mt at a productivity of 2.39 t ha⁻¹ (Anonymous, 2016a). All India index number of rice during 2014-15 was estimated as 100.14, 111.55 and 111.40 for area, production and productivity, respectively, considering 1993-94 as base year (Anonymous, 2016b). Newly formed Telangana State of India accounts for 1.42 M ha (26.62 % of total cropped area of state) area under rice producing about 4.54 Mt with an average rice productivity of 3.21 t ha⁻¹ (Anonymous, 2016c). Rice is cultivated by different methods, among them conventional method is the most predominant and under traditional method of irrigation, which not only consumes more water, but also causes severe wastage of water and nutrients. Thus leads to nutrient losses, degradation of land and causes environmental pollution by emitting more methane under anaerobic condition.

In order to tackle the problem of water scarcity and methane emission, a number of advanced methods of rice cultivation and other agronomic practices have been developed (Naik *et al.*, 2015). India needs to double its agricultural productivity by 2040 to reduce supply and demand gap. Hence, increasing the food grain production has become a challenge because of diminishing per capita arable land and availability of irrigation water resources and expanding abiotic and biotic stresses under climate change/variability. At the same time, huge yield gap (>50%) between attainable and actual farmers yield in many parts of the country including eastern India offers the scope for meeting the challenge. Further, high agricultural output also requires better storage and logistics support as the loss due to improper storage, handling and transportation of food grain is as high as 25-35%. Increasing food grain productivity and minimizing post-harvest losses can be

possible through implementation of scientific production and processing technologies in farmers' field (Bhadoria, 2016).

The food demand in the year 2000 was 192 million tonnes (MT) and by 2030 it will be around 335 MT (Bhadoria, 2016). In 2014, the population of undernourished people was around 190 million. Climate change, diversion of arable lands to urbanization, industrialization and bio-fuel production has aggravated the food crisis. Further, NFSA 'an act to provide food and nutritional security in human life cycle approach, by ensuring access to adequate quantity of quality food at affordable prices to people to live a life with dignity and for matters connected therewith or incidental thereto' (Anonymous, 2013) is aimed to provide subsidized food to two-third of the 1.2 billion population of the country. To meet with the demand and address the various issues, there is a need to increase food grain productivity with development of sustainable low cost technology and minimize the loss of grains during processing and storage by creating required infrastructure and appropriate technologies.

Globally agricultural activities consumes 69 per cent of the available total fresh water resources followed by industry (23 %) and domestic activities (8 %) (Dhiman *et al.*, 2015). Agriculture, comprised of crops, livestock, fisheries, aquaculture and forestry, is both a cause and a casualty of water scarcity. Climate change also affects freshwater resources negatively, in terms of both quantity and quality. More frequent and severe droughts are having an impact on agricultural production, while rising temperatures translate into increased crop water demand. Water withdrawals grew at almost twice the rate of population increase in the twentieth century, and a 60 per cent surge in food demand is expected by 2050. In European countries water diverted to agriculture is lower (33 %) as compared to industry (54 %) due to favourable climate. In India, the scenario is much different from both the global and European trends with as much as 83 per cent of total fresh water is consumed by agriculture followed by industry (12 %) and domestic activities (5 %), although the demand for latter two activities is projected to increase in coming decades due to fast paced economic growth, industrialization, urbanization and improved income of burgeoning population. In India the situation is highly precarious as the per capita availability of water has declined drastically in the last six decades i.e.,

from 5200 m³ in 1950 to 1700 m³ by 2009 and is expected to drop down further to 1000 m³ by 2050 (Dhiman *et al.*, 2015). There is an urgent need, therefore, to address water scarcity. For each 1°C hike in temperature global warming, 7 per cent of global population will see a decrease of 20 per cent or more in renewable water resources.

Irrigated agriculture contributes 40 per cent of global crop production in 20 per cent of total cultivated land. As much as 84 per cent of the economic impact of drought falls on agriculture, with major impacts on food security (Anonymous, 2016e). Rice is the most important staple crop in Asia, providing on an average 32% of total calorie uptake (MacLean *et al.*, 2002). Rice consumption worldwide was 581 Mt in 2015 as against a consumption of 531 Mt in 2005 (Prasad, 2011). To meet the global rice demand, it is estimated that about 114 Mt of additional milled rice need to be produced by 2035, which is equivalent to an overall increase of 26% in the next 25 years (Kumar and Ladha, 2011).

Traditionally, rice have been grown under inundated conditions in most parts of the world. Farmers generally construct bunds around their fields to retain water. They maintain a layer of water 5 to 15 cm deep on their fields during the cropping season, except for a week or two before the harvest, when the water is drained off the fields to facilitate ripening. Such use of water for growing rice is about two to five times greater than for the production of most other cereals. In India, the current scientific recommendation from the ICAR-Indian Institute of Rice Research, Hyderabad is to apply irrigation water up to a depth of 5 cm after the previously ponded water has disappeared from the field, being absorbed into the soil or evaporating (Kumar *et al.*, 2011). It is common practice, however, that most farmers keep their fields continuously flooded during the entire period of crop growth, which is unnecessary and wasteful. Inefficient water use not only increases cost of irrigation, but declines the water table, increases arsenic contamination and may emit the greenhouse gases from submerged rice field that lead to climate change in the world (Wang *et al.*, 1998).

Contrary to common belief, rice plants are not aquatic and do not perform best under flooded conditions, as stated by Datta (1981). Plants require water for growth but excess water that occurs during submergence or waterlogging is

harmful or even lethal. A submerged plant is defined as “a plant standing in water with at least part of the terminal above the water or completely covered with water” (Catling, 1992). Submergence subjects plants to the stresses of low light, limited gas diffusion, effusion of soil nutrients, mechanical damage, and increased susceptibility to pests and diseases (Greenway and Setter, 1996). It appears that rice developed as an upland plant, but was better able than other plants to adapt to inundated lowland, soil conditions. This adaptation was accomplished by rice plants forming air pockets (aerenchyma) in the cortex of their roots to facilitate the passage of oxygen below the soil's surface. Rice handles waterlogging stress by forming lysigenous aerenchyma and a barrier to radial O_2 loss (ROL) in roots in order to supply O_2 to the root tip (Nishiuchi *et al.*, 2012). While rice plants can survive under hypoxic soil conditions, they do not necessarily grow best under these conditions with no oxygen. While a number of technologies for rice production can save water and improve water productivity, these gains are usually achieved at the expense of yield (Bouman *et al.* 2007). It remains to be seen to what extent water productivity can be improved without compromising the productivity of land, labor and other production inputs. One method for reducing the application of water in paddy fields is called alternate wetting and drying (AWD), where fields, at least their surfaces, are allowed to dry out between irrigation issues through processes of evapotranspiration.

In alternate wetting and drying (AWD), irrigation water is applied to obtain flooded conditions after a certain number of days have passed after the disappearance of ponded water. The number of days of non-flooded soil in AWD before irrigation is applied can vary from 1 day to more than 10 days. Though some researchers have reported a yield increase using AWD (Zhang and Song 1989, Stoop *et al.*, 2002), recent work indicates that this is the exception rather than the rule (Belder *et al.*, 2004; Cabangon *et al.*, 2004 and Tabbal *et al.*, 2002). AWD has become a preferred water management practice for many farmers who use the System of Rice Intensification (SRI) as they can save some labor time this way, compared with applying small amounts of water to their fields on a daily basis as originally recommended.

Many researchers claim that SRI methods are very useful for small and marginal farmers who cultivate their land themselves. It has reduced their use of seed, water, and pesticides while giving more production. SRI is not a standard package of specific practices, to be adopted simply as recommended, but rather a combination of agronomic principles and empirical practices to be adapted suitably to respective agro-ecosystems (Uphoff, 2012).

By using locally-available seed and other inputs, farmers can produce about doubled production from the same land with a reduction in cost. With better management, farmers can triple their production. Besides these benefits, farmers can harvest their rice crop 15-25 days earlier, which will help them in early planting of the next crop (such as wheat, maize, oil seed, and vegetables) as well as enhance the yield from those crops as soil quality is improved (Uphoff, 2002; Chandrapala *et al.* 2010; Mohanty *et al.*, 2014 and Vishwakarma, 2015). Age of seedling as a component of SRI principle, should be within 10-12 days for better yield and earlier harvesting. Performance of age of seedlings with variation in the yield has been universally accepted and voluminous research findings to confirm this feature are available across the literature (Randriamibarisoa and Uphoff, 2002; Uphoff, 2005). However, most of the farmers have expressed difficulties with certain practices envisaged under SRI, one of them being high labour requirement for transplanting of young seedlings, compared to the 25-30 days old seedlings under the traditional method of planting, owing to their tiny size (Naidu *et al.* 2013). But seedlings can successfully be used up to 15 days of age in this method (Upreti, 2006). Age of seedlings at transplanting most often depend on the weather condition, availability of water, herbicide, labour and other inputs in farmers' fields. Transplanting older seedlings may induce delay in the onset of linear dry matter accumulation and tiller or leaf emergence (Pasuquin *et al.*, 2008). Hamid *et al.* (2016) observed that repeated flooding of varying depths and duration caused physical damage to the rice seedlings after transplanting. Thus late planted seedlings stand better chance of surviving or escaping higher rainfall causing flooding.

Expansion of area under irrigation and intensive use of chemical fertilizers contributed to increased food production in India with the start of green revolution.

This made India almost self-sufficient in food production from a grain deficit country. Organic matter or manure is found very beneficial for SRI methods, but in the case of less fertile soil, farmers should use a balance dose of fertilizer for more yields (Upreti, 2006). The role of combined effect of water (irrigation) and nutrients (fertilizer) with improved agronomic practices is enormous in this achievement. More than 55 per cent of the increase in global crop production, especially in emerging countries, comes from the use of chemical fertilizers with nitrogen (N) fertilizer being the dominant (Li *et al.*, 2009). Nutrients and water are complementary inputs, hence water use efficiency (WUE) and nutrient use efficiency (NUE) can be increased by increasing crop yields relative to that of evapotranspiration (Ritchie, 1983) and other avoidable losses. Nitrogen use efficiency of rice in India (0.40 kg grain/kg N) was reported 1/3rd lower than world (0.56 kg grain/kg N) (Norton *et al.*, 2015). With $NUE < 0.5$ kg grain/kg N, there is probably a large opportunity for improving NUE. At the other extreme, when $NUE > 0.9$ kg grain/kg N, it is likely that efficiency cannot be improved further without risky mining of soil nutrients. An increase in NUE does not always guarantee lower N pollution, but it is an essential step for reducing N loss to the environment while maintaining high agricultural productivity (Norton *et al.*, 2015).

The consumption of fertilizers in India in terms of NPK has increased substantially from a mere 1.1 million tonnes in 1966-67 in the pre-green revolution period to more than 25 million tonnes in 2014-15. As per the International Fertilizer Association, India ranked second in total world fertilizer consumption in 2012. The all-India average consumption of fertilizers has increased from 69.84 kg per hectare in 1991-92 to 128.08 kg per hectare in 2014-15 (Anonymous, 2016d). There is, however, wide inter-state variability in consumption of fertilizers, with states like Punjab, Haryana and Andhra Pradesh having per hectare consumption of over 200 kg and other states, like Odisha, Kerala, Madhya Pradesh, Jharkhand, Chhattisgarh and Rajasthan, reporting less than 100kg per hectare consumption.

Nitrogen plays a key role in rice production as it is required in huge amount. It is the essential component of cell molecules (*viz.* chlorophyll, nucleic acids, amino acids, ATP and a number of plant hormones) and is an important regulator involved in many biochemical processes (*viz.* protein synthesis, carbon

metabolism and amino acid metabolism) (Cai *et al.* 2012). Application of nitrogen fertilizer either in excess or less than the optimum level both affects yield and quality of rice to the significant extent; that's why appropriate fertilizer input is required not only for getting high grain yield but also for attaining the maximum profit. The best dose of mineral fertilizer is that which gives the maximum economic return at the minimum cost.

Whether making certain changes in water and nutrient management together with modifications in other crop-management practices can raise crop yield with reduced applications of water and nutrient is an empirical question, however, and one that needs to be evaluated across a wide number and range of conditions (Jagannath *et al.*, 2013). Simply reducing water applications does not suffice to give rice plants a better environment for growth, health and productivity. Changing certain soil parameters (organic matter, porosity, soil aeration, and soil biodiversity) and managing rice plants differently (less crowding, more careful transplanting, and root growth stimulation) are necessary to get the full benefit of reducing water applications (Jagannath *et al.*, 2013).

Keeping these points in view, the present investigation entitled **“Evaluation of water regimes and nutrient management on rice-rice cropping system under transplanted and modified system of rice intensification (MoSRI)”** was carried out with following objectives.

1. To study the effect of planting methods on growth, yield and nutrient uptake in rice-rice cropping system
2. To evaluate the effect of irrigation regimes on growth, yield and nutrient uptake in rice-rice cropping system
3. To examine the effect of nutrient management on growth, yield and nutrient uptake in rice-rice cropping system
4. To study the interaction effect of planting methods, irrigation regimes and nutrient management on growth, yield and nutrient uptake in rice-rice cropping system
5. To work out the economics and energetics of different treatments in rice cultivation.

CHAPTER-II

REVIEW OF LITERATURE

Rice is grown in more than a hundred countries with total cultivated area of about 160 million hectares and occupies 11% of the world's cultivated area with the production of more than 700 million tons. The world population is estimated to increase 9 - 11 billion by the year 2025 out of which 4.3 billion will be dependent on rice for their basic food. So, rice has a leading role in food security. Among the improved agro-management practices, seedling age plays an important role in enhancing the yield of rice. Age of seedling is a key factor which influences the tiller production, grain formation and other yield contributing parameters. It is the main factor for uniform stand establishment of rice which controls its growth and yield. The use of appropriate aged seedlings for transplantation and its timely planting are important non-cash inputs for attaining the higher yield of rice. Seedling vigor contributes to successive tillering, yield and quality of transplanted rice. Growth and production of rice depend on timely cultivation and growth duration of cultivar which is affected by the age of seedlings at transplantation. All the above and below ground morphological characters of rice plants vary with the seeding rate, age of seedling and growing environment.

Rice is a heavy water consumer but water for rice production is becoming scarce and expensive due to the increased demand for water from the ever growing population. Future predications on water scarcity limiting agricultural production have estimated that by 2025, about 15-20 m ha of Asia's irrigated rice fields will suffer from water shortage in the dry season especially since flood irrigated rice uses more than 45 % of 90 % of total freshwater used for agricultural purposes. Overexploitation of ground water during recent decades has caused serious problems in South Asia which is affecting rice growing areas. Further, they observed that groundwater tables have dropped on an average by about 1 m yr⁻¹ in southern India, where flooded rice is the dominant cropping system. Rice could face a threat due to water shortages and hence, there is need to develop and adopt water saving methods in rice cultivation so that production and productivity levels are elevated despite the looming water crisis. Among the various methods of rice

cultivation SRI method envisages on alternate wetting and drying (AWD) may help to reduce water losses and improve productivity.

Nitrogen amongst all nutrients is the utmost important regulating element in rice growth and development. Reduction of dry matter accumulation due to inadequacy of nitrogen in the growth period may prevent grain filling resulting into increased number of unfilled grains causes drop in yield. Better understanding of the accessibility of nitrogen from the innate organic nitrogen sources and the fate of added nitrogen fertilizer should benefit in emerging innovative nitrogen management practices and an increase in the efficiency of fertilizer. Despite the importance of nitrogen fertilizer with productivity, the amount of nitrogen fertilizer applied by farmers and the native soil nitrogen supply are not well matched. Rice shows excellent response to nitrogen application, but the recovery of applied nitrogen is quite low. Optimization of fertilizer nitrogen to rice has been an important aspect for quite long and still continues to attract scientists leading to new concepts and approaches. An integrated approach involving organic manures and chemical fertilizers will go a long way in building up of soil fertility on a permanent basis and the system will supply most of the nutrients in a judicious way. Hence, there is need to develop suitable optimal nitrogen management practices to match crop demand with fertilizer nitrogen supply for reducing losses and maximizing crop nitrogen utilization.

So, keeping in view an attempt has been made in this chapter to review the relevant research work pertaining to the present investigation entitled **“Evaluation of water regimes and nutrient management on rice-rice cropping system under transplanted and modified system of rice intensification (MoSRI)”**. The review has been presented under the following broad headings accomplished on the effect of water regimes and nutrient levels on modified age of seedlings and their spacing on rice in India and elsewhere. The detail reviews of available literature related on above aspects have been incorporated under following heads:

2.1 Effect of age of seedlings and spacing on rice crop

2.1.1 Growth attributes

2.1.2 Yield and yield attributes

- 2.1.3 Nutrient uptake
- 2.1.4 Soil nutrient status
- 2.1.5 Water use studies
- 2.1.6 Quality parameters
- 2.1.7 Economics
- 2.1.8 Energetics

2.2 Effect of water regimes on rice crop

- 2.2.1 Growth attributes
- 2.2.2 Yield and yield attributes
- 2.2.3 Nutrient uptake
- 2.2.4 Soil nutrient status
- 2.2.5 Water use studies
- 2.2.6 Quality parameters
- 2.2.7 Economics
- 2.2.8 Energetics

2.3 Effect of nutrient levels on rice crop

- 2.3.1 Growth attributes
- 2.3.2 Yield and yield attributes
- 2.3.3 Nutrient uptake
- 2.3.4 Soil nutrient status
- 2.3.5 Water use studies
- 2.3.6 Quality parameters
- 2.3.7 Economics
- 2.3.8 Energetics

2.4 Interaction effect of water regimes, nutrient levels and establishment methods on rice crop

- 2.4.1 Growth attributes
- 2.4.2 Yield and yield attributes
- 2.4.3 Nutrient uptake
- 2.4.4 Soil nutrient status
- 2.4.5 Water use studies
- 2.4.6 Quality parameters

2.4.7 Economics

2.4.8 Energetics

2.1 Effect of age of seedlings and spacing on rice crop

2.1.1 Growth attributes

Effect of age of seedling and spacing has been studied on the performance of rice. Young single seedlings of only 10–15 days are planted at 1 seedling hill⁻¹ at a spacing of at least 20 × 20 cm. This practice is introduced because young seedlings tend to produce more roots and tillers (Uphoff, 2001). Performance of age of seedlings with variation in the yield has been universally accepted and voluminous research findings to confirm this feature are available across the literature (Randriamibarisoa and Uphoff, 2002; Uphoff, 2005). In contrary to these, Mamun *et al.* (2013) observed a sharp increase in vigor due to increase in seedling age with the highest vigor calculated in 20 days and lowest under 8 days old seedlings. Age of seedlings at transplanting most often depend on the weather condition, availability of water, herbicide, labour and other inputs in research fields as well as in farmer's fields (Ginigaddara and Ranamukhaarchchi, 2011). Transplanting older seedlings induced a delay in the onset of linear dry matter accumulation and tiller or leaf emergence (Pasuquin *et al.*, 2008). Mobasser *et al.* (2007) reported that when seedlings stay for a longer period in the nursery beds, primary tiller buds on the lower nodes of the main culm become degenerated leading to reduced tiller production. He also found that when rice seedlings are transplanted at the right time in terms of age, tillering and growth proceed normally and only a fewer tillers are produced during vegetative period leading to poor yield if transplanting is delayed. Some of the researchers also commented that use of older seedlings in rice production is the major reason of lower rice yield as seedling age has a tremendous effect on plant height (Sharma and Masand, 2008), tiller production, panicle length, grain formation, grains per panicle, and other yield attributing characters (Ali *et al.*, 1995 and Sarwa *et al.*, 2011).

However, most of the farmers have expressed difficulties with certain practices envisaged under SRI, one of them being high labour requirement for transplanting of young seedling (Pasuquin *et al.*, 2008) compared to the 25-30 days old seedlings under the traditional method of planting, owing to their tiny size

(Naidu *et al.*, 2013). Repeated flooding of varying depths and duration may cause physical damage to the rice seedlings after transplanting. Thus late planted seedlings stand better chance of surviving or escaping higher rainfall causing flooding (Hamid *et al.*, 2016).

Many researchers reported that SRI recorded higher plant height (Mohanty *et al.*, 2014), number of tillers m^{-2} (Faruk *et al.*, 2009), leaf area index, leaf area appearance rate (Khanal, 2005) dry matter accumulation, root dry weight and root volume (Mohanty *et al.*, 2014) which were significantly more than those of conventional transplanting (CT) and drum seeding (DS). Larijani (2010) revealed that seedling ages influenced leaf area appearance rate (LAR) decreasing the total number of leaves on the main culm at mature seedling. Further he recorded that LAR was negatively linearly correlated with seedling age ranged from 0.0105 to 0.036 leaves⁻¹ GDD. The LAR is important for canopy development, since leaves are the source of carbohydrate for the plant (Khanal, 2005).

Kim *et al.* (1999) found that 10 days young seedlings out yielded 15 and 40 days after transplanting (DAT) produced more vigorous stem elongation and higher tillering ability. They also found that the crop growth rate was lower in 10 days old seedlings at 40 DAT but in later growth stages these seedlings gave the greater crop growth rate (Stoop *et al.*, 2002). Uphoff (2005) suggested that under SRI methods higher production was not due to adding nutrients but rather it is due to better response of younger rice seedlings (Laulanie, 1993) towards early planting and growing them on well drained soils in main field. He concluded it as a better method to maintain better tillering and rooting potential of rice. Similar results were also observed by Migo and Datta (1981) and Wang *et al.* (2002). Kavitha *et al.* (2011) in a two year *Kharif* season experiment done during 2006 and 2007 found 14 days old seedlings as significantly higher plant height, leaf area index and dry matter accumulation.

Uphoff (2002) reported that transplanting of very young seedlings usually 8-10 days old and not more than 15 days will have better tillering and rooting and it was reduced if transplanting was done after the 4th phyllochron usually about 15 days after emergence. Theetharappan and Palanjappan (1984) and Rao and Raju (1987) reported that older seedlings in height, dry matter production

and productive tillers m^{-2} over younger seedlings. Sahoo and Rout (2004) reported that young seedlings exhibited higher relative growth rate, net assimilation rate and crop growth rate and also took more time for flowering and maturity over older aged seedlings (Joseph, 1991; Krishna *et al.*, 2008). Similarly, Ginigaddara and Ranamukhaarchchi (2011) and observed that young seedlings of 10 days completed flowering leaving behind DSR with a difference of 9 days. many workers observed that single seedlings hill^{-1} produced 50% more tillers effective tillers hill^{-1} , high leaf area index (LAI) and much higher percentage of efficient LAI which delayed the descending rate of LAI when compared to three seedlings hill^{-1} (He *et al.*, 2011; Patra and Haque, 2011; Styger *et al.*, 2011 and Adhikari *et al.*, 2013). Similarly, Vishwakarma (2015) observed that transplanting of 10 days old seedling showed delay in 50% flowering and physiological maturity and Meyyappan *et al.* (2013) noted taller plants, more number of tillers m^{-2} and high LAI when compared to 14 and 18-days old seedlings.

2.1.2 Yield and yield attributes

Ramasamy *et al.* (1987) described that when aged rice seedlings were transplanted, the primary tillers produced panicles shattered before harvesting however, their emergence comes fast within 21 days after transplanting. He *et al.* (2011) suggested that enhanced root activity of rice subsequently resulted in to higher dry matter accumulation and translocation of assimilates during grain filling, and was helpful to coordinate better dry matter partitioning among grains number panicle $^{-1}$, seed setting rate and 1000 grain weight. Sarwa *et al.* (2011) determined that transplanting of younger seedlings (10 days old) produced maximum yield, regardless of nursery management.

In contrary to these, Hamid *et al.* (2016) found that Late transplanting of old seedlings produced higher yield than transplanting younger seedlings. They also found that lower yield of earlier planted rice was associated with greater hill mortality and seedling. Similarly, Kewat *et al.* (2002) recorded that transplanting seedlings at a closest spacing 20 cm x 10 cm produced significantly highest grain and straw yields than wider spacing of 20 cm x 20 cm and 20 cm x 15 cm but was comparable to 15 cm x 15 cm spacing. Along with those, they also found that, transplanting of 21 and 28 day-old-seedlings registered significantly higher grain and straw yields than transplanting of thin and lanky

seedlings of 14 days. It is now established fact that, age of seedlings has a significant influence on yield of rice (Patra and Haque; 2011; Salem *et al.*, 2011; Sarwa *et al.*, 2011; Styger *et al.*, 2011; Sanjeewanie and Ranamukharachhi, (2011); Naidu *et al.*, 2013).

These results are mostly supported by better development of yield attributes due to young age seedlings. Yield attributes like effective tillers/panicles hill⁻¹, panicle length, panicle weight, number of total grains panicle⁻¹, filled grain panicle⁻¹, sterility/chaffy grains percentage etc. are significantly better in young seedling with SRI method of crop establishment (Channabasappa *et al.*, 1998; Chandrapala *et al.*, 2010; Kavitha *et al.*, 2011; Dahal and Khadka, 2012; Deb *et al.*, 2012; Hussain *et al.*, 2012). Sudhakar (2015) reported very high degree of positive statistical correlation of yield attributes viz. panicles hill⁻¹, panicle length, panicle weight, number of total grains panicle⁻¹ and filled grain panicle⁻¹ with grain yield and sterility percentage was negatively correlated with grain yield. He also noted that, plant height, number of leaves and tillers hill⁻¹ and plant dry matter accumulation are highly correlated with the yield of straw. Similar results were also observed in investigations of Sharma and Ghosh (1998); Kavitha *et al.* (2011) and Sarwa *et al.* (2011).

Rasool *et al.* (2012) established that planting less number of seedlings per hill helps to produce healthy tillers which enables normal physiological growth resulting in more panicles with more filled spikelets and thus produces higher grain yield. Asbur (2013) also reported that transplanting of 7-21 day-old seedlings with single seedling per hill increased plant growth and grain yield of rice. Many literatures also suggest that lesser the number of seedlings per hill transplanted, greater was the effective tillers per unit area, spikelets per panicle and grain yields (Faruk *et al.*, 2009 and Ullah *et al.*, 2015).

Manjunatha *et al.* (2010) reported that higher number of panicle per hill, panicle length, number of grains per panicle and test weight was higher under planting of 9 days and 12 days old seedlings, respectively and further transplanting younger seedlings i.e. less than 15 days old seedlings had higher tillering capacity and more vigour which in turn helped in extracting nutrients from soil. Singh and Singh (2004) also reported that yield attributes viz. panicle number m⁻², panicle

length, number of filled grains panicle⁻¹ and 1000 grain weight were significantly higher with transplanting of younger seedlings as assessed to older seedlings. In contrary to this, Ramachandra *et al.* (2012) revealed that age of seedling did not differed significantly on yield of rice. However, planting 15 days old seedlings produced higher grain yield than planting 10 days old seedling. Ramasamy *et al.* (1987) described that when aged rice seedlings were transplanted, the primary tillers produced panicles shattered before harvesting however their, emergence comes fast within 21 days after transplanting. Channabasappa *et al.* (1998) also reported that under late planted conditions both 35 and 45 days old seedlings performed better for panicle number, panicle m⁻² and number of grains panicle⁻¹ than 25 days old seedlings. Channabasappa *et al.* (1998) reported that under late planted conditions both 35 and 45 days old seedlings performed better for panicle number, panicle m⁻² and number of grains panicle⁻¹ than 25 days old seedlings. In another experiment, Chapagain *et al.* (2011) compared SRI practices with conventional methods that showed some notable benefits including response in root number (>30%), number of effective tillers hill⁻¹ (>25%), days to flowering (10 d earlier while counting days after seeding), and harvest index (Adhikari *et al.*, 2013).

Commenting on the effects of SRI practices, McDonald *et al.* (2008) have insisted that no significant yield advantages for SRI over ‘best management practices’ (BMPs) have been documented experimentally except from Madagascar trials. When all the four components of SRI viz., young seedling, one seedling, square planting and cono-weeding were combined, it gave more number of panicles hill⁻¹, panicle length, panicle weight, number of filled grains panicle⁻¹ which ultimately resulted in higher grain and straw yield and improved harvest index during *kharif* season (Sridevi and Chellamuthu, 2008). Thakur *et al.* (2010) found that 94 per cent tillers produced panicles in modified SRI, whereas 89 per cent in conventional practices. Chandrapala *et al.* (2010) stated that the square geometry with wider spacing, planting of single seedling hill⁻¹ under SRI methodology was found to increase number of grains panicle⁻¹ and grain yields. According to Mohanty and Mohanty (2010), SRI method of establishment with

cono-weeding at 10 days interval starting from 10 days after transplanting is optimum to achieve higher production and productivity.

2.1.3 Nutrient uptake

Naidu *et al.* (2013) observed that planting pattern of 25 x 25 cm and 12 days old seedling recorded higher grain protein nitrogen, phosphorus and potash uptake and commented that possibly profuse and robust root system due to early seedling vigour might have facilitated greater ability to mobilize more nutrients, concomitant higher absorption and translocation of nutrients (Kumar *et al.*, 1995 and Shekhar *et al.*, 2009). Similarly, Barison (2002) in a meta-analysis of 108 farmers in Madagascar found that plants of the same variety took up 90% more N and K, and 60% more P, from soil under SRI with no change in harvest index due to better soil depth exploration. Rajesh and Thanunathan (2003) postulated that reduction in nutrient uptake with planting of 50 days old seedlings might be due to the fact that 50 days old seedlings remove insufficient nutrients due to low vigour causing slow vegetative growth and short reproductive phase. In contrast to these results, Reddy and Reddy (1992) observed a negative correlation with age of seedlings at transplanting and N uptake. Similarly, Bommayasamy *et al.* (2010) worked with rice (cv. 'ADT 43') on sandy clay soil reported that type of nursery and age of seedlings influenced N uptake at maturity. Fourteen-days-old seedlings from conventional type of nursery had higher N uptake compared to SRI method.

However, Chandrapala *et al.* (2010) worked on rice (cv. 'Rasi') observed that the 12 days old seedling under SRI resulted maximum N, P and K removal over conventional transplanting (25 days old seedling) and direct sowing of sprouted rice seed. In line finding was also reported by Balasubramanian *et al.* (2012) and Kabat and Satapathy (2013). Hussain *et al.* (2012) worked on silty-clay-loam soil (pH 6.9) also reported that the maximum N, P and K uptake was recorded for 14 days seedlings which was statistically at par with 21 days old seedlings but significantly higher than the 28 and 35 days old seedlings under SRI. Similarly, Singh *et al.* (2013a) on *Ustocrept* soil having pH 7.46 found that the transplanting of 10 days old seedling recorded significantly higher value of N, P and K uptake (268.5, 67.0 and 175.7 kg NPK ha⁻¹) as compared to 8, 12 and 14 days old seedling (Ram *et al.*, 2014). Vishwakarma (2015) observed significant increase in N, P and K contents

in grain and straw over 14 and 18-day old seedlings during *kharif* 2012 and 2013. He reported that content of nutrients (N and P%) were more in grains as compared to straw except K content, which follow reverse trends.

2.1.4 Soil nutrient availability

McHugh *et al.* (2002) found that at $P = 0.07$, there was an interaction between cultivation system and soil type. Conventional yields were relatively constant for all soil types, whereas SRI produced higher yields on clayey and organic soil than on loamy and sandy soil (Sudhakar *et al.*, 2015). Similarly, Chandrapala *et al.* (2010) observed that the conventional transplanted (25 days old seedling) resulted in low available N, P and K removal followed by 12-day old seedling under SRI, while it was maximum under direct seeded sprouted seed. Naidu *et al.* (2013) in sandy clay loam textured soil, low in organic carbon and available nitrogen, medium in available phosphorous and available potassium in *kharif* 2005 and 2006 found no significant influence due to different age of seedlings (8, 12, 16 and 20 d old). However, Bommayasamy *et al.* (2010) reported that the transplanting of 14 days old seedling under conventional method showed minimum figure of available N, P and K followed by 14 days old seedling under SRI, while it was maximum under conventional method with 21 days old seedling. According to Singh *et al.* (2013a) available nitrogen, phosphorus and potassium were significantly higher in crop transplanted with 10 days old seedling as compared to 8, 12 and 14 days old seedling.

2.1.5 Water use studies

The SRI is such a practice, offering rice-growing farmers yield increase and other benefits when they apply less water, provided this is done in conjunction with other changes in how they manage plants, soil, and nutrients (Uphoff and Randriamiharisoa, 2002). Some researchers have commented that SRI methods have been seen to increase yields substantially, often by 100% or more. They further added that SRI requires only about half as much water to grow a crop of rice as with conventional methods, it can raise the productivity of irrigation water in rice cultivation by as much as four times, or even more (Uphoff, 1999 and Stoop *et al.*, 2002). Vijayakumar *et al.* (2004) stated that grain yield and water productivity were significantly increased

by the package of planting of 14 days old dapog seedlings at 25 cm x 25 cm spacing. Manjunatha *et al.* (2010) also reported that modified SRI method and recommended SRI method recorded lower water requirement and higher water use efficiencies compared to normal method. Water use efficiency was higher in modified SRI method closely followed by recommended SRI method and these were significantly superior over normal SRI method. Jiaguo *et al.* (2013) calculated that SRI can save a total of 2,193 m³ of water per ha during the rice-growing season, a saving of 22%. Irrigation water was reduced by 1,933.5 m³ ha⁻¹ (by 23%). Water productivity was 1.12 kg of grain m⁻³, with an increase of 0.30 kg m⁻² (36%), and irrigation water use efficiency was 1.34 kg of grain m⁻², an increase of 0.37 kg m⁻² (38%), irrigation water applications were reduced 25.6% compared to TF (Traditional flooding) and total water use efficiency and irrigation water use efficiency was increased with SRI by 54 and 90% respectively. They concluded that SRI method causes greater water saving while at the same time producing more grain yield, in these trials 11.5% more compared to TF.

2.1.6 Quality parameters

System of rice intensification is well known for improved grain quality. Millers in India and Sri Lanka are willing to pay more for SRI paddy rice because it has fewer unfilled grains and fewer broken grains after milling. There have also been reports of reduced chalkiness due to denser grains that withstand shattering and keep their shape better after cooking (Kumar and Shivay, 2004). Wang *et al.* (2003) reported that system of rice intensification significantly enhanced root activity, increased soluble sugar, non-protein nitrogen, proline and malondialdehyde (MDA) content in leaf, dry matter translocation percentage from vegetative organs to grains and improved grain quality parameters significantly (Khakwani *et al.*, 2005). Jayakumar and Krishnasamy, (2005) reported higher root volume than 21 days old at flowering stage and it was also observed that careful and horizontal planting under SRI could be responsible to obtained better results. Ying *et al.* (2005) reported that heading duration under the SRI was relatively longer than corresponding to that of plants under traditional cultivation. Under the traditional cultivation, differences in rice quality were observed due to the early or

late heading of the different tillers plant⁻¹. Delayed heading resulted in a reduction in the crop grain quality. They reported that SRI improved rice quality, increased the rate of milled and head milled rice, and reduced the percentage of chalky kernel and chalkiness. They also reported that plants grown under SRI recorded higher chlorophyll content, resulting to higher photosynthetic rate and photosynthate contents, slow senescence and high rate of transport of dry matter from source to sink during grain filling period resulted better quality parameters.

Satyanarayana *et al.* (2007) also reported that with SRI, in addition to getting higher yield of paddy rice ha⁻¹ when this product is milled; there is a resulting increase out turn of saleable rice. SRI paddy contain fewer unfilled grains as a rule, and therefore, produce less chaff (Adhikari *et al.*, 2013); and as there is less shattering during milling the per cent of broken grains is reduced (Krishna *et al.*, 2008). However, Vishvakarma (2015) found that tender aged seedling (10-day old) recorded the data pertaining to quality characters viz. hulling (%) and milling (%), were unaffected due to different age of seedling during both the years. Further, head rice recovery (%), during the second year produced marked variation due to different aged seedlings and significantly higher value of these characters was recorded under younger aged seedling.

2.1.7 Economics

Any value greater than 2.0 is considered safe as the farmers get E 2.00 for every rupee invested (Reddy and Reddy, 2002). On the other hand, minimum BC ratio of 1.5 for the agricultural sector has been fixed for any enterprises to be economically viable. Kewat *et al.* (2002) recorded that transplanting seedlings at a closest spacing 20 cm x 10 cm produced significantly highest benefit: cost ratio (2.8) than wider spacing of 20 cm x 20 cm and 20 cm x 15 cm but was comparable to 15 cm x 15 cm spacing. they Similarly, transplanting of 21 and 28 day-old-seedlings registered significantly higher net monetary returns and benefit: cost ratio than transplanting of thin and lanky seedlings of 14 days. Similarly, Babu *et al.* (2014) in a pooled data of two years noted that highest cost of cultivation was incurred with conventional planting method followed by ICM and SRI, respectively. This was 7.0 and 14.7% higher than ICM and SRI, respectively. Further, SRI recorded the higher values of gross returns, net returns and benefit: cost ratio. Adhikari *et al.* (2013) observed

that the treatment with low seeding density and 40 days old seedlings produced beyond a doubt the highest net returns and B:C ratio, independent of the fertilizer treatment in nursery. They also concluded that closer spacing geometry with 100% RDN are economically viable and profitable, and can be recommended to farmers. In contrary to these studies, Mohanty *et al.* (2014) reported that in both year 2009 and 2010 SRI fetched 16.8 and 23.7% higher gross return, 36.7 and 51.7% higher net return and 16.3 and 21.3% higher return E^{-1} invested than conventional transplanting and drum seeding, respectively as per mean yield. Ramachandra *et al.* (2012) also brought analogous results in to light. In parallel to these, Dahal and Khadaka (2012) also observed that 8-days old seedlings showed significantly higher gross return, net return and B:C ratio over remaining seedling age treatments (viz. 8, 15, 22 and 29-days under SRI, recorded that) (Pramanik and Bera, 2013). Similarly, crop planted in the geometry of 25x25 cm^2 produced significantly higher gross return, net return and B:C ratio (1.84). Reddy *et al.* (2008) observed that single seedling $hill^{-1}$ along with 12 days old seedling showed significantly higher net profit, B: C ratio and profit day^{-1} under system of rice intensification. Hussain *et al.* (2012) found that the highest net return was realized for 14-day old seedling which was followed by 21 days old seedlings (Singh *et al.*, 2013a). Also, according to Shukla *et al.* (2014) transplanting of 10 days old seedling under SRI exhibited significantly higher value of gross income, net return and B: C ratio than the transplanting of 15 days old seedling. Parallel results were also noted in results of Ram *et al.* (2014) and Vishwakarma (2015).

Combination of young seedlings, single seedling, square planting and cono-weeding registered the highest net return and BCR compared to conventional practice (Chellamuthu and Sridevi, 2006). Jayadeva *et al.* (2010) reported that SRI had more economic advantage in terms of gross return and B: C ratio as compared to manual transplanting.

2.1.8 Energetics

Transplanting of rice seedlings in the traditional way is a labourious, time consuming and causes drudgery. Non-availability of labourers for transplanting at appropriate time leads to late planting, which results in poor yields. In rice,

planting methods have an impact on the growth, yield attributes and yield besides cost of cultivation and labour requirement (Sangeetha and Baskar, 2015). The combination of wide spacing and less water use in SRI provides ideal conditions for weed growth, which means that frequent weeding is necessary. One constraint that has been alleged in SRI is its labour intensity which is suitable for small scale production only (Thiyagarajan *et al.*, 2002). The few studies of its labor requirements show that SRI requires an estimated 38% to 54% more labor than traditional methods (Anonymous, 1995). According to Rakotomalala (1997) 62 per cent of the extra labour needed for SRI is for weeding and 17 per cent for transplanting. SRI method recorded higher recorded that energy output: input ratio (15.78) compared to transplanting (13.28) and aerobic rice (12.42) (Jayadeva and Shetty, 2002) and also Jayadeva *et al.* (2010) reported that the SRI establishment technique recorded higher energy output: input ratio than manual transplanting. However, Sheehy *et al.* (2005) strongly argued that the energy requirements for achieving such high yield in SRI are beyond the thermodynamic capabilities of rice plants' photosynthesis and the crop's use of solar energy.

2.2 Effect of water regimes on rice crop

2.2.1 Growth attributes

Sufficient water supply under the irrigated lowland rice system often leads to excessive vegetative growth which may result in less root activity, unhealthy canopy structure, and Lower HI (Zhang and Yang, 2004). Greenland (1981) stated that a minimum percolation rate of 10 mm d^{-1} is required for high yields. He argues that this percolation rate ensures the removal of toxic materials and an ample supply of oxygen. Ponnampersuma (1984) argues that a percolation rate of at least 1.5 mm d^{-1} is necessary to meet the oxygen demands of roots in flooded soil. From panicle initiation to flowering, crop growth rates are as high as $250\text{--}300 \text{ kg ha}^{-1} \text{ d}^{-1}$, thus requiring a non-limiting supply of water to the root zone of the crop (Thompson, 2002).

Shi *et al.* (2002) observed that maximum tillering, number of tillers hill^{-1} , chlorophyll content, dry matter production and root activity was higher in the intermittent irrigation and dry-cultivation treatment than in the flooded treatment. They observed that the treatment with a water table 5 cm below the soil surface produced relatively more roots in the lower soil layers (40–45 cm)

than the flooded treatment. Similarly, Thiagarajan *et al.* (2002) noted higher tiller density with limited irrigation when compared to continuous flooding. Gani *et al.* (2002) also observed that intermittent irrigation consistently performed better than continuously flooded irrigation, that is, it produced more tillers, leaf area, and biomass. Panicle initiation, 50 % flowering and maturity delayed by 6-7, 3-4 and 8 to 11 days, due to water regimes from continuous submergence to irrigation at 3 days after disappearance of ponded water, respectively. (Rai and Kushwaha, 2008). However, Chapagain and Yamaji (2010) reported that alternate wetting and drying interval treatments took 2-3 days more time to begin flowering, but took 3-5 days less time to mature. Prasertsak and Fukai (1997) observed that flowering was delayed by 11-15 days when rice was subjected to water stress (Ismaila *et al.*, 2014).

Higher specific root length in plants grown under aerobic condition than in continuous flooding and roots were recovered up to 90 cm depth under aerobic condition, while roots were confined to the upper 20 cm depth in continuous flooding (Dandeniya and Thies, 2012). Root length density, root weight density at 0-15 cm and 15- 30 cm depths were markedly improved due to alternate wetting and drying over continuous flooding (Yang *et al.*, 2003). When irrigation was applied at 1 to 5 DADPW, roots were concentrated at and above the water table interface, having greater horizontal development, whereas under more stress (irrigations at 7 DADPW, no irrigation), roots were concentrated in lower horizons having a more vertical distribution (Mishra *et al.*, 1997 and Bali and Uppal, 1995). Ye *et al.* (2013) observed that root dry matter partitioning was greater (5.5 %, 7.1 %, and 2.1 % at booting, grain filling and maturity stages, respectively) under the alternate wetting and drying than the conventional flooding of rice.

A moderate AWD regime can reduce the maximum number of tillers by 21–23 per cent and total leaf area by 14 per cent, but the number of productive tillers and effective leaf area show no significant difference with flooded condition. Also, water stress at grain-filling time induces early senescence and shortens the grain-filling period but increases the remobilization of assimilates from the straw to grains (Yang and Zhang, 2010). Irrigated rice is more susceptible to drought and unable to regulate transpirational functions effectively (Vandeleur *et al.*, 2009) and

shows low tissue water potential (Kato *et al.*, 2004) which may affect net photosynthesis rate. Chlorophyll functions on light antenna in photosystem II and plays an important role in plant growth and development (Jahan *et al.*, 2013). Water stress affects chlorophyll content in leaves of rice (Sheela and Alexander, 1996) which may lead to affect photosynthetic units and inactivation of photosynthesis (Hotta *et al.*, 1987). In addition, oxygen depleted in the flooded soil-system results oxygen is quickly anaerobiosis causes soil reduction and affects soil health (Sarwar and Khanif, 2005). Chowdhury *et al.* (2014) reported that except at 30 DAT, the maximum plant height, LAI and CGR was recorded in the treatment which received 2.5 cm irrigation at 0 days after disappearance (DAD) of ponded water i.e. on the same day when the ponded water disappeared and minimum in the treatment 6 DAD of ponded water.

2.2.2 Yield and yield attributes

The continuous land submergence leads to considerable loss of water through deep percolation and other means (Bouman, 2001). On the other hand, submerging rice field brings a series of physical, chemical and microbial changes in the soil, which profoundly affects growth of rice plant as well as availability, loss and absorption of nutrients (Ghildyal, 1978). Irrigation regime of saturation proved significantly superior over continuous submergence and AWD through field water tubes in producing yield attributes namely number of panicles m^{-2} , filled grains hill^{-1} and grain yield (Rahman and Sinha (2013); Chowdhury *et al.*, 2014 and Diproshan *et al.*, 2015). Stress during the reproductive phase can hamper the supply of photosynthates towards the sink resulting in poor yield attributes (Ramakrishna *et al.*, 2007).

On the other hand, many studies have shown that AWD can be managed to maintain grain yield in rice (Dios *et al.*, 2000) and that it sometimes even leads to an increase in yield (Yang *et al.*, 2007). Shi *et al.* (2002) observed that under intermittent irrigation, number of panicle m^{-2} , number of grains panicle $^{-1}$, per cent of filled grains, 1000 grain weight and grain yield were higher than under flooded conditions.

The grain yield of rice depends on the number of panicles m^{-2} , number of grains panicle $^{-1}$ and 1000-grain weight. The yield attributes were significantly

superior at Irrigation up to 2.5 cm at 3 DAD than Irrigation up to 2.5cm at 6 DAD but was at par with Irrigation up to 2.5cm at 6 DAD. The 1000-grain weight did not change with irrigation levels (Chowdhury *et al.* 2012). Similarly, Anitha and Chellappan (2011) found statistically similar grain yield of rice with intermittent irrigation and continuous flooding. Belder *et al.* (2002) recorded that grain yields ranged from 7.2 to 8.7 t ha⁻¹ and were not significantly affected by the water regimes of alternately submerged, non-submerged (ASNS) and continuously submerged (CS). Bouman and Tuong (2001) also reported that AWD in the tropics reduced water input, but yields usually declined when the soil water potential (SWP) during the non-submerged phase reached values between -10 and -40 kPa. In contrary to this, Shi *et al.* (2002) found that the intermittent irrigation treatments received 48 and 68 mm of irrigation water (i.e., 27 and 37%, respectively) less than the flooded treatments, whereas grain yields increased by 4 to 6%. Test weight and harvest index are usually not affected due to intermittent irrigation over continuous flooding or saturation (Aslam *et al.* 2015). Wardana *et al.* (2002) derived an equation to predict yield under different management practices and postulated from the equation that changing water management from flooding to intermittent irrigation adds approximately 2 t ha⁻¹ to yield.

Sandhu *et al.* (2012) revealed that among different irrigation schedules, the maximum number of panicles m⁻², weight of grains panicle⁻¹ and panicle length were observed in irrigation at one day after disappearance of water and it was statistically at par with irrigation at two days after disappearance of water. Maximum spikelet sterility was observed in irrigation at three days after disappearance of water and it was significantly lower than rest of the irrigation schedules. Parallel findings have been also reported by Pandey *et al.*, (2010); Dass and Chandra (2012); Kumar *et al.* (2014) and Brar *et al.* (2015). Karim *et al.* (2014) reported that AWD had significant effect on number of grains panicle⁻¹ (104) and grain yield (5.72 t ha⁻¹), over flood irrigation but found insignificant in number of tillers m⁻², number of panicles m⁻², number of filled grains panicle⁻¹, number of unfilled grains panicle⁻¹, 1000-grain weight and straw yield.

2.2.3 Nutrient uptake

Crop N uptake has often been considered in relation either to soil availability or to crop growth as it actually results from both (Gastal and Lemaire, 2002). Nitrogen absorption by crops is automatically reduced under dry conditions, even when mineral N is present in the soil colonized by roots (Dugo *et al.*, 2005). The absorption of N by roots requires the presence of water in the soil, as it is the agent that transports solutes to the soil-root interface (Garwood and Williams, 1967). Under water scarcity, N demand by plants is reduced, as growth rate is diminished.

Uptake of nutrients, especially N and P in grains and straw noted higher with irrigation at 1 and 3 day after disappearance of standing water than at 5 days after disappearance of standing water. Higher nutrient accumulation under 1 and 3 DADSW is ascribed to greater and healthy root growth, increased availability and efficient absorption from the soil and transport of nutrients from roots to shoots and grains (Dass and Chandra, 2012). Anurag (2006) noted significantly higher N, P and K uptake under irrigation scheduled at 3 day after disappearance of standing water than at 5 day after disappearance of standing water. Further, Kumar *et al.* (2014) observed that maximum N, P and K uptake was recorded under 7 cm irrigation at 1 Day after disappearance of ponded water, which was found significantly superior over 7 cm irrigation at 3 and 5 DADPW. Significantly highest PFP (partial factor productivity) of nitrogen was recorded in saturation due to higher grain yield obtained from that treatments in comparison to farmers practice and intermittent ponding (2 DAD 5±0) from 15 to 35 DAT followed by Continuous Ponding (Rahman and Sinha, 2013).

Ramakrishna *et al.* (2007) revealed that continuous submergence resulted in maximum N uptake was significantly superior to that under 1 day drainage and 3 day drainage. But agronomic nitrogen use efficiency was maximum with 1 day drainage followed by continuous submergence and it was the least with 3 day drainage. Singandhupe and Rajput (1996) found that total N uptake with irrigation at one day after draining was significantly higher than with irrigation at 6 days after draining. Uptake of P by rice crop was also higher under saturation than under submergence. In general, there is higher concentration and uptake of N and P under

AWD and higher concentration and uptake of K in continuous flooding plots in shoots and roots (Yang *et al.*, 2003).

2.2.4 Soil Nutrient availability

Decrease in soil water availability affects the rate of diffusion of many plant nutrients and finally the composition and concentration of soil solution (Singh and Singh, 2004). McHugh *et al.* (2002) found interaction for irrigation and soil type at $P = 0.07$, conventional flooding yields were constant for all soil types while alternate flooding and drying and especially non-flooding irrigation yields were higher for clayey and organic soil compared with loamy and sandy soil, which produced the lowest yield. Water and N are essential requirements for plant growth and survival. The photosynthetic rate, chlorophyll content, and concentrations of proline and soluble sugar vary in plants subject to different moisture conditions and nutritional status. Drought stress can increase organic compounds required for osmotic adjustment, such as soluble sugars and proline (Molinari *et al.*, 2007). Loss of fertilizer N through nitrification and denitrification noticed higher under AWD than CF (0.22 vs. 0.04 g N m⁻²), but removed only 2.5 per cent of the total applied N fertilizer and was thus quantitatively insignificant and negligible however, under alternate wetting and drying, agronomic N use efficiency, N recovery efficiency and partial factor productivity of N are reported to be significantly increased (Rahman and Sinha, 2013; Jiu *et al.*, 2013 and Ye *et al.*, 2013). Khairi *et al.* (2015) found in their experimental results that soil pH and EC both were found to be similar under different water treatments. They further added that under saturated or flooding condition, the anaerobic condition and biochemical reaction might not affect soil pH indicating phyto-availability of nutrients unaffected. The changes in soil nitrogen might be due to AWD treatment causing increased transformation processes of nitrogen in the soil, e.g. nitrification. However, Ahn (1993) earlier reported that flooding affects soil pH, which can be neutralized to pH 6.5-7.2 about one month after flooding and remains near-neutral until the soil dries.

2.2.5 Water use studies

In a conventional continuous flooding (CF) regime field is required to keep water depth of at least 5±3 cm resulting into more irrigation input requirement than

AWD regime. Consequently, the water input saving and water productivity of AWD was 26.7 and 39.5 per cent in 2008 DS and 32 and 44.8 per cent in 2008 WS, over CF, respectively (Huan *et al.* 2010). Chowdhury *et al.* (2014) found that under treatment I1 (2.5 cm irrigation at 0 DAD) the required number of irrigation was 28 for which applied amount of irrigation water was 70 cm (excluding the rainfall amount), whereas under treatment I2 (2.5 cm irrigation 3 DAD) and I3 (2.5 cm irrigation 6 DAD) the values were 32.5 cm and 22.5 cm respectively. Further they added that the value of WUE was found to be the maximum (65.09) with I3 (2.5 cm of irrigation at 6 DAD) and the minimum (45.38) with I1 (2.5 cm irrigation at 0 DAD). Thiagarajan *et al.* (2002) reported that limited irrigation of two cm depth after surface crack development recorded higher productivity (0.732 kg m^3) with 56 per cent saving in irrigation water compared to conventional practice of 5 cm continuous flooding (0.398 kg m^3). Abu and Malgwi (2012) found that irrigation at the depth of 85 per cent TAW (total available water) and 8 days frequency gave the highest grain yield (4772.0 and 4442.3 kg ha^{-1}), WUE (5.8 and 6.4 $\text{kg ha}^{-1} \text{ mm}^{-1}$) and WP (3.43 and 3.79 $\text{US\$ mm}^{-1}$, respectively). This shows that water depth of 85 % TAW and irrigation at 8 days frequency satisfied almost the full moisture requirement at all the growth stages of the crop, resulting in moderate WUE.

Shi *et al.* (2002) in comparison of flooded and intermittent irrigation found that the intermittent irrigation treatments received 48 and 68 mm of irrigation water (i.e., 27% and 37%, respectively) less than the flooded treatments, whereas grain yields increased by 4 to 6 per cent (Lu *et al.*, (2002). Several workers also recorded reduced water inputs and increased water productivity of rice grown under just-saturated soil conditions, compared with traditional flooded rice (Tabbal *et al.*, 2002 and Raju and Sreenivas, 2008). Oliver *et al.* (2008) in Bangladesh conducted an experiment containing continuous submergence (T_1) and number of delayed irrigations (T_2 , T_3 and T_4) denoting application of 5 cm irrigation water when water level in the perforated PVC pipe fell 10, 20 and 30 cm below ground level (G.L.), respectively. The study revealed that treatment T_1 attributed by the highest total water use (122.2 cm) and the lowest WUE ($58.53 \text{ kg}^{-1} \text{ ha}^{-1} \text{ cm}$) produced the highest grain yield (6.86 t ha^{-1}). Treatment T_2 , on the contrary, gave

the second highest yield (6.58 t ha^{-1}) and consequently the second highest WUE ($69.48 \text{ kg ha}^{-1} \text{ cm}^{-1}$) indicating quite a large water saving (15 cm) compared to treatment T_1 . It was found that it requires 3 to 4 days for 10 cm depletion of water level below the ground surface in silty-loam soil (Sandhu *et al.*, 2012). Pandey *et al.* (2010) recorded that irrigation schedule of 1 day after disappearance of ponded water (DADPW) required 604 mm less irrigation water than that of maintaining continuous submergence. Similarly one DADPW recorded higher water use efficiency ($76 \text{ kg ha}^{-1} \text{ day}^{-1}$) over continuous submergence in clayey soils (Rezaei *et al.*, 2009). In an another experiment Huan *et al.* (2010) observed that AWD obtained higher grain yield and also reduced the irrigation water inputs (26.7%) compared to those of CF (Karim *et al.*, 2014 and Hebram and Saren, 2015). Water productivity of AWD was also increased compared to CF (Omar *et al.*, 2012).

2.2.6 Quality parameters

Singh *et al.* (2017) found that brown rice, milled rice and head rice recovery decreased significantly with increase in irrigation interval from 30 CPE to 75 CPE due to water stress experienced by the crop. The crop irrigated at 30 CPE schedule resulted in 77.4, 69.2 and 56.7 per cent brown rice, milled rice and head rice recovery which was 4.6, 5.5 and 6.8 per cent higher than that crop irrigated at 75 CPE schedule, respectively. Omar *et al.* (2012) revealed that milling recovery (hulling, milling and head rice %) and both amylose and protein contents were significantly affected by irrigation intervals in both seasons, except hulling (%) in 2008. The highest hulling per cent (76.61 and 77.61 % during 2007 and 2008, respectively), milling per cent (70.84 and 71.17% during 2007 and 2008, respectively) and head rice recovery (60.12 and 61.47% during 2007 and 2008, respectively) were recorded in continuous flooding (CF) which was superior over other irrigation intervals i.e. 6 and 12 days. But, Brar *et al.* (2015) found brown rice recovery, and milled rice recovery was statistically *at par* among irrigation application at 2, 3 and 4 days after disappearance of ponded water but significantly superior to 5 days after disappearance of ponded water. Head rice recovery was *at par* in 2 and 3 days after disappearance of ponded water but better than 4 and 5 days after disappearance of ponded water intervals. Significantly lower head rice recovery under 4 and 5 days after disappearance of ponded water treatments can be

ascribed to incomplete grain filling due to impairment of photosynthates and translocation of assimilates towards sink.

2.2.7 Economics

Kunimitsu (2006) reported that the economic value of irrigation water for paddy fields ranges from 0.4 to 0.65 US\$ m⁻³, depending on the location of the paddy field. Monetary value of water consumed in agriculture ranges from 0.05 to 0.90 US\$ m⁻³ (Perry, 2001). Similarly, Abu and Malgwi (2012) revealed that treatments supplied with water depth of 85 TAW and 8 days frequency gave the highest net income (US\$ 1905.0 and US\$ 1739.2), benefit:cost ratio (3.08 and 2.96) and gross profit rate (67.5 and 66.2 %). Cost-benefit analysis of eight case-study areas throughout the Indonesia showed that total costs of Integrated crop and resource management (using AWD +LCC+ young aged seedling) farmers were higher than those of conventional farmers (Wardana *et al.*, 2002). Rahman and Sinha (2013) in West Bengal revealed that higher net returns (20281 ₹ ha⁻¹) and B:C ratio (1.78) at saturation as compared to farmers practice and intermittent ponding (2 DAD 5±0) from 15 to 35 DAT followed by CP (Wardana *et al.*, 2002). Kumar *et al.* (2013) recorded maximum B:C ratio (1.35) under 7 cm irrigation at 1 DADPW compared to 7 cm irrigation at 3 (1.11) and 5 (1.07) DADPW. In line results were also reported by Dass and Chandra (2012) and Paul *et al.* (2013). Singh *et al.* (2017) in 2012 and 2013 at Ludhiana in their pooled data found that monetary input (313.5 \$ ha⁻¹) and net returns (798.1 \$ ha⁻¹) were highest from crop irrigated at frequent interval at 30 CPE than at 45, 60 or 75 CPE (Subramanyam *et al.*, 2007).

2.2.8 Energetics

In north-west India, more than 60% of the groundwater pumps are powered by electricity. Because of the voting strength of the huge number of farmers, the state electricity boards are always under pressure to supply electricity free or at highly subsidized rates to the farmers. In, 2007, about 28% of the electricity consumed in Punjab was supplied to the farmers at a subsidized rates resulting in an annual loss of US\$400 millions to the state (Hira, 2009). Of the total consumption of electricity in 2014-15, industry sector accounted for the largest share (44.11%), followed by domestic (22.93%), agriculture (17.81%) and

commercial sectors (8.27%). In, 2013-14 about 1,52,744 Gw hr electricity power consumed in India was supplied to farmers at subsidized rates with an annual growth rate of 10.59% in year 2014-15 over year 2013-14 (Anonymous, 2016e).

Karim *et al.* (2014) reported that electricity consumption was found highest (4593 Kwhr ha⁻¹) in flood irrigation method due to highest amount of irrigation water used, while when compared to AWD (3543.33 Kwhr ha⁻¹). Singh *et al.* (2017) reported that frequent irrigation schedule at 30 CPE recorded higher energy input and energy output were maximum because of higher water input and grain yield which resulted in higher net energy gain (148.8 and 174.5 MJ ha⁻¹, respectively) and energy use efficiency (7.3 and 8.5, respectively) when compared to 45, 60 or 75 CPE. Brar *et al.* (2015) reported that the energy input, energy productivity and net return of 2 weeks ponding were 9.6, 5.7 and 20.9% higher than one week ponding, respectively. Further they reported that energy input and output decreased with increase in subsequent irrigation interval from 2 to 5 days after disappearance; however energy efficiency and energy productivity was maximum in 3 days after disappearance of ponded water as compared to all other irrigation intervals.

2.3 Effect of nutrient levels on rice crop

2.3.1 Growth attributes

Higher levels of nutrient giving significantly higher plant height, panicle initiation, number of tillers hill⁻¹, total chlorophyll content *etc.* were reported by many researchers (Mahajan and Tripathi, 1992; Dehal and Mishra, 1994; Ehsanullah *et al.*, 2012 and Pramanik and Bera, 2013). Gani *et al.* (2002) reported that high fertilizer rates increased root production (dry matter) but not too deep soil (low root depth/length) layers. Jiaguo *et al.* (2013) reported that organic fertilizer are slower than from chemical fertilizers in promoting higher tiller number during the productive tillering stage. High nitrogen supply suppresses crown-root elongation, resulting in small root systems (Yamazaki and Harada, 1982). Awan *et al.* (2011) reported maximum plant height (80.00 cm) and tillering m⁻² (601) when nitrogen was applied at maximum rate *i.e.* 156 kg·ha⁻¹, while minimum number of tillers (527) were recorded when nitrogen was applied at low rate of 110 kg·ha⁻¹ (Kaushal *et al.*, 2010). Chowdhury *et al.* (2014) observed that respective increase in grain yield due to only 120 kg N, 60 kg P₂ O₅ and 40 kg K₂O ha⁻¹ (F₁), 10 t

FYM ha⁻¹ + 100% F₁, 10 t FYM ha⁻¹ + 75% F₁ and 10t FYM ha⁻¹ + 50% F₁ over only 10t FYM ha⁻¹ was to be the tune of 32.73%, 49.27%, 37.02% and 31.25%, respectively over pooled data. They further added that grain yield followed the same trend as of growth and yield attributing characters and grain: straw ratio varies from 0.706 to 0.670 whereas harvest index from 41.33% to 40.05%.

2.3.2 Yield and yield attributes

Awan *et al.* (2011) reported maximum number of grains panicle⁻¹, grain yield and straw yield when nitrogen was applied at higher rate (156 kg ha⁻¹) while minimum was recorded from low level of nitrogen fertilizer (110 kg ha⁻¹). The percentage of grain yields an increase of 72.5, 44.4, 23.8 and 5.1 per cent in first year and 69.9, 44.1, 22.1 and 3.5 per cent in second year over N₀, N₅₀, N₁₀₀ and N₂₀₀ kg ha⁻¹ respectively (Pramanik and Bera, 2013). Similar results were also reported by those of Mahajan and Tripathi (1992) and Dehal and Mishra (1994). Diproshan *et al.* (2015) found 150 kg N ha⁻¹ exhibited the maximum yield attributes viz., number of panicles m⁻², filled grains hill⁻¹, test weight and grain as well as straw yield over other N levels (viz. 0, 50 and 100 kg N ha⁻¹). Similar results were also reported by Yoseftabar (2013). However, Bezbaruha *et al.* (2011) conducted experiment in rice crop reported that with 100% RF dose through inorganic fertilizers alone produced maximum productive tillers m⁻² (398.69) and filled grains panicle⁻¹. Increased grain yield associated with added fertilizer levels might be due to the cumulative effect of increased translocation of photosynthates to sink resulting in enhanced level of yield components (Murthy *et al.*, 2015).

Mohanty *et al.* (2014) reported that INM practices produced the highest amount of grain yield (6.2 and 6.7 t ha⁻¹) which was significantly higher than that obtained with RDF and organic manure. Wardana *et al.* (2002) in Indonesia observed that organic matter application has a positive effect on yield giving approximately 300 kg increase in yield per ton of applied organic matter under both intermittent irrigation and flooding conditions. Choudhary *et al.* (2011) observed that insignificantly higher values of yield attributes viz. panicles m⁻², panicle length, grains panicle⁻¹, panicle weight, 1000-grains weight were obtained under integrated sources (75% DN + 25% N Vermicompost) of nutrient management over 100% RDN. Larijani and Hoseini (2012) observed that there was

no significant difference between chemical fertilizer and organic fertilizer alone. Their results indicated more tiller number, chlorophyll content at panicle initiation and flowering time, more panicle m^{-2} , number of filled grains m^{-2} , spikelet per panicle and more grain yield with combined use of organic and chemical fertilizer compared with chemical fertilizer or organic matter alone.

2.3.3 Nutrient uptake

Gautam *et al.* (2013) reported that the effect of nutrient levels on N, P, K content in grain and straw of rice indicated that N content in grain and K content in straw was influenced significantly with increasing level of nitrogen from no nutrient to 100% RDF, whereas P and K content in grain and N and P content in straw remained unaffected with the application of nutrient. Singh *et al.* (2013b) recorded that concentrations of N in grains and straws of rice were significantly increased due to application of the recommended doses of chemical fertilizers and INM as compared to the control. Singh *et al.* (2010) reported application of graded levels of nitrogen to Basmati rice significantly increased the organic carbon and P content up to 60 kg ha^{-1} but N and K content increased significantly only up to 40 kg ha^{-1} . Further increase in nutrient doses did not affected nutrient content of grain (Rao *et al.*, 2014). However, Sharma *et al.* (2012) found that nitrogen content in grain was non-significant with N levels.

Plants absorbed the nutrients proportionately as the pool of available nutrients increases in soil solution (Murthy *et al.*, 2015). Increased nutrient absorption by rice with increased fertilizer doses has also been reported by Singh and Namdeo (2004). Chowdhury *et al.* (2014) recorded increased nitrogen, Phosphorus and Potash uptake due to poultry manure, vermicompost and FYM at 50% RDN over no-organic to the tune of 37.53%, 39.57% and 19.41% respectively. In differing to this, Bezbaruha *et al.* (2011) reported that maximum N (100.73 and 104.07 kg ha^{-1}), P (23.59 and 25.89 kg ha^{-1}) and K (151.27 and 156.24 kg ha^{-1}) uptake was received in 100% nutrients through inorganic fertilizers, and was statistically at par with the treatment 25% nutrient through organic and 75% through inorganic sources. Vermicompost applied plots built-up residual soil fertility because of slow release of nutrients and reduction of nutrient losses (Bezbaruha *et al.*, 2011). Jugseniya (2012) recorded increased nitrogen, P and K uptake in rice with increasing levels of

nitrogen in scented rice. Application of 180 N kg ha⁻¹ recorded higher nitrogen, P and K uptake at all stages which was significantly superior over 90 kg, 120 kg and 150 kg N ha⁻¹ nitrogen, except that at harvest (Singh *et al.*, 2015). Application of 180 kg N ha⁻¹ was on par with 150 kg and in turn 150 kg N ha⁻¹ was on par with 120 kg N ha⁻¹ in term of N uptake by grain. Nitrogen fertilization beyond 60 kg N ha⁻¹ level can reduce the agronomic efficiency, partial factor productivity and apparent recovery of nitrogen on hybrid rice (Singh *et al.*, 2015). The nutrient uptakes are reported to increase progressively with increasing levels of nutrients (Jadhav and Dahiphale, 2005; Pasha *et al.*, 2013 and Aruna *et al.*, 2016).

2.3.4 Soil nutrient status

Application of organic manure along with chemical fertilizer are reported to accelerate the microbial activity, increase nutrients use efficiency (Narwal and Chowdhury, 2006) and enhances the availability of the native nutrients to the plants resulting higher nutrients uptake (Bhandari *et al.* 1992). Combination of organic and inorganic fertilization showed significantly higher yields than sole chemical Fertilization. The superiority of integrated nutrient management (INM) might be due to presence of humic acid compounds which helps in dissolution of minerals and chelation of micronutrients (Mehra, 2006). Vermicompost applied plots built-up residual soil fertility because of slow release of nutrients and reduction of nutrient losses (Bezbaruha *et al.*, 2011). Higher nutrients uptake with the application of inorganic fertilizer reported to be due to higher nutrient concentration along with higher biomass production (Swarup and Yaduwanshi, 2006 and Banik *et al.*, 2006). Plants absorbed the nutrients proportionately as the pool of available nutrients increases in soil solution (Murthy *et al.*, 2015).

Chowdhury *et al.* (2014) observed that integrated use of fertilizer and organic manure (vermicompost) treatment improved the soil physical properties like bulk density and organic carbon over no organic. They also recorded higher value of available NPK due to poultry manure, vermicompost and FYM at 50% RDN over no-organic. Post soil fertility status revealed that the soil organic carbon and available nitrogen status increased progressively with incremental levels of N up to the highest dose tried. However, available phosphorus and potassium status was markedly progressively

decreased with incremental levels of N from 60 kg to the highest dose tried (Rao *et al.*, 2014). Singh *et al.* (1999) reported decreased nutrient response with enhanced N levels. The probable reason for lower N efficiency at higher N levels may be due to higher N losses with increased levels of N (Daftardar and Savant, 1995). Bezbaruha *et al.* (2011) noted that Rice cultivars recorded significantly higher residual soil nutrient Murthy *et al.* (2015) recorded that incremental doses of N by 50 % and above only improved the status of organic carbon and available N over initial value. Status of N, P and K uptake under 100% RDF through vermicompost. Jugseniya (2012) reported that available nitrogen, phosphorus and potassium status of soil after harvest of the crop varied significantly highest in 180 kg N ha⁻¹ which was significantly superior over corresponding lower levels of nitrogen. The above trend might be due to considerable quantities of nutrients left in the soil after meeting maximum requirement of the crop (Aruna *et al.*, 2016). Similar results were also reported by Pandey *et al.* (2000) and Kishor *et al.* (2008).

2.3.5 Water use studies

Yang and Zhang (2010) reported that controlled soil drying does not necessarily reduce grain yield even when plants are grown under normal nitrogen conditions. Several practices, such as post-anthesis controlled soil drying, alternate wetting and moderate soil drying regimes during the whole growing season, and non-flooded straw mulching cultivation, could substantially enhance WUE and maintain or even increase the grain yield of rice, mainly via the enhanced remobilization of pre-stored carbon reserves from vegetative tissues to grains and improved HI. (Jugseniya, 2012). Water and nutrients are complementary inputs, thus depend on each other for the combined and cumulative effect on crops to improve WUE and NUE (Halli *et al.*, 2016). Plants which have adequately used fertilizers may also show higher drought tolerance (Wang *et al.*, 2011) by a synergistic water–N interaction achieved by adoption of a moderate AWD regime with a normal amount of N application, consisting of re-watering.

Evapo-transpirational and transpirational water use efficiency can be increased by raising soil nutrient levels (Halli *et al.*, 2016). Adequately fertilized soils promote rapid leaf area expansion, thus increasing transpiration,

and more rapid ground cover, thus reducing evaporation and increasing evapotranspirational water use efficiency. Raised soil nutrient levels seem to exert additive effects on water use efficiency, and increasing or optimizing yields by adequate application of fertilizers will increase transpiration efficiency of the crop plants (Schmidhalter and Studer, 1998). Chowdhury *et al.* (2014) found that in case of nutrient levels WUE increased with increasing levels of nutrient in integrated combination with FYM 10 t ha⁻¹ + 100% of F₁ (F₂) produced the maximum value of WUE over all the nutrient levels but was found at par with F₁-120kg N, 60 kg P₂O₅, 40 kg K₂O ha⁻¹ (RDF) and F₃ - FYM @ 10 t ha⁻¹ +75% F₁.

2.3.6 Quality parameters

Grain quality in rice is more important than in many other cereals. In trade, rice quality is well recognized and marketability of rice depends very high on its quality (Anonymous, 1998). Environmental variation during the crop growth period influence quality traits (Bhashyam and Srinivas, 1984). Nitrogen is a building block component of protein. High-protein rice is more resistant to abrasive milling than low-protein rice (Cagampang *et al.*, 1966 and Leesawatwong *et al.*, 2005). High protein content also has been reported to improve milling and head rice recovery percentage (Perez *et al.*, 1996). Gautam *et al.* (2008) witnessed that 160 kg N ha⁻¹ obtained higher hulling %, milling % and head rice recovery compared to zero nitrogen application. In parallel to this, Kandil *et al.* (2010) added that highest hulling %, milling percentage, head rice recovery and crude protein content were found under higher nitrogen dose of 80 kg N ha⁻¹ noted *on par* with 60 kg N ha⁻¹. Gill and Walia (2013) reported that N₄ (125% of RDN) had a significant effect on brown rice, milled rice and head rice recovery and was significantly superior than other nitrogen levels but was statistically *at par* with N₃ (100% of RDN). They supposed better development of rice grain than hull and the increase in protein content with increasing doses of nitrogen might have improved the hulling rice recovery. Grain quality in terms of grain protein content, milling percentage and head rice recovery was progressively increased with the incremental doses upto 150% N, however the hulling percentage improved upto 125 % additional dose of N (Murthy *et al.*, 2015). Similar finding was also observed by Mahajan *et al.* (2011). In contrary to these, Chaudhary *et al.* (2011); Jugseniya

(2012) and Sharma *et al.* (2012) had no significant effect in respect to hulling, milling and head rice recovery with respect to nitrogen management.

2.3.7 Economics

Chowdhury *et al.* (2014) found that under organic sources of nutrient, maximum cost of cultivation was recorded under vermicompost @ 50% RDN, while net returns and benefit: cost ratio were under poultry manure @ 50% RDN. Under inorganic sources of N, maximum cost of cultivation, net return and benefit: cost ratio were recorded highest under 125% RDN. The variation in the cost of cultivation were explained by the differences of cost of organic and fertilizer sources. Also grain and straw yields were the major factors which caused differences in net return and benefit : cost ratios. INM can fetch better gross returns over that of RDF and sole organics, but then also it fetched very similar net return to that of RDF due to high cost of cultivation. The return ₹⁻¹ invested for INM was lower than RDF (Mohanty *et al.*, 2014). Sultan *et al.* (2007) reported that application of 120:60:60 NPK kg ha⁻¹ showed maximum net return and B:C ratio as compared to 100:50:50, 140 :70 :70, and 80: 40 :40 NPK kg ha⁻¹ (Mannan *et al.* (2010). Jugseniya (2012) calculated that nitrogen fertilization resulted in increase in the monetary returns up to 120 kg ha⁻¹ and further increase in the nitrogen dose (150 and 180 kg ha⁻¹) did not improve the income. However, Aruna *et al.* (2016) noted that net returns recorded in N5 (175% RDN) was superior and was followed by N4 (150% recommended dose of nutrients), N3 (125% RDN) and N2 (100% RDN) in descending order. Similarly, the gross returns, net returns and rupee per rupee invested were increased progressively with incremental doses of N (Rao *et al.*, 2014), the increase was statistically measurable up to additional dose of N @ 60 kg ha⁻¹ (50 % increase) (Murthy *et al.*, 2015).

2.3.8 Energetics

Energy is one of the valuable inputs in production agriculture. Agriculture itself is energy user and energy supplier in the form of bio-energy (Alam *et al.*, 2005). Mohanty *et al.* (2014) found that among nutrient management practices, use of sole organics became most energy efficient by expending the least energy and the maximum energy was spent by RDF followed by INM practices. Sharma *et al.* (2015) found maximum highest grain production efficiency under control treatment followed by pelleted 5t FYM+50:30:20 kg

$\text{N:P}_2\text{O}_5\text{:K}_2\text{O ha}^{-1}$. Murthy *et al.* (2015) reported that energy use efficiency of N was increased by increase in N level by 25 % only (application of NPK @ 120-60-40 to 150-60-40 kg ha^{-1}) then it declined with further increments of N. Singh *et al.* (2016) observed that in 50% RDN through FYM + 50% RDN through VC+BF significantly higher values of gross energy output (121.69 GJ/ha), net energy output (105.03 GJ/ha), energy use efficiency (12.79%) and energy productivity (0.96 kg/MJ) were recorded over control (farmer's practice) and 100% N through vermicompost (VC) + Biofertilizer (BF). Energy intensity in economic terms (3.93 MJ/₹) was maximum with application of 100% RDN through FYM + BF over all the other organic sources. Similar finding was also reported by Baishya *et al.* (2014).

2.4 Interaction effect of water regimes, nutrient levels and establishment methods on rice crop

2.4.1 Growth attributes

McHugh *et al.* (2002) indicated that cultivation system, geographic location, and soil type account for 28%, 12%, and 9%, respectively, of the overall variation in yields. Irrigation type during vegetative growth, nutrient additions or not, and transplant age were the important management factors accounting for 5%, 4%, and 3%, respectively, of the overall variation in grain yields (McHugh *et al.*, 2002). Ali *et al.* (2013) concluded that transplanting of younger seedlings (15 days age) in combination with intermittent irrigation provided the highest plant height, LAI, dry matter hill^{-1} , number of tillers hill^{-1} effective tillers hill^{-1} followed by the seedlings of same age transplanted in continuous flooded plots. Meena *et al.* (2003) reported significant improvement in dry matter accumulation of rice with increasing nutrient levels on account of better growth and development of the plant. They observed that although, dry matter accumulation was not influenced significantly by spacing but numerically dry matter accumulation m^{-2} was higher under wider spacing.

Jiu *et al.* (2013) recorded in a water and nutrient interactive treatments, that ROA (root oxidation activity) during grain filling was the highest under the AWD-SSNM, and the smallest under the CF- Farmer's N Practice (FNP), and the intermediate under the Conventional Flooding (CF)-SSNM and AWD- FNP treatments. They found root dry weight significantly correlated with shoot dry

weight at the heading time ($r = 0.93^{**}$, $P = 0.01$, $n = 16$), and the ROA significantly correlated with the photosynthetic rate of flag leaves during the grain filling period ($r = 0.84^{**}$, $P = 0.01$, $n = 24$), indicating root and shoot interactions. They also reported that LAI of productive tillers + main stems at the heading time, the total LAI at maturity, and LAD from heading to maturity were the smallest for the CF-FNP treatment, the greatest for the AWD-SSNM treatment, and intermediate for treatments of CF-SSNM and AWD-FNP. Ashouri (2012) revealed about interaction of irrigation regime (I1= continuous submergence (CS), I2 = 5, I3 = 8 and I4 = 11 days interval) and nitrogen level (N1= 0, N2 = 90, N3 = 120 and N4 = 150 kg ha⁻¹) that on biomass of I₁N₄, I₂N₄ and I₃N₄, produced same biomass and I₄N₁ had minimum value.

2.4.2 Yield and yield attributes

Sarwa *et al.* (2011) studied effect of age of seedling, seedling density and nitrogen levels revealed that 10 days old nursery seedlings irrespective of seedling density hill⁻¹ and nitrogen level produced higher yields and yield attributes *viz.* productive tillers, 1000 seed weight and straw yield. Ali *et al.* (2013) concluded that transplanting of younger seedlings (15 days age) in combination with intermittent irrigation performed the best in filled grains panicle⁻¹, unfilled grains panicle⁻¹, grain yield. At harvest 15-d-old seedlings transplanted in intermittent irrigated plots provided the highest filled grains panicle⁻¹, unfilled grains panicle⁻¹, grain yield, straw yield, harvest index over other treatments combinations. However, the heaviest grains (22.61 g) were obtained from continuous flooded plots where 15-d-old seedlings were transplanted and the lightest grains (21.00 g) obtained from continuous flooded plots where 30-d-old seedlings transplanted. Lu *et al.* (2002) reported that in the treatments without N fertilizer, there were no significant differences among the water regimes (*viz.* flooding, AWD, rainfed and saturated). Liu *et al.* (2013) when compared WUE found that under conventional flooding(CF)-Farmer's N Practice (FNP) treatment, grain yield was increased by 5.7–6.1%, 6.0–6.6%, and 12.4–14.5%, respectively, under CF-Site Specific N Management (SSNM), AWD-FNP, and AWD-SSNM treatments.

Chapagain *et al.* (2011) found synergistic responses when SRI practices were combined with organic management that ultimately led to comparable grain

yields. McHugh *et al.* (2002) recorded on SRI plots that grain yields were higher for AWD irrigation followed by NF irrigation and continuously flooded. The results of the study suggest that, by combining AWD irrigation with SRI cultivation practices, farmers can increase grain yields while reducing irrigation water demand. Jiaguo *et al.* (2013) reported that SRI practices along with the modified water saving techniques increase rice yield by 0.49 t ha^{-1} compared to traditional techniques. Jagannath *et al.* (2013) in a meta-analysis of data revealed that average yield in SRI methods was 5.9 tons ha^{-1} compared to 5.3 tons ha^{-1} when using more standard rice-production practices. Higher yield was seen in all the studies with less input of water whenever mostly SRI crop management practices were introduced.

Mannan *et al.* (2012) observed that grain yield varied due to water stress and nitrogen levels. The highest grain yield was observed in the plots where continuous standing water was maintained and higher doses of N were applied. While, low grain yield (23%) in the crop affected by water stress at the vegetative stage compared to standing water and applied higher doses of N due to less number of panicles with shorter in length. Ashouri (2012) found that the effect of nitrogen level and interaction of irrigation regime and nitrogen level on harvest index was not significant. Turmel (2011) found that when compost was used in combination with urea-N fertilizer, yields in the intermittently flooded system were comparable to the flooded system; however, when compost was not used, yields were greater with flooding.

2.4.3 Nutrient uptake

Adoption of moderate AWD with an appropriate nitrogen application rate may exert a synergistic effect on grain yield and result in higher WUE and nitrogen use efficiency. It is hypothesized that there would be a synergistic interaction between soil moisture and N fertilizer on crop growth if both water and N were managed properly, and that such a synergistic interaction would increase crop yield, WUE and NUE (Liu *et al.*, 2013). Lawlor and Cornic (2002) stated that a water deficit could have a more marked effect on N assimilation than on the uptake process, as nitrate reductase activity diminished sharply, albeit in a reversible fashion, in line with low relative water content values. Wang *et al.* (2016) reported

that synergistic water–N interaction can be achieved by adoption of a moderate AWD regime with a normal amount of N application, consisting of re-watering at SWP of -15 kPa and N rate at 200 kg ha^{-1} or midday LWP at approximately -0.69 and -0.86 MPa and specific leaf N content at $2.2\text{--}2.3$ and $2.0\text{--}2.1 \text{ g m}^{-2}$ at early and late growth stages, respectively. Jiu *et al.* (2013) recorded that N content and the total N uptake in plants at maturity were smaller under SSNM than under FNP when the irrigation technique was the same, and the total N uptake was more under AWD than under CF when N management was the same.

Chowdhury *et al.* (2014) found that irrigation and nutrient levels significantly influenced the N, P and K contents and nutrient uptake, in rice grain and straw. It was the maximum in the treatment which received the maximum number of irrigation and highest doses of NPK from the combination of organic and inorganic sources (Pan *et al.*, 2009). Gatti *et al.* (2011) observed that N concentrations on dry matter basis were significantly higher in dry treatments than in flooded conditions and higher N rates (100 and 150 kg ha^{-1}) resulted in a significant increase N concentrations in both cultural (flooded and alternate irrigation) methods. Mannan *et al.* (2012) observed that nitrogen uptake was higher both in grain and straw in the crop which was not affected by water stress at their growth stages and supplied higher level of nitrogen. N-uptake was lower in the crop that affected by water stress especially at the vegetative or at reproductive stages although the rate of N supply was high. Sun *et al.* (2011) found that water and nutrient stress decreased leaf nitrogen and phosphorus concentration but increased potassium concentration supposing that the combination of water and nutrient stress made significant effects on nitrogen and phosphorus concentration, but no significant effects on potassium concentration.

2.4.4 Soil nutrient availability

Nitrogen absorption by crops is automatically reduced under dry conditions, even when mineral N is present in the soil colonized by roots (Gonzalez *et al.*, 2005). Under water scarcity, N demand by plants is reduced, as growth rate is diminished. If the effect on N supply is greater than that on plant growth, the result will be a N deficiency. The absorption of N by roots requires the presence of water in the soil, as it is the agent that transports solutes to the soil-root

interface (Garwood and Williams, 1967). Singh *et al.* (2013a) reported that soil organic carbon (SOC) was statistically at par under SRI and CT, and it ranged from 0.36% to 0.47% with the recommended doses of fertilizers and INM, but declined to 0.31% in the control. Gopalakrishnan *et al.* (2013) recorded total N and OC% were found to be significantly higher in both SRI-organic and SRI-inorganic treatments over BMP treatments. Fan and Li (2001) found that N-use efficiency was increased by water deficit and diminished by the dose of N applied. Pirmoradian *et al.* (2004) reached the same conclusions in rice, but the effect was only significant at high fertilizer application rates. Nitrogen transformation processes closely depend on water and its mobility in the soil and the factors affecting soil nutrition, storage capacity and accessibility, soil texture, root depth and organic matter concentration deserve particular attention (Keller, 2005).

Pan *et al.* (2009) demonstrated that reduced yield and N uptake by rice plants in dry conditions could be depending on the larger process of nitrification in the dry soil followed by higher rates of N leaching. Gatti *et al.* (2011) in a study suggest that potential for rice growth under non-flooded conditions through cultivation practices allowed delayed availability of urea-N if nitrification inhibitors are effective in controlling the rate of nitrate formation result in improved N use efficiency by rice plants. Turmel (2011) reported that soil macronutrient availability are affected significantly by water regime and fertilizer source and reported that available soil N (NO_3^- and NH_4^+) was increased by flooding, addition of compost and mineral N fertilizer. They also found consistent response of available soil N to mineral fertilizer addition in both the flooded and intermittently flooded water regimes but by the end of the second season, only compost had a significant positive effect on the soil N availability. In contrast to available soil N, available soil P declined significantly in the continuously flooded plots. Soil P was increased significantly by compost application in both field seasons. They further concluded that water regime and mineral fertilizer had no effect on the soil available K.

2.4.5 Water use studies

Changing certain soil parameters (organic matter, porosity, soil aeration, and soil biodiversity) and managing rice plants differently (less crowding, more

careful transplanting, and root growth stimulation) are necessary to get the full benefit of reducing water applications (Jagannath *et al.*, 2013). Kumar *et al.* (2011) reported that there is a reduction in the water requirement (32%) and also increased yield in SRI as compared to conventional method of crop establishment. Gopalakrishnan, *et al.* (2013) indicated water savings with SRI management up to 17–47 %. Both the SRI-organic and SRI-organic + inorganic received significantly lower irrigation water compared to BMP (best management practice) with water savings averaged 31 and 37 % during *Kharif* and *Rabi* seasons, respectively. Further, irrigation water use efficiency (WUE) was found to be higher in SRI-organic compared to SRI-organic + inorganic treatments. Liu *et al.* (2013) found that under CF-FNP treatments, WUE (grain yield over the amount of irrigation water and rainfall) increased by 5.7–5.8, 11.7–18.6% and 22.9–26.7%, respectively, under CF-SSNM, AWD-FNP and AWD-SSNM treatments (Lu *et al.*, 2002). Kumar *et al.* (2011) found that SRI method saved irrigation water without any penalty on yield compared to conventional method by using intermittent irrigation. McHugh *et al.* (2002) reported that productivity of water for SRI was twice as high for AWD irrigation (0.30 kg m^{-3}) than for continuous flooding (0.13 kg m^{-3}) on the highly permeable (seepage + percolation $>5 \text{ cm d}^{-1}$) terraced paddy field. 55% less irrigation water than the conventional practice of continuous submergence are required in AWD as reported by McHugh (2002). Jagannath *et al.* (2013) reported that total water use efficiency was 52% greater with use of most of the SRI methods (0.60 grams of grain per liter), as mean productivity for SRI practices (0.39 grams of grain per liter). Lin *et al.* (2011) recorded intermittent irrigation increased total WUE and IWUE, compared to CF (continuous flooding), under all three organic fertilization treatments (25%, 50% and 75% through organic source) and reported that lower proportion of organic fertilization (25% through organic) in intermittent irrigation increased WUE by 43–44%, and IWUE was raised by 78–79%, compared with CF.

Ashouri (2012) found that interaction of irrigation regime (I1= continuous submergence (CS), I2 = 5, I3 = 8 and I4 = 11 days interval) and nitrogen level (N1= 0, N2 = 90, N3 = 120 and N4 = 150 kg ha⁻¹) of I₁N₄ and I₁N₁ consumed maximum water with 5480 and 5440 m³ and I₃N₄, I₃N₃ and I₄N₁ with 3590, 3580

and 3550 m³ consumed minimum water. WUE in I₁ to I₄ were 1.44, 1.53, 1.68 and 1.33 kg m⁻³ respectively. Diproshan *et al.* (2015) recorded that water use efficiency increased from 2.71 to 5.10 kg ha⁻¹ mm⁻¹ with increase in level of N from 0 to 150 kg N ha⁻¹. The water use efficiency was recorded highest under the combination of irrigation regime I₂ (Saturation up-to panicle initiation stage followed by maintaining, 1±2 cm standing water till maturity) and N₃ (100 kg N ha⁻¹) followed by the combination of irrigation regime I₂ (Saturation up-to panicle initiation stage followed by maintaining, 1±2 cm standing water till maturity) and N₄ (150 kg N ha⁻¹). Simply reducing water applications does not suffice to give rice plants a better environment for growth, health and productivity.

2.4.6 Quality parameters

Pan *et al.* (2009) reported non-significant interactions between irrigation regimes and N rates for quality parameters i.e. brown rice recovery, milled rice recovery and head rice recovery. In an another experiment Gatti *et al.* (2011) found that milling process on the grain samples under alternate wetting and drying did not affect negatively the head rice yield but resulted in a slight improvement of commercial grain quality and higher head rice yield (66.7%) was obtained under intermediate N (150 kg ha⁻¹).

2.4.7 Economics

Chapagain *et al.* (2011) found that production costs for SRI plots were comparatively higher (0.89 US\$/kg) compared to the conventional plots (0.74 US\$/kg). Despite the reduced material costs of SRI plots (i.e., 80% reduction in seed costs and 70% reduction in fertilizers and pesticides costs), the overall production costs were still higher as the costs of increased labor coupled with comparatively lower yields. However, net returns increased by about 1.48 times for SRI-organic compared to conventional inorganic methods and were associated with a price premium for organic rice. SRI can greatly increase net benefits as it saves approximately 25 to 50 per cent water over conventional production (Randriamiharisoa and Uphoff, 2002; Chapagain and Yamaji, 2010), thereby reducing production costs under water-scarce conditions.

Wardana *et al.* (2002) showed that total costs (material and labor costs) of integrated crop and resource management (using AWD +LCC+ young aged

seedling) farmers were higher than those of conventional farmers. However, the share of labor (70%) and material costs (30%) was similar ICM farmers apply higher amount of organic matter and used reduced amount of urea. Pramanik and Bera (2013) found that transplanting of 10-days seedling and application of nitrogen fertilizer 150 kg ha^{-1} recorded higher net return ₹⁻¹ (2.73 and 2.87) and B:C ratio (1.73 and 1.87) invested in the hybrid rice. Mohanty *et al.* (2014) found that SRI method with INM practices realized significantly the highest gross return followed by SRI with sole organics. Further, SRI method of crop establishment with INM fetched significantly the highest net return and the lowest net return was obtained from CT with sole organic nutrition.

Chowdhury *et al.* (2012) considering the economic returns (gross return, net return and net return per rupee investment) concluded that, irrigating the rice crop up to 2.5 cm 3 DAD of ponded water (I_2) and fertilizing the rice crop with FYM @ 10 t ha^{-1} + 120 kg N , $60 \text{ kg P}_2\text{O}_5$ and $40 \text{ kg K}_2\text{O ha}^{-1}$ (F_2) have been recorded to be best treatments. Rajitha and Reddy (2014) have found that SRI with integrated nutrient management (50% Farm Yard Manure (FYM) + 50% RD of NPK) and SRI with 100% organic manuring saved 28.63% and 34.25% input cost respectively, compared to conventional method of transplanting with recommended fertilizer and cultural practices (Chapagain and Yamaji, 2010).

2.4.8 Energetics

Farmers using SRI methods prefer AWD because it requires less labor. Initially for farmers using both SRI and conventional practices, labor inputs were 26% higher with the SRI but mastering the techniques in Madagascar and Sri Lanka now report that their labor inputs per hectare are lower with the SRI, so the SRI can become labor-saving over time (Barison, 2002). Mohanty *et al.* (2014) found that interaction effect of crop establishment and nutrient management practices on energy productivity of rice showed that the highest energy productivity was obtained from SRI method of crop establishment with INM practices, which was at par with SRI method of crop establishment receiving organic nutrition. Chapagain and Yamaji (2010) concluded by the results obtained in there experiment that reduced water, seed and labor requirements, while

maintaining or increasing yields, SRI methods are poised to become more widely adopted.

CHAPTER-III

MATERIALS AND METHODS

This chapter deals with the concise description of the materials used and the techniques adopted during the course of investigation. The present investigation entitled **“Evaluation of water regimes and nutrient management on rice-rice cropping system under transplanted and modified system of rice intensification (MoSRI)”** was conducted at the ICAR-Indian Institute of Rice Research (IIRR) Farm, Rajendranagar, Hyderabad during *kharif* and *rabi* seasons for two consecutive years (2015-16 and 2016-17).

3.1 Geographical situation

The experimental site Rajendranagar, Hyderabad is situated in North Eastern Dry Zone (Zone 2) of Telangana state between 17° 19' N latitude and 78° 23' E longitude with an altitude of 584 meters above the mean sea level. According to Troll's climatic classification, it falls under semi-arid tropics (SAT).

3.2 Climatic condition

The source of rainfall is south-western monsoon. It receives an average annual rainfall of 821 mm, mostly (85%) precipitated during the period of June to October. The monthly meteorological data for the period from August, 2015 to April, 2017 was collected from the meteorological observatory located at Agricultural Research Institute (ARI) Rajendranagar, Hyderabad are presented in Appendix A and Appendix B and Fig. 3.1 and Fig. 3.2 for *Kharif* and *Rabi* 2015-16 and in Appendix C and Appendix D and Fig. 3.3 and Fig. 3.4 for *Kharif* and *Rabi* 2016-17 Weather condition during the crop growth period.

The weather during crop growth in *Kharif* 2015 (10th August to 15th December 2015) and *Kharif* 2016 (23rd June to 6th November 2016) were normal with long sunny days. The weekly mean maximum temperature ranged from 29.1 to 33.1 °C with an average of 31.1 °C during *Kharif* 2015 and 27.6 to 32.8 °C with an average of 30.0 °C during *Kharif* 2016. The weekly mean minimum temperature ranged from 15.6 to 23.9 °C with an average of 20.3 °C during *Kharif* 2015 and 15.0 °C to 23.2 °C with an average 20.5 °C during *Kharif* 2016. The weekly mean relative humidity (%) recorded at 7.30 hr (RH-I) was 83.0 to 91.3 % in *Kharif*

2015, 82.1 to 95.3 % in *Kharif* 2016 and at 14.00 hr (RH-II) it ranged from 37.7 to 86.6 % during *Kharif* 2015, 30.0 to 81.9 % in during *Kharif* 2016. During the crop growth period, a total rainfall of 331.5 mm was received in 20 rainy days in *Kharif*, 2015 and 785.9 mm in 42 rainy days in the second year.

Bright sunshine during crop growth period ranged from 2.4 to 9.0 hours with an average of 6.2 hours during *Kharif*, 2015 and 1.3 to 9.2 hours with an average of 5.4 hours in *Kharif* 2016. The daily mean evaporation (mm) during the crop growth period was 4.2 mm and 3.7 mm during *Kharif* 2015 and *Kharif* 2016, respectively.

The weather during crop growth in *Rabi* 2015-16 (8th January 2015 to 15th May) and *Rabi* 2016-17 (5th December, 2016 to 16th April, 2017) were normal with long sunny days. The weekly mean maximum temperature ranged from 29.1 to 41.5 °C with an average of 35.6 °C during *Rabi* 2015-16 and 29.7 to 41.5 °C with an average of 34.5 °C during *Rabi* 2016-17. The weekly mean minimum temperature ranged from 11.0 °C to 25.7 °C with an average of 19.9 °C during *Rabi* 2015-16 and 10.3 °C to 25.4 °C with an average 17.8 °C during *Rabi* 2016-17. The weekly mean relative humidity (%) recorded at 7.30 hr (RH-I) was 45.0 to 83.3 % in *Rabi* 2015-16, 55.7 to 92.0 % in *Rabi* 2016-17 and at 14.00 hr (RH-II) it ranged from 19.3 to 40.6 % during *Rabi* 2015-16 and 18.9 to 43.0 % in during *Rabi* 2016-17. A total rainfall of 146.6 mm was received during crop growth period in *rabi* 2015-16 and 23.2 mm in *Rabi* 2016-17. Bright sunshine during crop growth period ranged from 6.8 to 9.5 hours with an average of 8.5 hours during *Rabi* 2015-16 and 6.8 to 9.8 hours with an average of 8.4 hours in *Rabi* 2016-17. The daily mean evaporation (mm) during the crop growth period was 3.6 mm and 9.3 mm during *Rabi* 2015-16 and *Rabi* 2016-17, respectively.

3.3 Experimental site

The experiment was conducted at the ICAR-Indian Institute of Rice Research (IIRR) Farm, Rajendranagar, Hyderabad in bunded rice block. The site selected for experiment was ideal, as it had assured irrigation and drainage facilities. Geographical situation of plot is shown below by the help of google map (Plate 3.1).

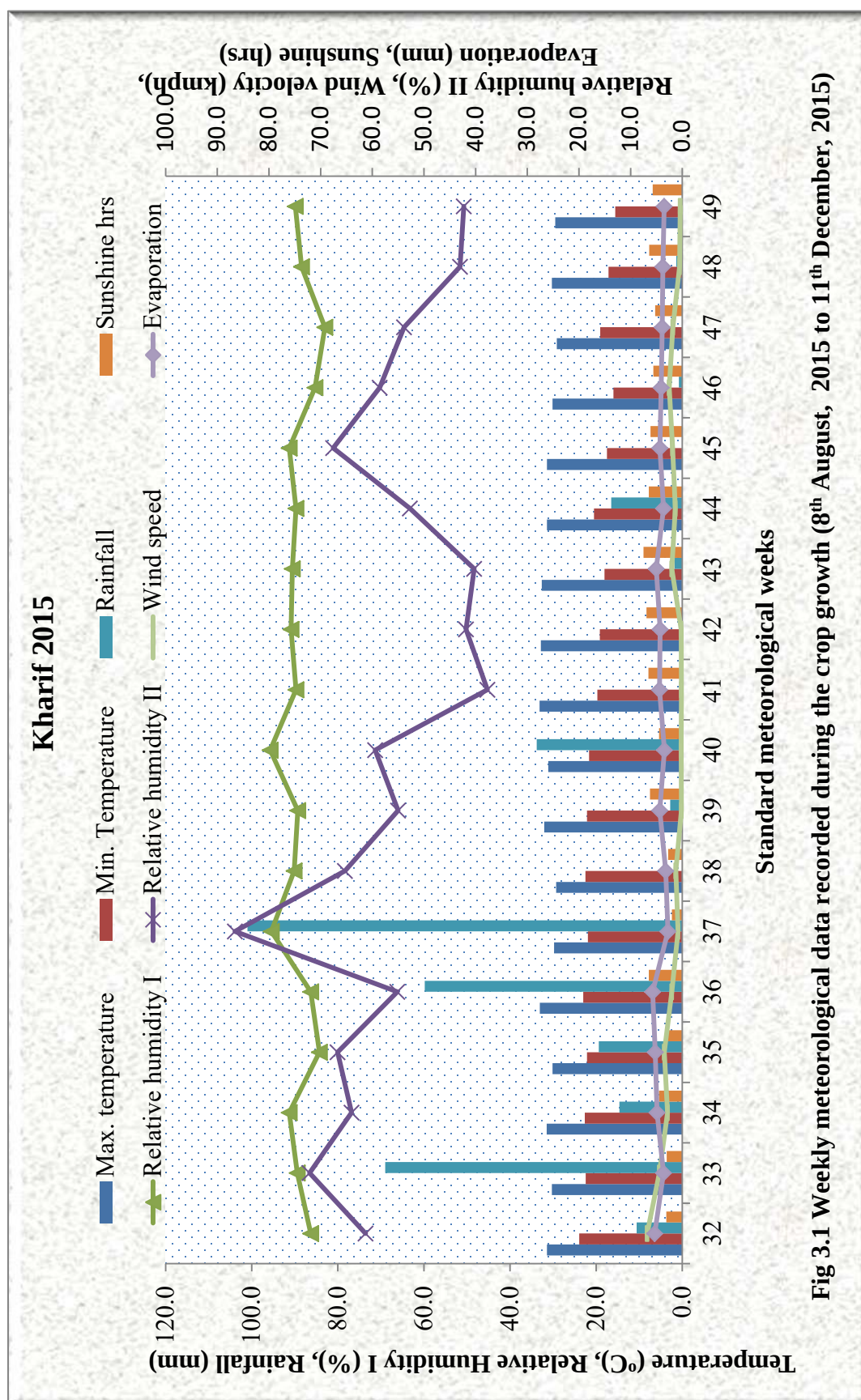


Fig 3.1 Weekly meteorological data recorded during the crop growth (8th August, 2015 to 11th December, 2015)

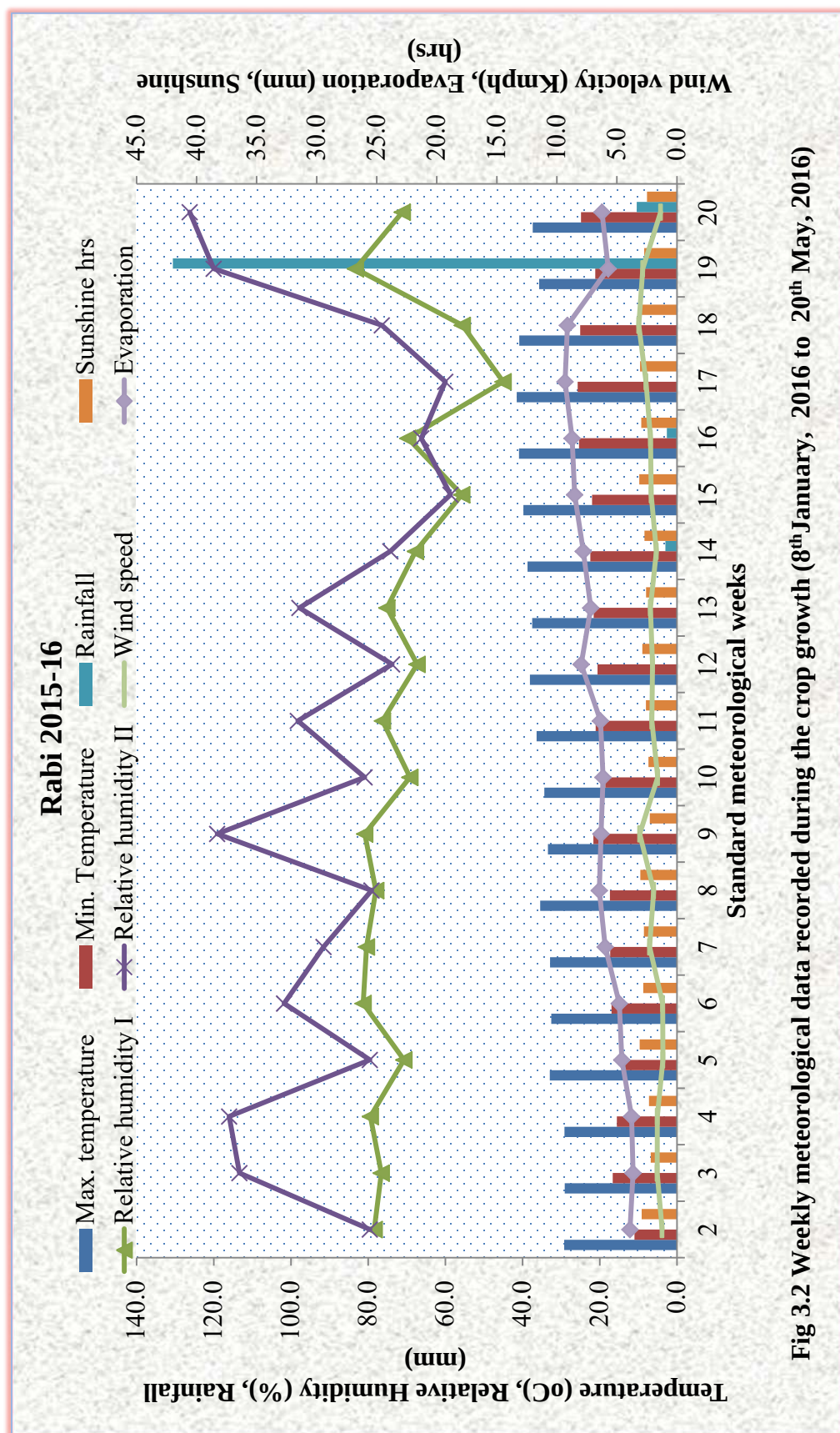


Fig 3.2 Weekly meteorological data recorded during the crop growth (8th January, 2016 to 20th May, 2016)

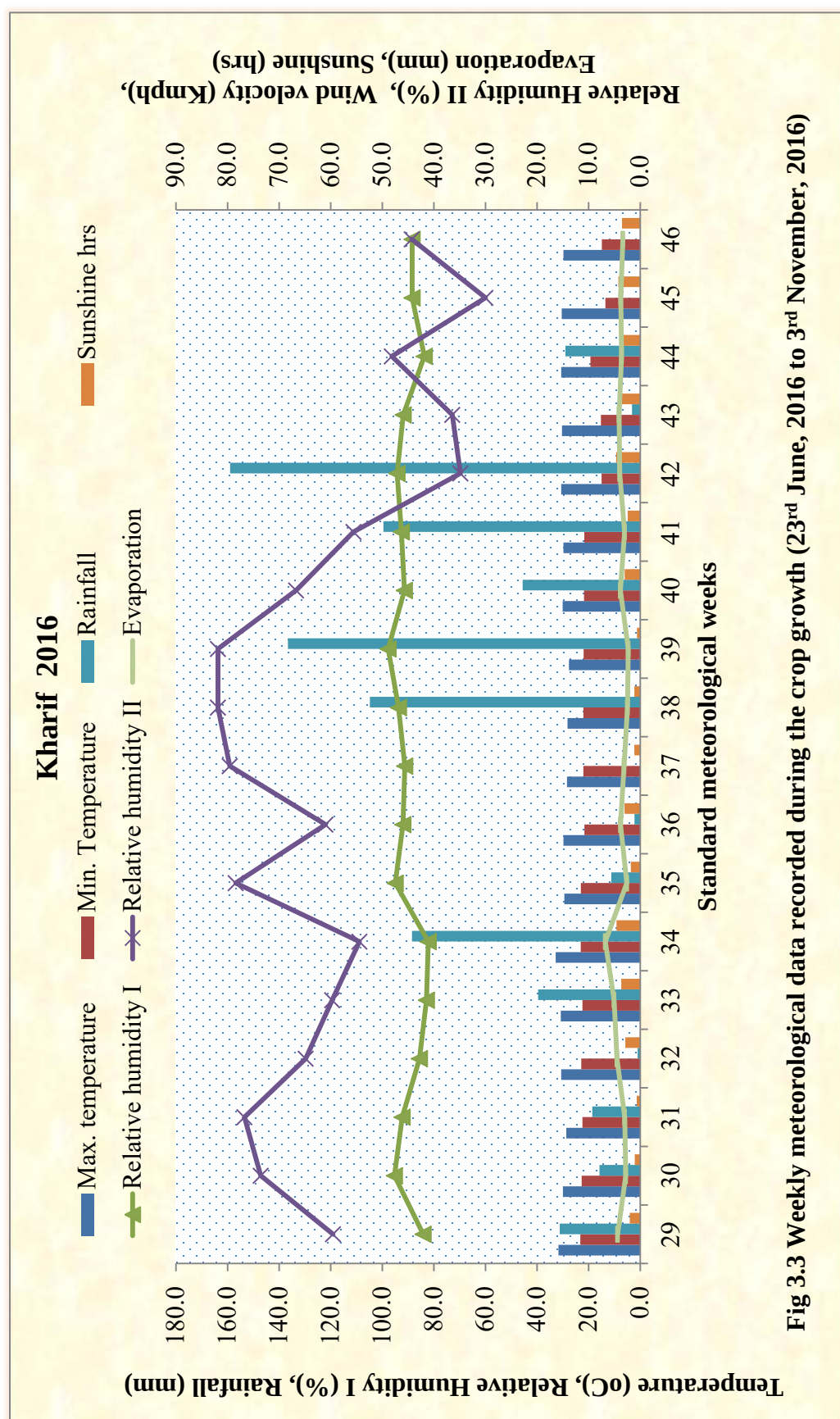


Fig 3.3 Weekly meteorological data recorded during the crop growth (23rd June, 2016 to 3rd November, 2016)

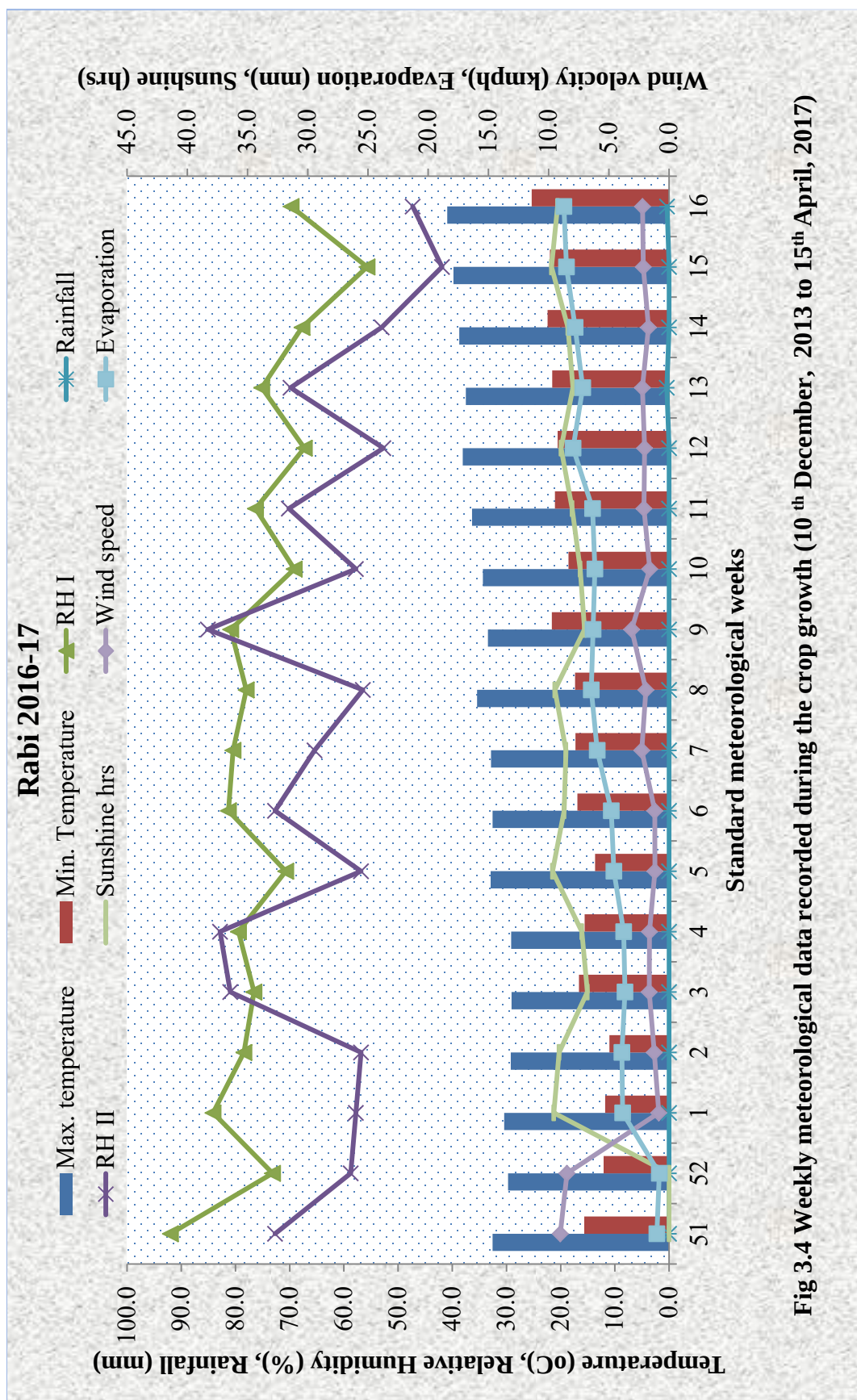


Fig 3.4 Weekly meteorological data recorded during the crop growth (10th December, 2013 to 15th April, 2017)

3.4 Cropping history

Prior to the experiment, the land was planted with rice-rice cropping system under normal agronomic practices. The recommended doses of fertilizers were applied to grow this crop.

Google Maps You can enter notes here.



Plate 3.1: Google map view of field plot B-5, IIRR Research Farm, Rajendranagar

3.5 Physico-chemical properties of experimental soil

Random soil samples were collected up to 15 cm soil depth from 10 random spots in the experimental area with the help of soil screw auger to determine the physico-chemical properties of the soil. Composite sample was prepared from the collected soil for mechanical and chemical analysis of soil. The soil of experiment field was clay loam. The soil was air-dried, powdered and allowed to pass through 2 mm sieve and was analyzed for physical and chemical properties. The details of the physico-chemical properties of soil are presented in Table 3.1.

3.6 Test variety

A medium duration, aromatic short grain rice variety “DRR Dhan 42” was taken as test crop. The variety has been graded as semi dwarf (100-105 cm), having long slender grains and drought tolerance (especially at flowering and grain filling stage). The crop variety matures in 120-125 days.

3.7 Treatments and layout plan

The experiment was laid out in Strip-split plot design (SSPD). Experiment was undertaken during four consecutive seasons *i.e.* *kharif* and *rabi* of 2015-16 and 2016-17 with three replications. The treatments comprised of 2 planting methods, 3 water regimes and 3 nutrient levels. There were 18 treatment combinations replicated thrice (Plate 3.2 and 3.3). The layout plan and other details of the experiment are depicted in Fig. 3.5 and the details of the field experiment conducted are given in Table 3.2 and 3.3:

Table 3.1: Physico-chemical properties of the experimental soil

Particulars	Value obtained				Method adopted
I. Physical properties					
1. Particle size analysis					
	2015-16		2016-17		
	<i>Kharif</i> 2015	<i>Rabi</i> 2015-16	<i>Kharif</i> 2016	<i>Rabi</i> 2016-17	
a. Sand (%)	18.50	18.50	18.50	18.50	International pipette method (Piper, 1966)
b. Silt (%)	22.54	22.52	22.51	22.52	
c. Clay (%)	58.96	58.98	58.99	58.98	
2. Bulk density (mg m ³)	1.32	1.32	1.33	1.33	Core sampler method (Dastane, 1967)
II. Chemical analysis					
1. Soil pH (1:2.5)	7.77	7.81	7.76	7.80	pH meter (Piper, 1966)
2. Electrical conductivity (ds m ⁻¹)	0.76	0.78	0.74	0.77	Conductivity bridge (Jackson, 1973)
3. Organic carbon (%)	0.49	0.50	0.48	0.50	Wet oxidation method (Jackson, 1973)
4. Available nitrogen (kg ha ⁻¹)	178.2	175.6	176.4	174.9	Alkaline permanganate method (Subbaiah and Asija, 1956)
5. Available phosphorus (kg ha ⁻¹)	44.35	45.07	45.24	45.89	Olsen’s method (Olsen <i>et al.</i> , 1954)
6. Available potassium (kg ha ⁻¹)	529.5	524.3	526.4	527.9	Flame photometry method (Jackson, 1973)

Table 3.2 Treatment combination details of experiment

S. No.	Treatment combinations	Treatment details
1	M₁I₁N₁	Transplanting + Saturation + 100% RDN through inorganic
2	M₁I₁N₂	Transplanting + Saturation + 125% RDN through inorganic
3	M₁I₁N₃	Transplanting + Saturation + 50% inorganic + 50% organic (based on % nitrogen content)
4	M₁I₂N₁	Transplanting + 5 cm water level depletion in perched water tube + 100% RDN through inorganic
5	M₁I₂N₂	Transplanting + 5 cm water level depletion in perched water tube + 125% RDN through inorganic
6	M₁I₂N₃	Transplanting + 5 cm water level depletion in perched water tube + 50% inorganic + 50% organic (based on % nitrogen content)
7	M₁I₃N₁	Transplanting + 10 cm water level depletion in perched water tube + 100% RDN through inorganic
8	M₁I₃N₂	Transplanting + 10 cm water level depletion in perched water tube + 125% RDN through inorganic
9	M₁I₃N₃	Transplanting + 10 cm water level depletion in perched water tube + 50% inorganic + 50% organic (based on % nitrogen content)
10	M₂I₁N₁	Modified SRI + Saturation + 100% RDN through inorganic
11	M₂I₁N₂	Modified SRI + Saturation + 125% RDN through inorganic
12	M₂I₁N₃	Modified SRI + Saturation + 50% inorganic + 50% organic (based on % nitrogen content)
13	M₂I₂N₁	Modified SRI + 5 cm water level depletion in perched water tube + 100% RDN through inorganic
14	M₂I₂N₂	Modified SRI + 5 cm water level depletion in perched water tube + 125% RDN through inorganic
15	M₂I₂N₃	Modified SRI + 5 cm water level depletion in perched water tube + 50% inorganic + 50% organic (based on % nitrogen content)
16	M₂I₃N₁	Modified SRI + 10 cm water level depletion in perched water tube + 100% RDN through inorganic
17	M₂I₃N₂	Modified SRI + 10 cm water level depletion in perched water tube + 125% RDN through inorganic
18	M₂I₃N₃	Modified SRI + 10 cm water level depletion in perched water tube + 50% inorganic + 50% organic (based on % nitrogen content)

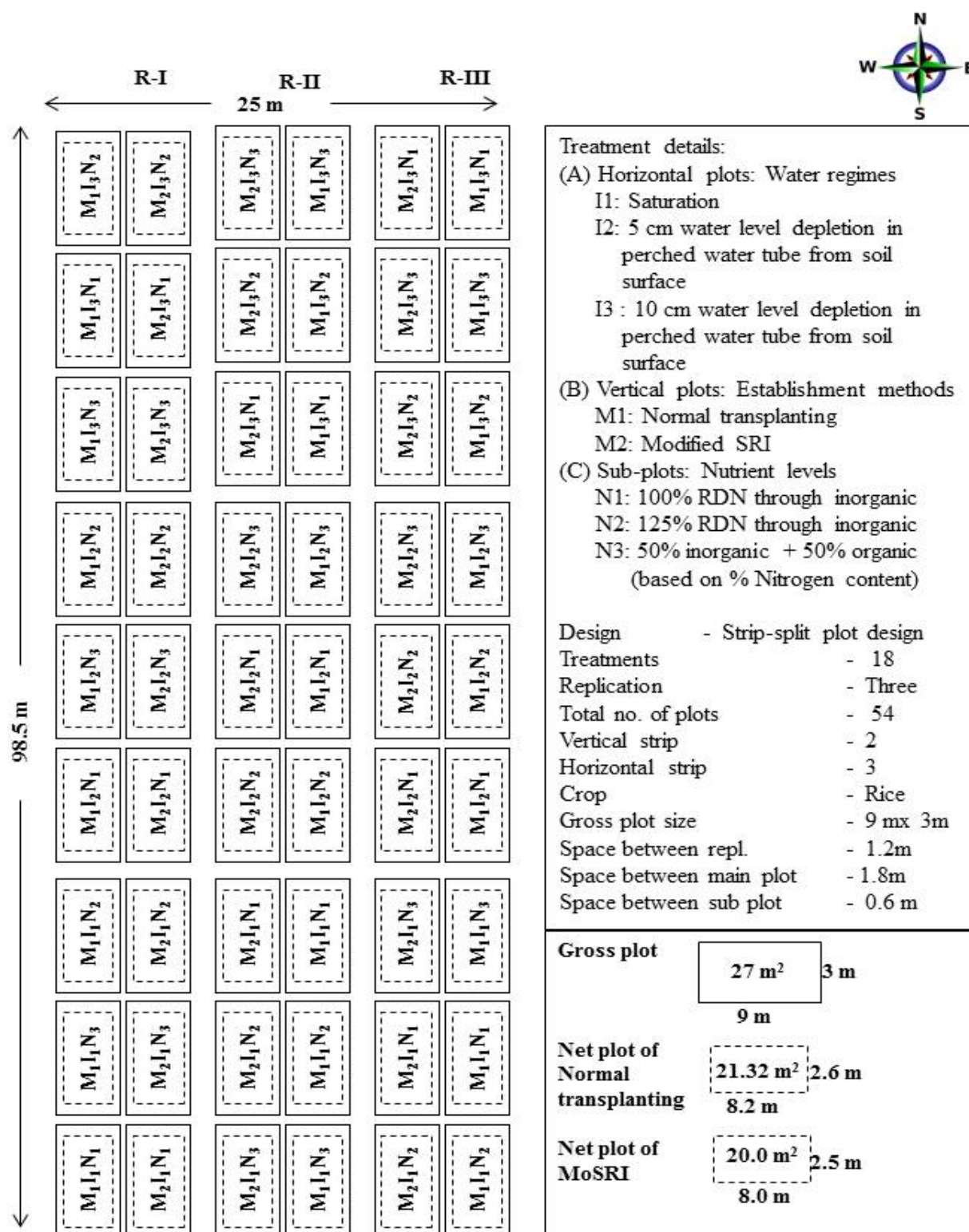


Fig. 3.5: Layout of the experiment during Kharif-2015 to Rabi-2016-17

Table 3.3: Plot size and spacing

Planting methods	Spacing (cm)	Age of seedling	Gross plot (m)	Number of hills
MoSRI (Square planting)	25 x 25	18-20 days	9 x 3	16
Transplanting	20 x 10	25-28 days	9 x 3	50

3.7.1 Treatment Details:

Experimental site: IIRR Research Farm, Rajendranagar, Hyderabad

(A) Horizontal plots: Water regimes (I)

I₁: Saturation

I₂: 5 cm water level depletion in perched water tube

I₃: 10 cm water level depletion in perched water tube

(B) Vertical plots: Establishment methods (M)

M₁: Normal transplanting

M₂: Modified SRI

(C) Subplots: Nutrient levels (N)

N1: 100% RDN through inorganic

N2: 125% RDN through inorganic

N3: 50% inorganic + 50% organic (based on % nitrogen content)

3.8 Cultural operations and application of treatments

The schedule of various cultural operations carried out during the course of investigation is given in Table 3.4.

Table 3.4: Schedule of cultural operations

Particulars	<i>Kharif</i> 2015	<i>Kharif</i> 2016	<i>Rabi</i> 2015-16	<i>Rabi</i> 2016-17
Date of sowing (Main field nursery)				
MoSRI	10-08-2015	23-06-2016	08-01-2016	07-12-2016
Normal Transplanting	10-08-2015	23-06-2016	08-01-2016	07-12-2016
Date of transplanting				
MoSRI	28-08-2015	15-07-2016	27-01-2016	28-12-2016
Transplanting	05-09-2015	25-07-2016	05-02-2016	06-01-2017
Date of harvesting				
MoSRI	13-12-2015	30-10-2016	10-05-2016	12-04-2014
Transplanting	19-12-2015	06-11-2016	15-05-2016	16-04-2014
Days to maturity (days)				
MoSRI	124	129	123	125
Transplanting	130	135	128	129



Plate 3.2: Overview of crop field at tillering stage



Plate 3.3: Overview of crop field at maturity

3.8.1 Nursery and transplanting

3.8.1.1 Normal nursery preparation

Seeds were soaked for 24 hours in a tightly tied cloth bag and incubated inside soil pit for 24 hours. Inside pit a layer of thick (5-10 cm) dried rice straw was spread above and below the cloth bag. In transplanting, nursery bed preparation was done by puddling the field twice for better tilth. Nursery beds were made of 1.0 m width and 10.0 m length was prepared and raised a little (about 10 cm). Bed was prepared one day before seeding. Around the bed, 40 cm drainage cum irrigation channel was prepared (Plate 3.4). The sprouted seeds were broadcasted uniformly on nursery bed. Recommended seed rate of transplanting i.e. 20 kg seeds in 1000 m² area of nursery bed is sufficient to transplant one hectare main field.

Twenty five to twenty eight days old seedlings were planted manually (two to three seedlings hill⁻¹) with a spacing of 20 cm x 10 cm. During transplanting, the seedlings were carefully removed from nursery bed and planted within 30 minutes after removing from nursery in the main field at normal depth (4-6 cm).

3.8.1.2 Modified system of rice intensification (MoSRI)

In Modified System of Rice Intensification (MoSRI) nursery bed was prepared similar to normal nursery bed preparation but it was raised to about 15 cm height with 1.0 m width and 10.0 m length. Around the bed, 40 cm drainage cum irrigation channel was prepared. On this nursery bed, soil and vermicompost (1:1) mixture of 2-3 cm thick layer was spread. Bed was prepared one day before seeding. Seed soaking and incubation for 24 hours in a tightly tied cloth bag was done in a similar fashion as followed for normal bed. The sprouted seeds were broadcasted uniformly on nursery bed. Recommended seed rate of SRI i.e. 5 kg seeds in 100 m² area of nursery bed is sufficient to transplant one hectare main field. After broadcasting the sprouted seed, 1:1 soil and vermicompost mixture was again applied (0.5 to 1 cm) over the seeds and neatly mulched with rice straw (i.e. 2-3 days in *kharif* and 4-5 days in *Rabi*) to prevent the seed from direct exposure to sun, rain, birds, chilling injury *etc* (Plate 3.4).

Eighteen to twenty days old seedlings were planted manually (one seedling hill⁻¹) with a spacing of 25 cm x 25 cm. During transplanting, the seedlings were carefully removed along with roots from nursery bed and planted within 30 minutes after removing from nursery in the main field at very shallow depth.

3.8.2 Main-field preparation

The experimental plot was dry ploughed once followed by two times puddling with power tiller in criss-cross manner and later leveled uniformly (Plate 3.5). Fields were drained and allowed surface soil to settle for 1 day after the final puddling. The soil is ready when a small “V” mark made in the puddle soil with a stick holding in its shape. At this moisture, the soil can hold the seedlings upright. Bunds for individual plots and irrigation channels were formed as per the treatment details and to prevent seepage between plots, plastic sheets were installed in the bunds down to a depth of one meter.

3.8.3 Nutrients management practices

The recommended dose of phosphorus @ 60 kg P₂O₅ ha⁻¹ as single super phosphate (SSP) and potassium @ 40 kg K₂O ha⁻¹ as muriate of potash (MoP) was applied to all the treatments uniformly as basal. Nitrogen was applied as per the treatments described as under.

3.8.3.1 RDN (100 % inorganic)

Recommended dose of nitrogen (120 kg ha⁻¹) was applied through urea in three equal splits at basal, 25 DAT and at 50 DAT.

3.8.3.2 RDN (125 % inorganic)

The 125 % of nitrogen (150 kg ha⁻¹) was applied through urea in three equal splits at basal, 25 DAT and at 50 DAT.

3.8.3.3 RDN (50 % inorganic and 50 % organic)

The 50 % recommended dose of nitrogen through inorganic source (60 kg ha⁻¹) was applied through urea in three equal splits at basal, 25 DAT and at 50 DAT. The nitrogen (60 kg ha⁻¹) through vermicompost as organic source was applied as basal only at the time of manual transplanting.



SRI nursery preparation



NTP nursery preparation



Plate 3.4: General view of nursery beds



Plate 3.5: Puddling of main field with power tillers

3.8.4 Irrigation management practices

Irrigation management was adopted as per the treatment described below.

3.8.4.1 Saturation

The soil was kept as close to saturation as possible, thereby reducing the hydraulic head of the ponded water, in practice it means that a shallow irrigation is given to attain about 1-2 cm depth of ponded water through water meter. Whenever, water falls below 2 cm marked peg, irrigation was given so that the soil was kept always at above the saturation level throughout crop growth period. Irrigation water was applied through plastic pipe from the source and a water meter was used for measuring irrigation water (Plate 3.6).



Plate 3.6: General view of a saturated plot

3.8.4.2 Water level depletion in perched water tube

The irrigation treatments were imposed after 15 days of transplanting up to grain filling stage of crop in both methods of planting and 5 cm irrigation was applied based on water level depletion in perched water tube as per treatments (5 and 10 cm depletion of water in perched water tubes). The irrigation water was applied through plastic pipe from the source and a water meter was attached for measuring irrigation water. In this experiment, field water tubes crowned with SONAR wave based water level sensor have been developed which are digital electronic devices that can measure real time micro-climate based weather data (temperature and relative humidity) along with water level in the field water tubes. The information was further transmitted to the mobile devices at periodic intervals to take care of field water to achieve maximum water use efficiency (Plate 3.7).

3.9 Weed management practices

Two times manual weeding at 25 and 50 DAT in conventional transplanting and cono-weeding three to four times in MoSRI at 10, 20 and 30 and/or 40 DAT in both the directions was followed to keep the experimental plots weed free (Plate 3.8).

3.10 Plant protection

The crop was free from major pests and diseases during both the years of study. The indigenous technology knowledge (ITK) was used to avoid the wild Boars infestation (tying of women old sarees around the plot) during grain filling stage in both the years of study.

3.11 Harvesting and threshing

Harvesting was done at physiological maturity stage which is judged visually when about 95 per cent spikelets were turned into golden colour. Initially the border rows were harvested. Later the net plot hills were harvested and bundled. The post-harvest observations were recorded from the harvest samples. The hills from net plot area were threshed and winnowed. After sun drying, the net plot grain and straw yield were recorded as per treatment and reported in t ha^{-1} .

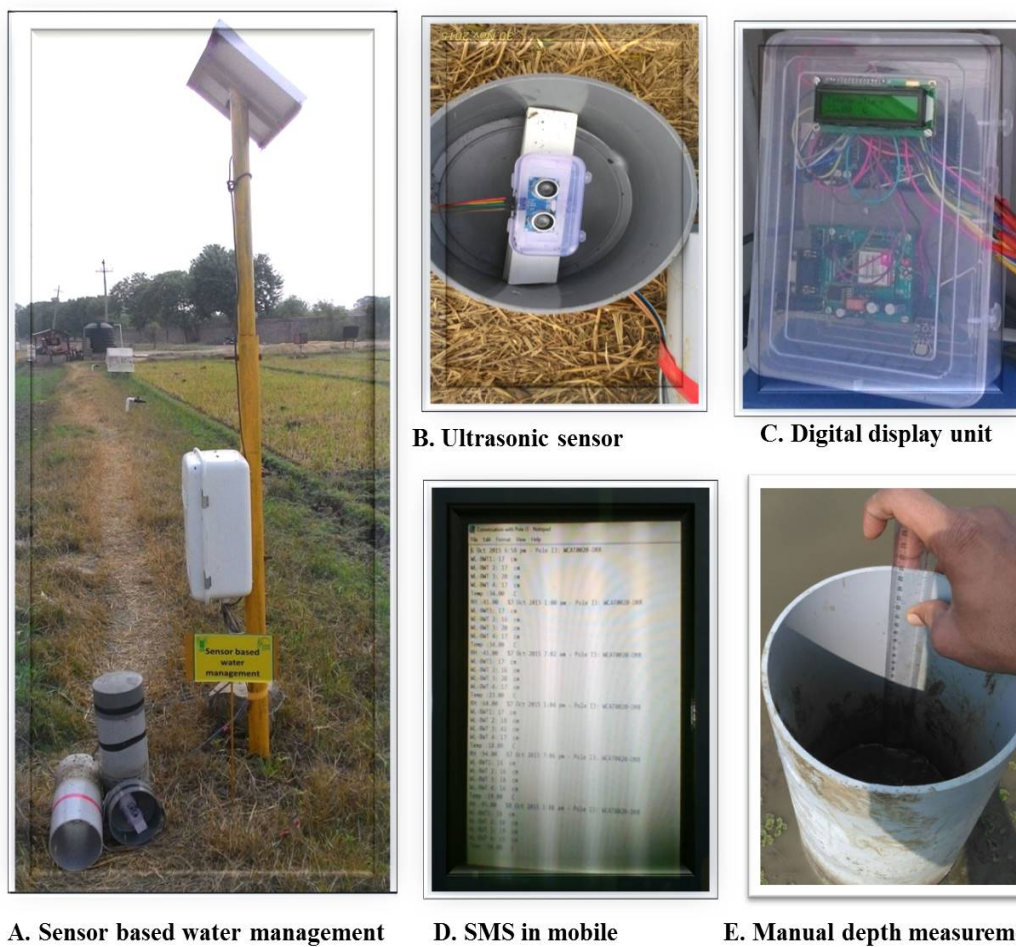


Plate 3.7: Ultrasonic water level measurement tools and devices



Plate 3.8: Cono-weeding in MoSRI plot

3.12 Crop observations

The techniques followed to record the various observations are described here:

3.12.1 Pre-harvest observations

The five hills from each plot were selected randomly from the second row of the plot. The randomly selected hills were tagged and used for recording observations on various plant characters.

3.12.1.1 Growth Parameters

3.12.1.1.1 Plant height (cm)

Plant height was measured from five tagged hills by measuring length from the basal node of the plant to the tip of the topmost leaf at 30, 60, 90 DAT and at harvest stages and mean height was recorded in cm. The mean was calculated at different time interval to obtain plant height.

3.12.1.1.2 Number of tillers (hill⁻¹)

The number of tillers was counted from tagged plants at regular interval of 30, 60, 90 DAT and at harvest stages.

3.12.1.1.3 Number of leaves (hill⁻¹)

Number of green leaves was measured from tagged hills by counting at an interval of 30, 60 and 90 DAT.

3.12.1.1.4 Total dry matter accumulation (g)

Five hills were uprooted randomly from adjacent to net plot rows excluding border rows at 30, 60, 90 DAT and at harvest. The root portion of the plant was discarded. The above ground portion of the plant samples were washed under tap water and dried in hot air oven at 65°C till the constant weight was obtained. The plant samples at 30, 60, 90 DAT and at harvest were weighed separately. The oven dry weight of plant samples was presented as g m⁻².

3.12.1.1.5 Root studies

The root length, root volume and root dry weight were determined at 30, 60 and at 90 DAT. Roots of five plants marked for destructive sampling were carefully removed with a shovel, thoroughly washed and separated from shoot portion with knife.

3.12.1.1.5.1 Root length (cm)

The root length measured from the base of the stem to the tip of the root and mean length was presented as cm.

3.12.1.1.5.2 Root volume (cm³)

Each root was submerged in a beaker for measuring the volume. The water replaced from the beaker was measured with measuring cylinder and expressed as cc hill⁻¹.

3.12.1.1.6 Days to panicle exertion

The duration in days taken for naked eye visual appearance of 50% plants' panicle out of culm counted from the date of transplanting was taken as panicle exertion and expressed in days.

3.12.1.1.7 Days to 50 % flowering

The duration in days, when 50 per cent plants from net plot area flowered were, based on visual assessment from the date of transplanting.

3.12.1.2 Growth Analysis

3.12.1.2.1 Leaf area (cm²)

Leaf area (cm²) of three randomly selected hills from each plot was estimated at 30, 60 DAT and at 90 DAT by using LICOR -3100 automatic leaf area meter and values were presented as cm².

3.12.1.2.2 Leaf area index

The leaf area index (LAI) is the ratio of leaf area per plant to the ground occupied by each plant (spacing). The LAI was calculated as given by Watson (1952).

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

3.12.1.2.3 Leaf area duration (dm² days)

Leaf area duration (LAD) indicates the magnitude and persistence of leaf area during crop growth period. LAD based on leaf area of individual plants from successive harvest was calculated as per the formula given by Hunt (1978).

$$\text{LAD} = \frac{(\text{LAI}_2 + \text{LAI}_1) \times (t_2 - t_1)}{2}$$

Where, LAI_1 and LAI_2 are leaf area index obtained at times t_1 and t_2 , respectively.

LAD expressed in dm^2 days.

3.12.1.2.4 Crop growth rate ($\text{g day}^{-1} \text{hill}^{-1}$)

The crop growth rate (CGR) of a unit area of canopy cover at any instant time (t) is defined as “the increase of plant material per unit of time” and was computed using the formula given by Watson (1958).

$$\text{CGR} = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{1}{P}$$

Where, W_1 and W_2 are the values of dry weights of plant (g) harvested from equal but separate areas of ground, (P) at times t_1 and t_2 in days, respectively. CGR is expressed in $\text{g m}^{-2} \text{day}^{-1}$.

3.12.1.2.5 Relative growth rate ($\text{g g}^{-1} \text{day}^{-1}$)

The relative growth rate (RGR) of a plant at time instant (t) is defined as the increase of plant material per unit of material initially present per unit of time and is mathematically expressed (Hunt, 1978) as shown below.

$$\text{RGR} = \frac{\ln W_2 - \ln W_1}{t_2 - t_1}$$

Where, W_1 and W_2 are the dry weights (g) at times t_1 and t_2 in days, respectively.

ln is natural logarithm. RGR is expressed in $\text{g g}^{-1} \text{day}^{-1}$.

3.12.1.2.6 SPAD meter readings

Chlorophyll meter (model SPAD 502 of Minolta co., Japan) was used to measure SPAD values. The leaf selected for measurement of SPAD reading was between fourth from base to leaf tip of the plant. The SPAD values were measured on 10 leaves in each plot and then mean value was calculated.

3.12.2 Post-harvest observations

3.12.2.1 Number of panicle (m²)

Productive tillers count at harvest was taken from one square meter area in net plot of each treatment and expressed as number m⁻².

3.12.2.2 Panicle length (cm)

Ten panicles were selected randomly from the net plot area for recording the panicle length. It was measured from the base of the primary rachis to top most spikelet and average length was expressed in cm.

3.12.2.3 Panicle weight (g)

Weights of ten sampled panicles were recorded and mean weight was expressed in g panicle⁻¹.

3.12.2.4 Number of filled and unfilled grains panicle⁻¹

Filled and unfilled number of grains panicle⁻¹ was determined by counting the total number of grains in five panicles of randomly selected plants and number of filled and unfilled grains were separated and thereafter mean was calculated.

3.12.2.5 Sterility percentage (%)

It is the proportion of number of unfilled grains per panicle to the total number of grains per panicle represented by percentage.

$$\frac{\text{Chaffy grain percentage/}}{\text{Sterility percentage}} = \frac{\text{Number of unfilled grains panicle}^{-1}}{\text{Total number of grains panicle}^{-1}} \times 100$$

3.12.2.6 Test weight (g)

Thousand grains were counted from the lot of grain yield per plot after threshing and winnowing of net plot the weight was recorded as test weight in gram (g).

3.12.2.7 Grain yield (t ha⁻¹)

Plants of the net plot area were harvested separately in each plot threshed and grains were separated, dried under sun and the grain yield per plot was recorded after cleaning. From this yield of per plot grain yield ha⁻¹ was computed and expressed as t ha⁻¹.

3.12.2.8 Straw yield (t ha⁻¹)

After threshing the grain, the remaining straw was dried under sun and yield per plot was recorded and the yield per hectare was computed and expressed in t ha⁻¹.

3.12.2.9 Harvest index

It is the proportion of total dry matter represented by economic yield as suggested by Donald and Humblin (1962).

$$\text{Harvest Index} = \frac{\text{Grain yield (t ha}^{-1}\text{)}}{\text{Biological yield (Grain + Straw) (t ha}^{-1}\text{)}} \times 100$$

3.13 Chemical analysis

3.13.1 Soil analysis

Soil samples were collected before planting and after harvest of the crop and analyzed for available nitrogen, available phosphorus and available potassium. The analysis was done by micro Kjeldahl (alkaline potassium permanganate method), Vanadomolybdate yellow colour and Flame photometer for nitrogen, phosphorus and potassium, respectively.

3.13.2 Plant analysis

Plant samples collected at the time of harvest of rice were oven dried and ground into fine powder and used for chemical analysis.

3.13.2.1 N, P and K content (%)

Plant samples were analyzed for N, P and K content. Samples were dried in an oven at 60°C till constant weight was obtained. The different plant parts viz. grain and straw were grinded separately. The analysis was done by micro kjeldahl (Piper, 1966), vanadomolybdate yellow colour (Jackson, 1958) and flame photometer (Piper, 1966) for nitrogen, phosphorus and potassium, respectively.

3.13.2.2 Nutrient uptake (kg ha⁻¹)

The N, P and K uptake was also worked out multiplying concentration with respective dry weight of rice grain and straw on oven dry basis *i.e.*

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \text{Concentration (\%)} \times \text{Dry matter yield (t ha}^{-1}\text{)} \times 10$$

3.14 Water use studies

3.14.1 Effective rainfall (mm)

In this study, rainfall less than 6.25 mm on any day is considered as

ineffective. Similarly, any amount of rainfall over 75 mm day⁻¹, and rainfall in excess of 125 mm in ten days is considered as ineffective (Dastane *et al.*, 1974). Rainfalls during last 15 days before maturity were also considered ineffective.

3.14.2 Irrigation water measurement (mm)

Amount of water applied to each treatment was measured by water meter (mm).

3.14.3 Irrigation water productivity (kg ha mm⁻¹)

Irrigation water productivity was determined based on the ratio of the yield to the water applied during the irrigation season as following (Gupta and Acharya, 1993). Irrigation water productivity was expressed in kg ha mm⁻¹.

$$\text{Irrigation water productivity} = \frac{\text{Grain yield (kg ha}^{-1}\text{)}}{\text{Applied irrigation water (mm)}}$$

3.14.4 Water productivity (kg ha mm⁻¹)

Water productivity was calculated by taking into account of irrigation water supplied and contribution from rain water. Then total yield is divided by total water applied. Water productivity was expressed in kg ha mm⁻¹.

$$\text{Water productivity} = \frac{\text{Grain yield (kg ha}^{-1}\text{)}}{\text{Irrigation} + \text{effective rainfall}}$$

3.15 Economics

3.15.1 Cost of cultivation (₹ ha⁻¹)

While computing the economics, different variable costs of items were considered. The cost includes expenditure on seeds, manures, fertilizers, plant protection chemicals and labour charges were considered at the prevailing market price and presented as ₹ ha⁻¹ (Appendix XX).

3.15.2 Gross return (₹ ha⁻¹)

Gross return was calculated by multiplying the grain and straw yield with their respective prevailing market prices (Perin *et al.*, 1979) and presented as ₹ ha⁻¹.

3.15.3 Net return (₹ ha⁻¹)

The net return hectare⁻¹ was calculated by subtracting the cost of cultivation from the gross return and presented as ₹ ha⁻¹.

3.15.4 Benefit: Cost ratio

The Benefit cost ratio (B:C ratio) was worked out by using the following formula:

$$\text{Benefit: cost ratio} = \frac{\text{Net return (₹ ha}^{-1}\text{)}}{\text{Cost of cultivation (₹ ha}^{-1}\text{)}}$$

3.16 Energetics

3.16.1 Energy input (GJ ha⁻¹)

The energy input was calculated as the summation of energy requirement for labour, farm machineries, seed, fertilizers and irrigation used in system and expressed in (GJ ha⁻¹). The energy conversion factors are given in Appendix XX (Mittal and Dhawan, 1988; Devasenapathi *et al.*, 2009).

3.16.2 Gross energy output (GJ ha⁻¹)

Output energy from the main product (grain) and byproduct (straw) was calculated by multiplying the amount of production and its corresponding energy equivalent expressed as (GJ ha⁻¹).

3.16.3 Energy indices

The energy indices were calculated by using the following formulas.

$$\text{Energy output : input ratio} = \frac{\text{Gross energy output (GJ ha}^{-1}\text{)}}{\text{Total energy input (GJ ha}^{-1}\text{)}}$$

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

$$\text{Net energy output} = \text{Gross energy output (GJ ha}^{-1}\text{)} - \text{Energy input (GJ ha}^{-1}\text{)}$$

$$\text{Energy intensity} = \frac{\text{Gross energy output (MJ ha}^{-1}\text{)}}{\text{Cost of cultivation (₹ ha}^{-1}\text{)}} \quad (\text{MJ ₹}^{-1})$$

3.17 Statistical analysis

The statistical analysis of data collected on different parameters of rice in all the seasons was carried out in strip-split plot design as described by Gomez and Gomez (1984). The level of significance used in “F” test was given at 5 per cent. Critical difference (CD) values are given in the table at 5 per cent level of significance, wherever the ‘F’ test was

significant at 5 per cent level. The skeleton of analysis of variance and formula used for various estimations are given below:

Table 3.5: The skeleton of the analysis of variance

Source of variation	DF	SS	MSS	F cal.	F tab.
Replication	r-1				
Vertical factor (A)	a-1				
Error (a)	(r-1)(a-1)				
Horizontal factor (B)	b-1				
Error (b)	(r-1)(b-1)				
AxB	(b-1)(a-1)				
Error (c)	(r-1)(a-1) (b-1)				
Subplot factor (C)	c-1				
AxC	(c-1)(a-1)				
BxC	(b-1)(c-1)				
AxBxC	(a-1)(b-1) (c-1)				
Error (d)	ab(r-1)(c-1)				
Total	rabc-1				

The following formula was used for standard error, critical difference and coefficient of variance estimation.

$$(a) \quad SEm_{\pm} = \sqrt{\frac{EMS}{r}}$$

$$(b) \quad CD = SEm_{\pm} \times \sqrt{2} \times t_{11 \text{ D.F. at } 5\% \text{ error degree of freedom}}$$

$$(c) \quad CV (\%) = \frac{\sqrt{EMS}}{GM} \times 100$$

Where,

r = Number of replication,
freedom

D.F = Degree of

T = Number of treatment,

S.S. = Sum of square

C.D. = Critical difference,

C.V. = Coefficient of variance

M.S.S. = Mean sum of square,

EMS = Error mean square

SEm $_{\pm}$ = Standard error of mean

CHAPTER-IV

RESULTS AND DISCUSSION

The results obtained from the investigations on “**Evaluation of water regimes and nutrient management on rice-rice cropping system under transplanted and modified system of rice intensification (MoSRI)**” at the ICAR-Indian Institute of Rice Research (IIRR) Farm, Rajendranagar, Hyderabad during *kharif* and *rabi* seasons for two consecutive years (2015-16 and 2016-17) are presented in this chapter. In this chapter, a brief description related to the observations recorded on various aspects of investigation has been given. Experimental results are presented and discussed with appropriate reasonings with the help of tables and graphs and interpretations are made only on significant findings on the basis of statistical parameters.

4.1 Pre-harvest studies

The data on various parameters at pre-harvest stages of rice were recorded and presented here under.

4.1.1 Growth parameters

4.1.1.1 Plant height (cm)

Observations on plant height were recorded at 30 days interval from 30 to 90 DAT and at harvest which were significantly influenced by establishment methods and water regimes at variable stages and seasons; however effect of nutrient levels was not observed during both the years as depicted in Table 4.1(a and b). Plant height of rice increased continuously from 30 DAT up to harvest.

Among crop establishment methods, modified system of rice intensification (MoSRI) (M_2) produced significantly taller plants at 30 DAT in both the years and in mean data. Similar trend was recorded up to 60 DAT. However, at 90 DAT and at harvest no significant variation in plant height was observed due to establishment methods in *kharif* seasons, but in *rabi* rice plant height was significantly affected by establishment methods only upto 30 DAT and afterwards the variation in plant height was not significant.

Table 4.1(a): Plant height of *khariif* rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	Plant height (cm)											
	Kharif											
	30 DAT			60 DAT			90 DAT			At harvest		
	2015	2016	mean	2015	2016	mean	2015	2016	mean	2015	2016	mean
Establishment methods												
M1	35.4	37.6	36.5	63.0	65.4	64.2	88.2	91.5	89.8	95.8	95.9	95.8
M2	40.2	43.2	41.7	67.4	70.9	69.1	88.1	92.8	90.4	95.4	97.3	96.3
SEm±	0.50	0.54	0.49	0.35	0.46	0.34	0.43	0.64	0.26	0.30	0.68	0.5
CD (P=0.05)	3.04	3.27	2.91	2.14	2.82	2.09	NS	NS	NS	NS	NS	NS
Water regimes												
I1	39.2	41.0	40.1	69.0	70.1	69.5	90.5	92.5	91.5	96.9	96.9	96.9
I2	37.3	40.1	38.7	65.0	67.1	66.0	88.6	91.9	90.2	96.1	96.4	96.2
I3	36.9	40.0	38.4	61.6	67.2	64.4	85.3	92.1	88.7	93.8	96.5	95.1
SEm±	0.84	0.97	0.62	0.97	0.78	0.49	0.80	0.93	0.24	1.04	0.96	0.5
CD (P=0.05)	NS	NS	NS	3.79	NS	1.5	3.13	NS	0.7	NS	NS	NS
Nutrient levels												
N1	37.9	40.5	39.2	65.3	66.9	66.1	88.3	92.0	90.1	96.4	96.4	96.4
N2	38.3	40.9	39.6	64.9	68.7	66.8	88.4	92.4	90.4	95.5	96.8	96.2
N3	37.3	39.7	38.5	65.4	68.7	67.0	87.7	92.1	89.9	94.8	96.5	95.7
SEm±	0.29	0.39	0.32	1.43	0.66	0.78	0.81	0.65	0.45	0.90	0.67	0.3
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (MxIxN)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

M2: Modified system of rice intensification;

I1: Saturation;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

Table 4.1(b): Plant height of *rabi* rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	Plant height (cm)											
	Rabi											
	30 DAT			60 DAT			90 DAT			At harvest		
	2015-16	2016-17	mean	2015-16	2016-17	mean	2015-16	2016-17	mean	2015-16	2016-17	mean
Establishment methods												
M1	38.8	37.4	38.1	67.6	66.1	66.8	89.2	87.8	88.5	93.1	93.1	93.1
M2	43.9	42.5	43.2	70.9	69.4	70.1	92.7	91.2	91.9	96.3	95.2	95.8
SEm±	0.79	0.69	0.43	0.83	0.83	0.81	2.13	2.08	1.5	1.61	1.30	1.0
CD (P=0.05)	4.81	4.41	2.49	NS	N5	NS	NS	NS	NS	NS	NS	NS
Water regimes												
I1	42.8	41.4	42.1	71.4	69.9	70.7	96.3	94.9	95.6	100.0	98.5	99.3
I2	40.9	39.4	40.1	69.8	68.3	69.1	91.0	89.5	90.3	95.0	94.8	94.9
I3	40.4	39.0	39.7	66.5	65.0	65.8	85.5	84.1	84.8	89.2	89.1	89.1
SEm±	0.70	0.61	0.52	0.80	0.80	0.59	1.80	1.80	1.41	1.45	1.39	0.8
CD (P=0.05)	NS	NS	NS	3.14	3.14	2.03	7.05	7.06	3.4	5.68	5.46	3.0
Nutrient levels												
N1	41.4	40.0	40.7	69.1	67.6	68.3	91.03	89.47	90.3	94.76	93.3	94
N2	41.9	40.4	41.1	70.3	68.9	69.6	93.45	92.09	92.8	97.05	95.89	96.5
N3	40.9	39.4	40.1	68.3	66.9	67.6	88.33	86.87	87.6	92.33	93.18	92.8
SEm±	0.62	0.55	0.39	0.59	0.59	0.57	1.32	1.26	0.89	1.88	1.67	1.49
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (MxIxN)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

I1: Saturation;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

M2: Modified system of rice intensification;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

Water regimes had no significant influence on plant height at initial stage of 30 DAT in both the years in both the seasons of *kharif* and *rabi*. However, at 60 and 90 DAT, significantly taller plants were recorded under irrigation at saturation throughout life cycle of crop (I_1); and it was statistically at par with irrigation at 5 cm water level depletion in perched water tube from soil surface (I_2). Irrigation at 10 cm water level depletion in perched water tube from soil surface (I_3) exhibited the shortest plant height at all the growth stages during both the years and in mean data. At harvest the plant height of rice crop was not affected due to water regimes in both the years and in *kharif* and *rabi* seasons also.

As regards to influence of nutrient levels on plant height, comparable plant height of rice was observed under 125% RDN through inorganic source throughout the growth period of crop during both the years and in mean data.

Interaction effect due to establishment methods, water regimes and nutrient levels on plant height was not significant at any of the observational stages, during both the years and in mean data as well as during both the seasons.

4.1.1.2 Number of tillers (hill^{-1})

Number of tillers hill^{-1} observed at 30, 60, 90 DAT and at harvest was significantly influenced by establishment methods and water regimes; however variable results were recorded under nutrient levels during both the years [Table 4.2 (a and b)]. The data concerning to establishment methods revealed that significantly higher number of tillers hill^{-1} at 30, 60, 90 DAT and at harvest was recorded under modified SRI (10.5, 21.6, 25.6 and 24.2 in *kharif*; and 10.2, 20.2, 23.8 and 22.9 during *rabi*, respectively in two years mean) as compared to normal transplanting (4.8, 9.0, 10.2 and 9.6 in *kharif*; and 5.1, 8.1, 9.4 and 8.7 during *rabi*, respectively) during both the years and in mean data.

As regards to water regimes, at 30 DAT, all the water regimes produced comparable number of tillers hill^{-1} during both the seasons as well as years, whereas at 60, 90 DAT and at harvest, significantly higher number of tillers (hill^{-1}) were recorded under saturation throughout the lifecycle of rice of rice (I_1) in both the years and seasons (mean data viz., 16.8, 20.3 and 18.8 during *kharif*; 15.4, 18.0 and 17.1

Table 4.2(a): Number of tillers of *kharif* rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	Number of tillers (hill ⁻¹)											
	Kharif											
	30 DAT			60 DAT			90 DAT			At harvest		
	2015	2016	mean	2015	2016	mean	2015	2016	mean	2015	2016	mean
Establishment methods												
M1	4.8	4.8	4.8	8.8	9.3	9.0	9.9	10.6	10.2	9.0	10.3	9.6
M2	11.3	9.7	10.5	20.8	22.5	21.6	25.2	26.0	25.6	23.3	25.1	24.2
SEm±	0.35	0.38	0.36	0.78	0.24	0.27	0.35	0.75	0.43	0.16	0.49	0.17
CD (P=0.05)	2.15	2.33	2.21	4.77	1.49	1.64	2.11	4.59	2.61	0.97	2.96	1.05
Water regimes												
I1	8.5	7.5	8.0	16.0	17.6	16.8	20.6	19.9	20.3	18.2	19.5	18.8
I2	7.9	7.2	7.5	14.9	16.1	15.5	17.6	18.3	17.9	16.2	17.5	16.8
I3	7.7	7.1	7.4	13.5	13.9	13.7	14.4	16.7	15.5	14.1	16.1	15.1
SEm±	0.21	0.22	0.16	0.64	0.69	0.36	0.30	0.69	0.35	0.60	0.66	0.42
CD (P=0.05)	NS	NS	NS	2.11	2.70	1.42	1.17	2.70	1.35	2.36	2.56	1.66
Nutrient levels												
N1	8.2	7.3	7.7	14.7	15.6	15.1	17.2	18.5	17.8	15.9	17.6	16.8
N2	8.3	7.1	7.7	15.3	16.5	15.9	19.1	19.2	19.2	17.1	18.7	17.9
N3	7.6	7.4	7.5	14.4	15.5	14.9	16.3	17.2	16.7	15.4	16.8	16.1
SEm±	0.23	0.30	0.18	0.72	0.69	0.50	0.22	0.17	0.13	0.55	0.46	0.37
CD (P=0.05)	NS	NS	NS	NS	NS	NS	0.87	NS	0.53	NS	1.79	1.44
Interaction (MxIxN)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

M2: Modified system of rice intensification;

I1: Saturation;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

Table 4.2(b): Number of tillers of *rabi* rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	Number of tillers (hill ⁻¹)											
	Rabi											
	30 DAT			60 DAT			90 DAT			At harvest		
	2015-16	2016-17	mean	2015-16	2016-17	mean	2015-16	2016-17	mean	2015-16	2016-17	mean
Establishment methods												
M1	5.2	4.9	5.1	8.6	7.7	8.1	9.6	9.1	9.4	9.2	8.2	8.7
M2	10.3	10.1	10.2	20.6	19.8	20.2	24.9	22.7	23.8	24.3	21.4	22.9
SEm±	0.19	0.19	0.19	0.37	0.36	0.36	0.59	0.43	0.51	0.43	0.23	0.32
CD (P=0.05)	1.13	1.14	1.02	2.23	2.20	2.17	3.61	2.60	3.09	2.59	1.39	1.96
Water regimes												
I1	8.4	7.6	7.7	16.8	14.7	15.4	19.7	17.0	18.0	19.1	15.9	17.1
I2	8.0	7.5	7.7	15.1	13.5	14.3	17.3	15.7	16.5	16.9	14.7	15.8
I3	7.5	7.5	7.5	12.6	13.1	12.8	15.5	15.1	15.3	15.1	13.8	14.4
SEm±	0.19	0.23	0.17	0.51	0.21	0.27	0.27	0.29	0.25	0.45	0.25	0.30
CD (P=0.05)	NS	NS	NS	2.00	0.83	1.08	1.07	1.13	0.99	1.78	0.96	1.20
Nutrient levels												
N1	7.9	7.7	7.8	14.8	13.8	14.3	17.3	16.0	16.7	16.9	14.9	15.9
N2	7.8	7.5	7.6	14.7	14.3	14.5	17.7	16.5	17.1	17.2	15.2	16.2
N3	7.6	7.4	7.5	14.2	13.2	13.7	16.7	15.2	16.0	16.3	14.4	15.3
SEm±	0.21	0.16	0.16	0.47	0.14	0.28	0.45	0.11	0.22	0.28	0.35	0.30
CD (P=0.05)	NS	NS	NS	NS	NS	NS	0.87	NS	0.53	NS	1.79	NS
Interaction (MxIxN)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

I1: Saturation;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

M2: Modified system of rice intensification;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

during *rabi*, respectively) which was comparable with irrigation at saturation throughout lifecycle of crop which was statistically at par with irrigation at 5 cm water level depletion in perched water tube from soil surface (I_2). Irrigation at 10 cm water level depletion in perched water tube from soil surface (I_3) displayed lowest number of tillers hill⁻¹ in all the growth stages during both the years and in mean data.

The data pertaining to nutrient levels revealed that, there was no significant variation in number of number of tillers hill⁻¹ of rice up to 60 DAT and thereafter at 90 DAT and at harvest stages of *kharif* and *rabi* rice 125% RDN was superior in producing higher number of tillers hill⁻¹ in *kharif*2015 and *rabi* 2015-16 during 90 DAT and *rabi* 2016-17 at harvest

Interaction of establishment method, water regime and nutrient level did not influenced significantly for number of tillers hill⁻¹ at any of the stages of observation during both the seasons and years of experimentation.

4.1.1.3 Number of leaves (hill⁻¹)

Data presented in Table 4.3 (a and b) revealed that number of leaves (hill⁻¹) influenced significantly due to establishment methods during both the years and also in both the seasons of *kharif* and *rabi* rice. From the data it is clearly visible that at 30, 60 and 90 DAT, establishment method of modified SRI (mean data viz., 35.7, 96.9 and 84.1 in *kharif*; 30.7, 85.0 and 74.4 in *rabi*, respectively) produced significantly higher number of leaves hill⁻¹. over normal transplanting (mean data viz., 16.7, 40.4 and 36.6 in *kharif*; 16.7, 32.5 and 28.7 in *rabi*, respectively).

Water regimes did not show any significant difference in number of leaves hill⁻¹ at initial stage of 30 DAT in *kharif* and *rabi* seasons of both the years. However, at 60 and 90 DAT, saturation throughout life cycle of crop (mean data viz., 75.3 and 67.1 during *kharif*; 63.4 and 55.8 during *rabi*, respectively) produced significantly greater number of leaves hill⁻¹ during both the seasons and years and in mean data. Significantly lowest number of leaves hill⁻¹ was observed under irrigation at 10 cm water level depletion in perched water tube from soil surface at all the observational stages.

Table 4.3(a): Number of leaves of *kharif* rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	Number of leaves (hill ⁻¹)							
	<i>Kharif</i>							
	30 DAT		60 DAT		90 DAT			
	2015	2016	mean	2015	2016	mean	2015	2016
Establishment methods								
M1	13.5	19.9	16.7	38.6	42.3	40.4	33.5	35.7
M2	31.6	39.9	35.7	91.4	102.5	96.9	80.6	87.5
SEm±	0.99	1.58	1.3	3.4	1.1	0.5	1.1	2.5
CD (P=0.05)	6.01	9.60	7.7	21.0	6.8	3.1	6.9	15.5
Water regimes								
I1	23.9	30.9	27.4	70.4	80.2	75.3	67.2	67.0
I2	22.0	29.5	25.8	65.3	73.6	69.5	57.3	61.7
I3	21.6	29.2	25.4	59.2	63.3	61.3	46.8	56.1
SEm±	0.60	0.90	0.6	2.8	3.1	1.6	1.0	2.3
CD (P=0.05)	NS	NS	NS	10.5	12.3	6.1	3.8	9.1
Nutrient levels								
N1	22.9	29.9	26.4	64.6	71.1	67.8	56.1	62.2
N2	23.3	29.4	26.3	67.3	75.3	71.3	62.3	64.7
N3	21.3	30.4	25.9	63.1	70.7	66.9	52.9	58.0
SEm±	0.65	1.23	0.7	3.1	3.1	1.8	1.7	1.6
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (MxIxN)	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

I1: Saturation;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

M2: Modified system of rice intensification;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

Table 4.3(b): Number of leaves of *rabi* rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	Number of leaves (hill ⁻¹)							
	30 DAT				60 DAT			
	2015-16	2016-17	mean	2015-16	2016-17	mean	2015-16	2016-17
<i>Rabi</i>								
Establishment methods								
M1	17.1	16.2	16.7	35.9	29.1	32.5	31.1	26.3
M2	31.8	29.5	30.7	86.6	83.4	85.0	80.2	68.6
SEm±	0.59	0.47	0.5	1.54	1.58	1.5	1.17	1.25
CD (P=0.05)	3.59	2.84	3.2	9.38	9.61	9.3	7.10	7.58
Water regimes								
I1	26.2	23.3	23.8	70.7	59.1	63.4	63.4	50.8
I2	25.2	23.6	24.4	63.3	54.1	58.7	56.0	46.5
I3	23.8	21.7	22.8	52.8	55.5	54.1	50.1	45.1
SEm±	0.63	0.39	0.4	2.13	0.91	1.1	1.36	0.75
CD (P=0.05)	NS	NS	NS	8.38	3.56	4.4	5.32	2.96
Nutrient levels								
N1	22.9	29.9	26.4	64.6	71.1	67.8	56.0	47.6
N2	23.3	29.4	26.3	67.3	75.3	71.3	57.4	49.3
N3	21.3	30.4	25.9	63.1	70.7	66.9	53.6	45.4
SEm±	0.65	1.23	0.7	3.1	3.1	1.8	0.56	0.48
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (MxIxN)	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

I1: Saturation;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

M2: Modified system of rice intensification;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

Nutrient levels, did not indicate any significant variation on number of leaves hill⁻¹, although numerically higher number of leaves were observed under 125% RDN through inorganic sources at all the observational stages.

Interaction effect of establishment methods, water regimes and nutrient levels was not significant at every stage of crop growth in both the seasons and years [Table 4.3 (a and b)].

4.1.1.4 Leaf area (cm²)

Leaf area of rice was influenced significantly due to establishment methods and water regimes; however nutrient levels gave comparable results during both the seasons and years. Leaf area recorded at 30, 60 and 90 DAT was found significantly higher in modified SRI (M₂) over normal transplanting during both the years and in mean data.

Results of leaf area recorded at 30 DAT on effect of water regimes on leaf area (cm hill⁻¹) revealed no significant difference due to various water regimes. However, at 60 and 90 DAT, significantly higher leaf area was observed under saturation maintained throughout the lifecycle of crop compared to other treatments during both seasons the years except at 60 and 90 DAT of *kharif* 2016 where all the water regimes behaved similar for leaf area hill⁻¹. Water regime of irrigation at 5 cm water level depletion in perched water tube from soil surface was next in order. Lowest leaf area was observed under the treatment of irrigation at 10 cm water level depletion in perched water tube from soil surface.

From the data pertaining to nutrient levels, non-significant differences among levels of nutrients was witnessed during both the seasons and years throughout the growth period of rice.

As regards to interaction effect between establishment methods, water regimes and nutrient levels on leaf area no significant difference was noted throughout the crop growth period [Table 4.3 (a and b)].

4.1.1.5 Leaf area index (LAI)

Leaf area index increased progressively from 30 DAT to 90 DAT and was significantly influenced due to different establishment methods and water regimes;

Table 4.4(a): Leaf area of *khariif* rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	Leaf area (cm ²)							
	<i>khariif</i>							
	30 DAT		60 DAT		90 DAT			
	2015	2016	mean	2015	2016	mean	2015	2016
Establishment methods								
M1	198.6	248.0	223.3	933.3	1065.5	999.4	793.6	851
M2	365.7	497.6	431.7	1886.2	2422.8	2154.5	1689.9	1935
SEm±	9.1	19.7	14.3	30.9	5.1	13.4	32.7	49
CD (P=0.05)	55.2	119.7	87.0	187.9	31.1	81.7	199.2	297
Water regimes								
I1	289.6	385.6	337.6	1621.0	1805.9	1713.5	1537.0	1463
I2	269.9	368.1	319.0	1399.6	1735.8	1567.7	1130.1	1378
I3	287.0	364.7	325.9	1208.6	1690.8	1449.7	1058.1	1339
SEm±	4.7	11.3	6.1	32.4	73.6	43.1	46.1	55
CD (P=0.05)	NS	NS	NS	127.3	NS	169.2	181.2	NS
Nutrient levels								
N1	279.4	372.7	326.1	1398.4	1674.9	1536.6	1265.8	1401
N2	287.8	366.4	327.1	1509.1	1813.1	1661.1	1281.2	1458
N3	279.3	379.3	329.3	1321.8	1744.5	1533.1	1178.2	1321
SEm±	7.8	15.4	5.4	57.1	69.6	30.6	60.3	42.0
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (MxIxN)	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

I1: Saturation;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

M2: Modified system of rice intensification;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

Table 4.4(b): Leaf area of *rabi* rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	Leaf area (cm ²)							
	<i>Rabi</i>							
	30 DAT		60 DAT		90 DAT			
	2015-16	2016-17	mean	2015-16	2016-17	mean	2015-16	2016-17
Establishment methods								
M1	236	256	246	917	963	940	759	740
M2	414	406	410	2336	2592	2464	1889	1842
SEm±	8.6	10.6	9.3	42.5	47.1	44.8	34.7	33.5
CD (P=0.05)	52.2	64.6	56.7	258.3	286.8	272.5	211.1	203.8
Water regimes								
I1	341	348	344	1740	1903	1821	1417	1382
I2	338	339	339	1592	1741	1667	1296	1264
I3	296	308	302	1546	1689	1617	1259	1228
SEm±	5.6	5.3	5.2	26.0	28.1	27.0	21.1	20.7
CD (P=0.05)	NS	NS	NS	102.0	110.2	106.1	83.0	81.4
Nutrient levels								
N1	334	338	336	1631	1783	1707	1328	1295
N2	324	333	329	1690	1848	1769	1376	1342
N3	317	323	320	1557	1702	1630	1268	1236
SEm±	10.7	8.6	9.6	16.6	18.0	17.3	13.5	13.3
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (MxIxN)	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

M2: Modified system of rice intensification;

I1: Saturation;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

Table 4.5(a): Leaf area index of *kharif* rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	Leaf area index							
	<i>kharif</i>							
	30 DAT				60 DAT			
	2015	2016	mean	2015	2016	mean	2015	2016
Establishment methods								
M1	0.99	1.24	1.28	4.67	5.33	5.00	3.97	4.26
M2	0.59	0.80	0.56	3.32	3.88	3.60	3.03	3.10
SEm±	0.01	0.03	0.01	0.06	0.12	0.04	0.05	0.08
CD (P=0.05)	0.09	0.16	0.09	0.39	0.75	0.23	0.31	0.50
Water regimes								
I1	0.80	1.04	0.95	4.63	4.86	4.74	4.32	3.82
I2	0.76	1.00	0.89	3.95	4.63	4.29	3.29	3.63
I3	0.81	1.01	0.92	3.40	4.32	3.86	2.89	3.58
SEm±	0.02	0.03	0.02	0.07	0.09	0.11	0.11	0.15
CD (P=0.05)	NS	NS	NS	0.29	0.38	0.45	0.45	NS
Nutrient levels								
N1	0.79	1.02	0.91	3.95	4.36	4.16	3.52	3.69
N2	0.81	0.99	0.92	4.31	4.81	4.56	3.73	3.79
N3	0.77	1.04	0.93	3.72	4.63	4.18	3.25	3.55
SEm±	0.03	0.05	0.03	0.16	0.15	0.08	0.16	0.14
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (MxIxN)	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

I1: Saturation;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

M2: Modified system of rice intensification;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

Table 4.5(b): Leaf area index of *rabi* rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	Leaf area index							
	<i>Rabi</i>							
	30 DAT		60 DAT		90 DAT			
	2015-16	2016-17	mean	2015-16	2016-17	mean	2015-16	2016-17
Establishment methods								
M1	1.18	1.28	1.23	5.39	4.81	5.10	3.79	3.70
M2	0.66	0.70	0.68	4.40	4.15	4.27	3.02	2.95
SEm±	0.02	0.02	0.02	0.10	0.10	0.10	0.07	0.01
CD (P=0.05)	0.10	0.11	0.11	0.64	0.58	0.61	0.44	0.43
Water regimes								
I1	0.99	1.06	1.03	5.22	4.78	5.00	3.63	3.54
I2	0.93	1.00	0.97	4.74	4.34	4.54	3.30	3.22
I3	0.84	0.91	0.88	4.73	4.33	4.53	3.29	3.21
SEm±	0.01	0.02	0.01	0.08	0.10	0.10	0.07	0.02
CD (P=0.05)	NS	NS	NS	0.34	0.38	0.40	0.29	0.08
Nutrient levels								
N1	0.96	1.04	1.00	4.92	4.50	4.71	3.43	3.34
N2	0.92	0.99	0.96	5.09	4.66	4.88	3.55	3.46
N3	0.88	0.95	0.92	4.67	4.28	4.47	3.25	3.17
SEm±	0.03	0.03	0.03	0.08	0.07	0.08	0.06	0.12
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (MxIxN)	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

I1: Saturation;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

M2: Modified system of rice intensification;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

however, leaf area index was not influenced significantly due to nutrient levels throughout the crop growth period in both the seasons and years. The data pertaining to LAI at 30, 60 and 90 DAT was found significantly higher in normal transplanting (mean data viz., 1.28, 5.00 and 4.11 in *kharif*; 1.23, 5.10 and 3.75 during *rabi*, respectively) over modified SRI (mean data viz., 0.56, 3.60 and 3.06 in *kharif*; 0.68, 4.27 and 2.99 during *rabi*, respectively).

Among the water regimes, saturation throughout the lifecycle of crop (4.74 and 4.07 in *kharif*; 5.00 and 3.59 in *rabi* mean data, respectively) relished significantly higher LAI throughout the growth period except at 30 DAT; initial stage of both the years and seasons where similar LAI was noticed in all the water regimes. Lowest value of LAI was observed under the water regime of 10 cm water level depletion in perched water tube from soil surface.

Interaction between, establishment methods, water regimes and nutrient levels was non-significant throughout the crop growth period in both the seasons and years.

4.1.1.6 Leaf area duration (days)

Leaf area duration (LAD) was observed at an interval of 0-30, 30-60 and 60-90 DAT. Mean leaf area duration was low between 0-30 DAT, thereafter it increased linearly and attained peak values between 60-90 DAT during both the years. It was significantly influenced by establishment methods and water regimes and also inconsistent results were obtained in nutrient levels as depicted in Table 4.6(a and b).

Modified system of rice intensification recorded significantly higher leaf area duration between 0-30 (16.7 and 18.5 days in *kharif* and *rabi* mean data, respectively), 30-60 DAT (91.7 and 95.0 in *kharif* and *rabi* mean data, respectively) and 60-90 DAT (136.8 and 132.7 days in *kharif* and *rabi* mean data, respectively) compared to normal transplanting (16.7 and 18.5 in *kharif* and *rabi* mean data, respectively) during both the seasons and years as well as in mean data.

Perusal of data of water regimes exhibited that, saturation throughout life cycle acknowledged significantly higher value of LAD during entire growth period except at 0-30 DAT during *kharif* seasons of both the years. However, same water regime i.e. saturation throughout life cycle of crop at 0-30 DAT in *rabi* seasons recorded the

Table 4.6(a): Leaf area duration of *kharif* rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	Leaf area duration							
	<i>kharif</i>							
	30 DAT				60 DAT			
	2015	2016	mean	2015	2016	mean	2015	2016
Establishment methods								
M1	14.9	18.6	16.7	84.9	98.5	91.7	129.5	144.2
M2	8.8	11.9	10.4	58.6	70.1	64.3	95.2	104.6
SEm±	0.2	0.4	0.2	1.0	1.5	0.6	1.7	3.3
CD (P=0.05)	1.4	2.4	1.4	6.2	9.2	3.5	10.4	20.1
Water regimes								
I1	12.0	15.7	13.8	81.4	88.5	85.0	134.2	131.5
I2	11.4	15.0	13.2	70.7	84.5	77.6	108.6	124.8
I3	12.1	15.1	13.6	63.1	79.9	71.5	94.3	116.9
SEm±	0.3	0.5	0.2	1.4	2.2	1.7	2.8	2.5
CD (P=0.05)	NS	NS	NS	5.4	NS	6.7	11.0	10.9
Nutrient levels								
N1	11.9	15.4	13.6	71.1	80.8	76.0	112.0	121.3
N2	12.1	14.9	13.5	76.7	87.1	81.9	120.5	130.0
N3	11.5	15.6	13.5	67.4	85.0	76.2	104.6	121.9
SEm±	0.4	0.7	0.2	2.7	2.5	1.8	4.8	2.2
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (MxIxN)	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

I1: Saturation;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

M2: Modified system of rice intensification;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

Table 4.6(b): Leaf area duration of *rabi* rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	Leaf area duration							
	<i>Rabi</i>							
	30 DAT				60 DAT			
	2015-16	2016-17	mean	2015-16	2016-17	mean	2015-16	2016-17
Establishment methods								
M1	17.7	19.2	18.5	98.6	91.4	95.0	137.8	127.7
M2	9.9	10.6	10.2	75.9	72.8	74.3	111.3	106.4
SEm±	0.3	0.3	0.3	1.4	1.2	1.3	0.7	2.5
CD (P=0.05)	1.5	1.6	1.6	8.4	7.5	7.9	4.1	15.2
Water regimes								
I1	14.8	16.0	15.4	93.1	87.6	90.4	132.8	124.8
I2	14.0	15.1	14.5	85.0	80.1	82.6	120.5	113.3
I3	12.7	13.6	13.1	83.6	78.5	81.1	120.3	113.1
SEm±	0.2	0.2	0.2	1.7	1.5	1.6	0.9	2.5
CD (P=0.05)	0.8	0.9	0.9	6.6	6.0	6.3	3.5	10.0
Nutrient levels								
N1	14.4	15.6	15.0	88.2	83.1	85.6	125.2	117.6
N2	13.8	14.9	14.3	90.2	84.8	87.5	129.6	121.9
N3	13.2	14.3	13.7	83.3	78.4	80.8	118.8	111.7
SEm±	0.4	0.5	0.5	1.1	1.0	1.0	0.9	2.2
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (MxIxN)	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

I1: Saturation;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

M2: Modified system of rice intensification;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

higher LAD over rest of the water regimes except I₂ (irrigation at 5 cm water level depletion in perched water tube from soil surface) which was comparable and have similar LAD values. Similar, findings were observed at 30-60 DAT and 60-90 DAT where, saturation throughout the lifecycle was superior over other regimes. The lowest value of LAD was prominent under irrigation at 10 cm water level depletion in perched water tube from soil surface.

As regards to nutrient levels non-significant differences were observed for LAD at 0-30, 30-60 and 60-90 DAT. However, numerically 125% RDN through inorganic source exhibited higher LAD at all the intervals of growth stages during both the years.

Interaction effect of establishment methods, water regimes and nutrient levels on LAD was noted non-significant at all the stages of observation during both the years as well as in mean data of two years and in both the seasons of experimentation.

4.1.1.7 SPAD value

Water regimes and nitrogen levels significantly influenced SPAD values of rice at certain durations, but establishment methods failed to give any significant results at different growth stages during both the years of study [Table 4.7 (a and b)]. An increasing trend in total chlorophyll content was observed from 30 DAT to 60 DAT and there after it was in decreasing trend. In establishment methods, SPAD value of rice at 30, 60 and 90 DAT exhibited no significant variation during both the seasons and years of experimentation.

On perusal of data pertaining to water regimes, it was noted that, all the water regime treatments recorded comparable SPAD values at initial stage of 30 DAT during both the seasons and years and also in mean data. However, at 60 DAT significantly higher SPAD value was observed under saturation throughout lifecycle of crop (42.7 and 43.9 in mean data of *kharif* and *rabi*, respectively) which was statistically on par with irrigation at 5 cm water level depletion in perched water tube from soil surface (41.0 and 42.7 in mean data of *kharif* and *rabi*, respectively). Significantly lowest value of SPAD was logged under irrigation at 10 cm water level depletion in perched water tube from soil surface (39.7 and 41.1 in mean data of *kharif*

Table 4.7(a): SPAD value of *khariif* rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	SPAD value							
	<i>khariif</i>							
	30 DAT				60 DAT			
	2015	2016	mean	2015	2016	mean	2015	2016
Establishment methods								
M1	35.9	36.8	36.4	39.2	42.2	40.7	37.5	38.2
M2	35.9	38.2	37.1	39.5	43.6	41.6	39.4	36.8
SEm±	0.2	0.3	0.2	0.7	0.6	0.6	0.7	0.2
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Water regimes								
I1	36.1	37.5	36.8	41.2	44.2	42.7	39.4	37.5
I2	36.0	37.8	36.9	39.3	42.7	41.0	38.3	37.8
I3	35.7	37.3	36.5	37.7	41.8	39.7	36.6	37.3
SEm±	0.3	0.5	0.4	0.6	0.5	0.5	0.9	0.6
CD (P=0.05)	NS	NS	NS	2.5	1.8	2.2	NS	NS
Nutrient levels								
N1	35.8	37.3	36.5	39.2	42.4	41.3	38.2	37.3
N2	36.2	38.2	37.2	39.7	43.8	41.9	38.9	38.2
N3	34.8	36.0	35.4	37.2	41.4	40.8	38.2	37.0
SEm±	0.4	0.2	0.2	0.5	0.3	0.3	0.5	0.4
CD (P=0.05)	1.7	1.0	1.5	2.0	1.3	1.5	NS	NS
Interaction (MxIxN)	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

I1: Saturation;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

M2: Modified system of rice intensification;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

Table 4.7(b): SPAD value of *rabi* rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	SPAD value							
	30 DAT				60 DAT			
	2015-16	2016-17	mean		2015-16	2016-17	mean	
<i>Rabi</i>								
Establishment methods								
M1	34.5	35.6	35.6		42.1	41.1	41.6	
M2	35.5	36.6	36.5		43.6	43.5	43.5	
SEm±	0.2	0.3	0.2		0.4	0.3	0.3	
CD (P=0.05)	NS	NS	NS		NS	NS	NS	
Water regimes								
I1	36.3	35.9	36.1		43.5	44.2	43.9	
I2	36.4	36.4	36.4		43.3	42.2	42.7	
I3	35.3	36.1	35.7		41.7	40.5	41.1	
SEm±	0.6	0.8	0.5		0.3	0.7	0.2	
CD (P=0.05)	NS	NS	NS		1.4	2.6	0.8	
Nutrient levels								
N1	35.8	36.8	35.8		43.0	42.1	42.6	
N2	36.4	37.8	36.6		43.3	42.7	43.0	
N3	34.8	35.7	34.9		41.2	40.1	40.6	
SEm±	0.3	0.4	0.2		0.5	0.5	0.3	
CD (P=0.05)	1.3	1.5	0.9		1.6	1.7	1.1	
Interaction (MxIxN)	NS	NS	NS		NS	NS	NS	

M1: Normal transplanting;

I1: Saturation;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

M2: Modified system of rice intensification;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

and *rabi*, respectively). At 90 DAT no significant variation in SPAD value was noted due to water regimes at both the seasons and years.

Results on influence of nutrient levels on SPAD value of rice showed significant variation and highest SPAD value of rice was recorded in 125% RDN which was comparable to 100% RDN at most of the stages of observations during both the seasons and years. The lower values of SPAD were exhibited in integrated nutrient management.

Interaction of establishment methods, water regimes and nutrient levels on SPAD value was noted non-significant throughout the crop growth period during both the years and in mean data.

4.1.1.8 Dry matter accumulation (g hill^{-1})

Dry matter accumulation (DMA) was recorded at 30, 60, 90 DAT and at harvest and data are presented in Table 4.8(a and b). An increasing trend in total dry matter accumulation (DMA) hill^{-1} was observed from 30 DAT to up to harvest. Data revealed that establishment methods, clearly noted remarkable variation in DMA hill^{-1} at 30, 60, 90 DAT and at harvest and significantly higher DMA hill^{-1} was observed under modified SRI (M_2) (8.0, 31.7, 67.1 and 72.1 g hill^{-1} in *kharif*; 7.8, 31.0, 62.0 and 65.9 in *rabi* mean data, respectively) over normal transplanting during both the years.

DMA hill^{-1} indicated that saturation throughout lifecycle of crop produced comparable dry matter accumulation hill^{-1} at 30 DAT of both the seasons and years. However, at 60, 90 DAT and at harvest significantly higher DMA hill^{-1} (24.1, 50.3 and 52.2 g hill^{-1} in *kharif*; 24.0, 45.8 and 49.7 g hill^{-1} in *rabi* mean data respectively) during both the seasons and years and in mean data except during *kharif* 2016 where all the water regimes produced similar DMA hill^{-1} . The lower values of DMA hill^{-1} were obtained under irrigation at 10 cm water level depletion in perched water tube from soil surface at all the stages of observation during both the years.

As regards to nutrient levels, non-significant results were noted for DMA hill^{-1} in rice. However, numerically higher values of DMA hill^{-1} were exhibited by 125% RDN through inorganic source during both the seasons and years.

Table 4.8(a): Dry matter accumulation of *kharif* rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Dry matter accumulation (g hill ⁻¹)											
Treatments	<i>kharif</i>										
	30 DAT			60 DAT			90 DAT			At harvest	
	2015	2016	mean	2015	2016	mean	2015	2016	mean	2015	2016
Establishment methods											
M1	3.2	3.3	3.3	11.1	14.1	12.6	23.1	25.2	24.2	25.1	26.9
M2	7.9	8.1	8.0	28.3	35.1	31.7	64.3	69.9	67.1	69.7	74.5
SEm±	0.2	0.0	0.1	0.7	1.4	0.4	0.7	1.3	1.0	1.3	1.1
CD (P=0.05)	1.4	0.2	0.6	4.4	8.7	2.2	4.5	7.7	6.1	7.9	6.7
Water regimes											
I1	5.6	5.8	5.7	22.2	26.1	24.1	47.7	50.3	49.0	50.7	53.6
I2	5.3	5.7	5.5	19.6	24.7	22.2	43.5	48.2	45.9	47.8	51.4
I3	5.8	5.7	5.7	17.3	23.0	20.2	39.8	44.2	42.0	43.6	47.1
SEm±	0.2	0.1	0.1	0.7	1.2	0.3	1.2	1.3	1.2	1.0	1.3
CD (P=0.05)	NS	NS	NS	2.9	NS	1.0	4.9	NS	4.7	3.9	NS
Nutrient levels											
N1	5.7	5.8	5.8	20.3	24.4	22.3	44.2	47.5	45.9	47.3	50.7
N2	5.6	5.6	5.6	20.5	25.4	22.9	45.9	49.4	47.7	50.0	52.7
N3	5.4	5.7	5.6	18.5	24.0	21.2	41.0	45.7	43.4	44.9	48.8
SEm±	0.1	0.1	0.1	0.7	1.1	0.8	0.9	0.7	0.7	0.9	0.8
CD (P=0.05)	NS	NS	NS	NS	NS	NS	3.5	NS	NS	3.3	NS
Interaction (MxIxN)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

I1: Saturation;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

M2: Modified system of rice intensification;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

Table 4.8(b): Dry matter accumulation of *rabi* rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Dry matter accumulation (g hill ⁻¹)												
Rabi												
Treatments	30 DAT			60 DAT			90 DAT			At harvest		
	2015-16	2016-17	mean	2015-16	2016-17	mean	2015-16	2016-17	mean	2015-16	2016-17	mean
Establishment methods												
M1	3.1	3.0	3.1	12.0	11.2	11.6	22.7	20.8	21.8	24.9	23.5	24.2
M2	7.6	8.0	7.8	32.3	29.6	31.0	63.5	60.5	62.0	68.0	63.8	65.9
SEm±	0.2	0.1	0.17	0.6	0.6	0.6	1.2	1.0	1.1	1.4	1.8	1.6
CD (P=0.05)	2.15	2.33	2.21	4.77	1.49	1.6	7.0	6.0	6.5	8.7	11.2	9.9
Water regimes												
I1	5.5	5.6	5.5	24.9	23.1	24.0	47.1	44.5	45.8	51.8	47.6	49.7
I2	5.4	5.6	5.5	21.8	20.0	20.9	43.1	39.6	41.4	46.0	44.1	45.0
I3	5.2	5.2	5.2	19.9	18.1	19.0	39.1	38.0	38.5	41.6	39.2	40.4
SEm±	0.1	0.1	0.1	0.4	0.4	0.4	0.9	1.0	0.9	0.5	1.1	0.4
CD (P=0.05)	NS	NS	NS	1.7	1.7	1.7	3.5	3.8	3.4	1.8	4.2	1.6
Nutrient levels												
N1	5.3	5.6	5.4	22.3	20.5	21.4	43.6	40.4	42.0	46.6	44.0	45.3
N2	5.5	5.4	5.4	23.1	21.3	22.2	45.2	42.4	43.8	49.1	45.0	47.0
N3	5.3	5.4	5.4	21.1	19.3	20.2	40.5	39.3	39.9	43.8	41.9	42.9
SEm±	0.2	0.1	0.1	0.5	0.5	0.5	0.7	0.5	0.5	0.4	0.9	0.6
CD (P=0.05)	NS	NS	NS	NS	NS	NS	2.6	1.9	2.0	1.7	2.9	2.4
Interaction (MxIxN)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

I1: Saturation;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

M2: Modified system of rice intensification;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

The data pertaining to nutrient levels revealed that, there was no significant variation in DMA hill⁻¹ of rice during *kharif* seasons of both the years except at 90 DAT and at harvest stages of *kharif* 2015, 125% RDN was superior in producing higher number of tillers hill⁻¹. Similarly, during *rabi* seasons of both the years, there was no significant variation in DMA hill⁻¹ till 60 DAT and thereafter at 90 DAT and at harvest stages of rice 125% RDN was superior in producing higher number of tillers hill⁻¹.

Establishment methods, water regimes and nutrient levels showed non-significant interaction effect for DMA hill⁻¹ throughout the crop growth period during both the seasons and years [Table 4.8 (a and b)].

4.1.1.9 Crop growth rate (g hill⁻¹ day⁻¹)

Crop growth rate (CGR) was computed from 0-30, 30-60, 60-90 and 90 DAT-at harvest and depicted in Fig.4.1 and 4.2. Crop growth rate of rice was increased gradually up to 60-90 DAT and decreased thereafter at 90DAT-at harvest. Establishment methods showed significant variation in crop growth rate and higher CGR was observed under modified SRI over normal transplanting at all time interval of observations except at harvest in *kharif* 2015 and *rabi* 2016-17, where both the establishment methods took same pace of growth in both the seasons and years (Appendix V and VI).

In case of water regimes at initial stage of 0-30 DAT no significant effect was recorded; however at 30-60 DAT the CGR was significantly higher in saturation throughout lifecycle during both the years and in mean data in *kharif* season but, in *rabi* rice significant variation was seen only in *rabi* 2015-16. Afterwards during 60-90 DAT and 90 DAT- at harvest water regime did not affected the crop growth rate.

Nutrient level did not influence the CGR at any of the observational stage during both the seasons and years as well as in mean data. Interaction effect of establishment methods, water regimes and nutrient levels was not significant at all the stages of both the seasons and years.

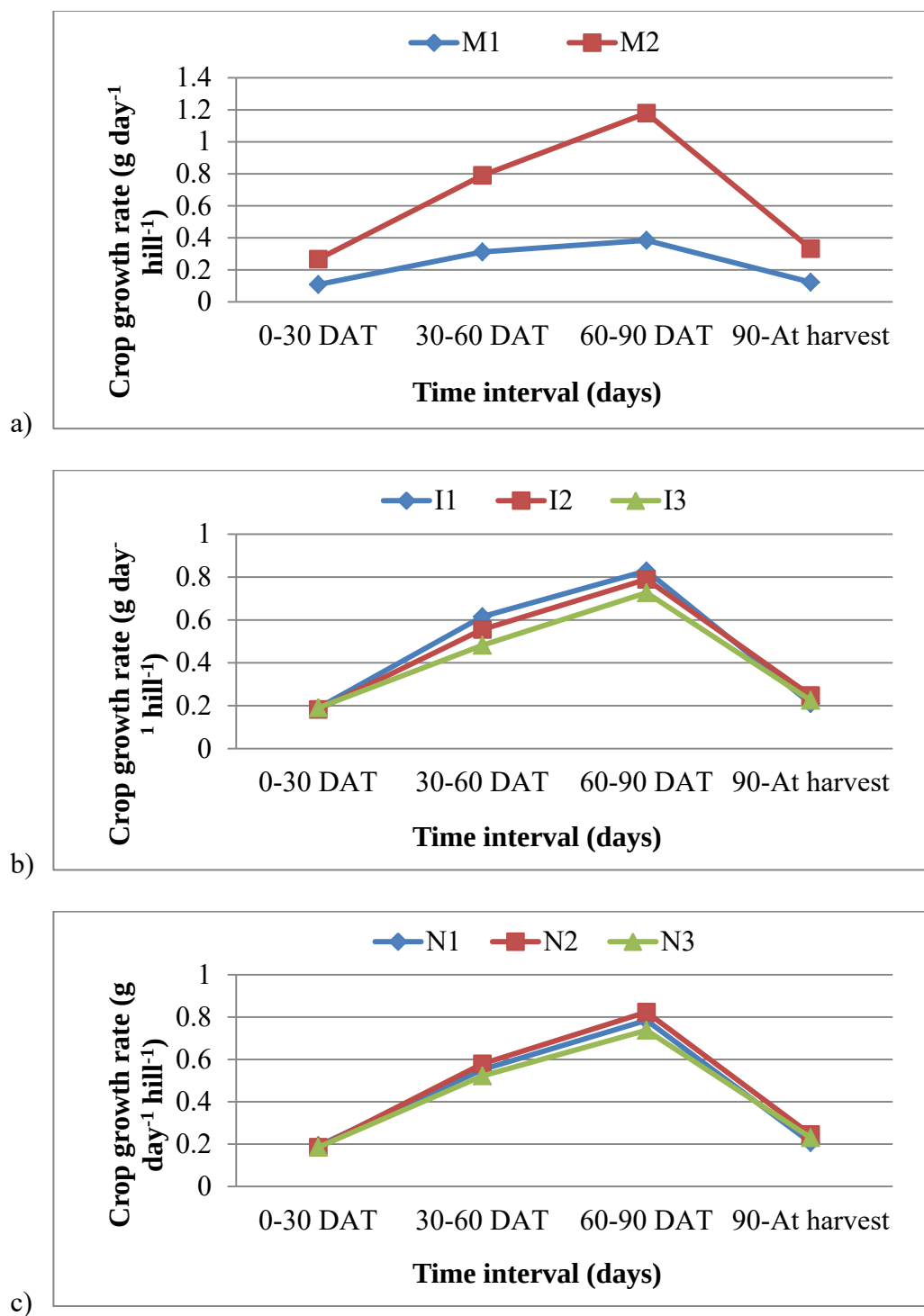


Figure 4.1: Crop growth rate of rice as influenced by (a) establishment methods, (b) water regimes and (c) nutrient levels (*kharif* mean data)

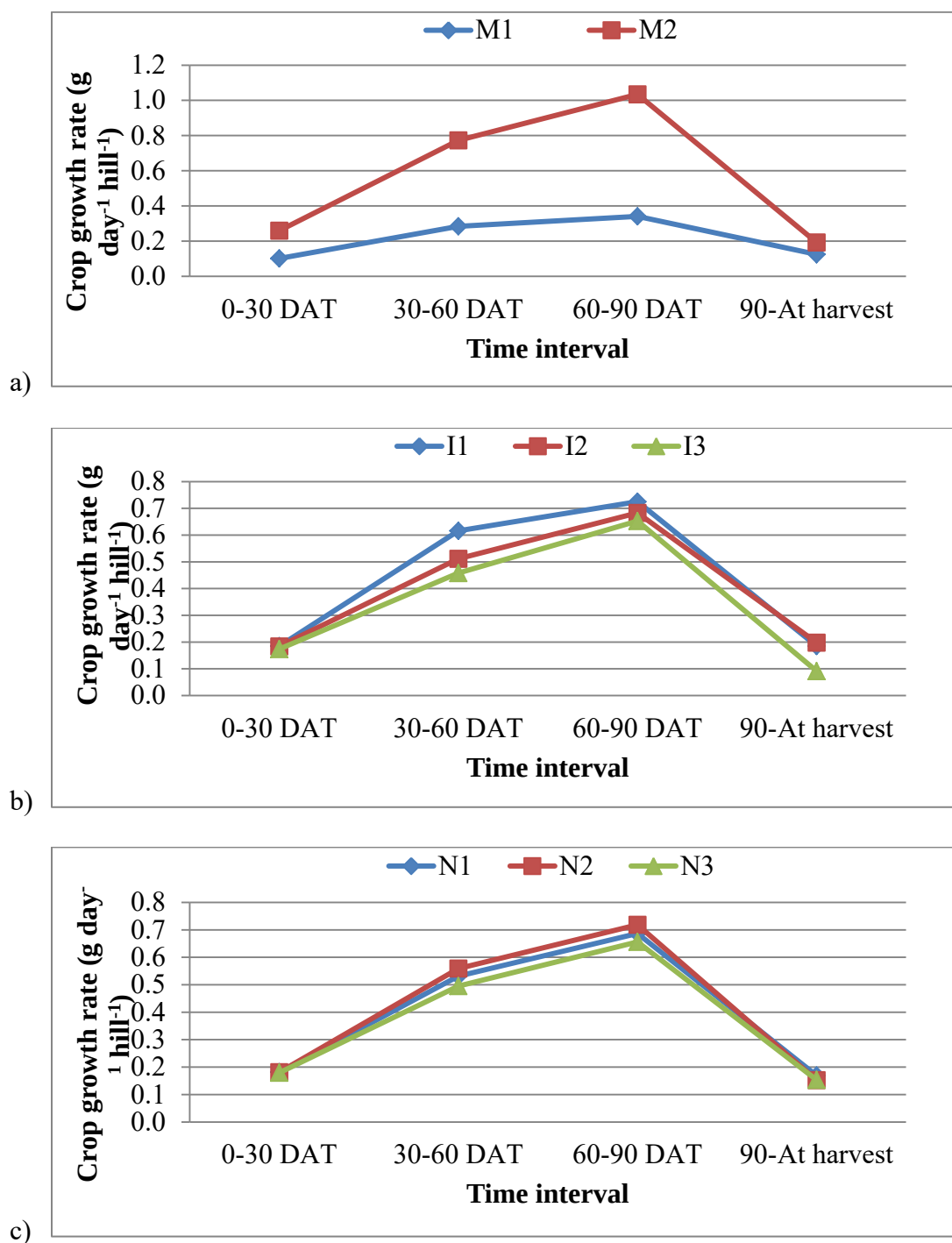


Figure 4.2: Crop growth rate of rice as influenced by (a) establishment methods, (b) water regimes and (c) nutrient levels (*rabi* mean data)

4.1.1.10 Relative growth rate ($\text{g g}^{-1} \text{hill}^{-1} \text{day}^{-1}$)

The data on relative growth rate (RGR) was reported from 30-60, 60-90 and 90 DAT-at harvest and depicted in Fig.4.3 and 4.4. In general RGR was higher during 30-60 DAT and showed declining trend thereafter. Relative growth rate of rice was non-significantly influenced by establishment method and nutrient levels throughout growth period except at 30-60 DAT in kharif 2015, where modified SRI recorded higher RGR over normal transplanting. On the other hand in *rabi* rice significant variation in RGR was seen during 60-90 DAT in both the years and in 90 DAT at harvest in 2015. They exhibited similar trend and modified SRI produced higher RGR.

Water regimes influenced RGR at 30-60 DAT and indicated that saturation throughout the lifecycle produced significantly higher RGR which was comparable with irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface and on par thereafter during both the seasons and years as well as in mean data. The Relative growth rate was higher during 30-60 DAT and showed declining trend afterwards (Appendix VII and VIII).

Among nutrient levels no significant differences in RGR was noticed during all the observational stages in both the seasons and years. Interaction effect of these factors was also non-significant for RGR.

4.1.1.11 Root length (cm)

Observations scheduled for root length were taken at 30 days interval from 30, 60 and 90 DAT which were significantly influenced by establishment methods and water regimes at intervals and seasons; however effect of nutrient levels was not observed during both the years as depicted in Table 4.10(a and b). Root length of rice increased gradually from 30 DAT up to 90 DAT. As concerning to establishment methods, significantly longer roots were documented under modified SRI at 30, 60 and 90 DAT (20.0, 27.3 and 29.4 cm in *kharif*; 20.5, 28.1 and 31.3 cm in *rabi* mean data, respectively) as compared to normal transplanting (17.0, 24.3 and 25.7 cm in *kharif*; 17.0, 24.6 and 27.7 cm in *rabi* mean data, respectively).

Water regimes, did not influenced the root length significantly at initial stage of 30 DAT. However, at 60 and 90 DAT, irrigation at 10 cm water level depletion in

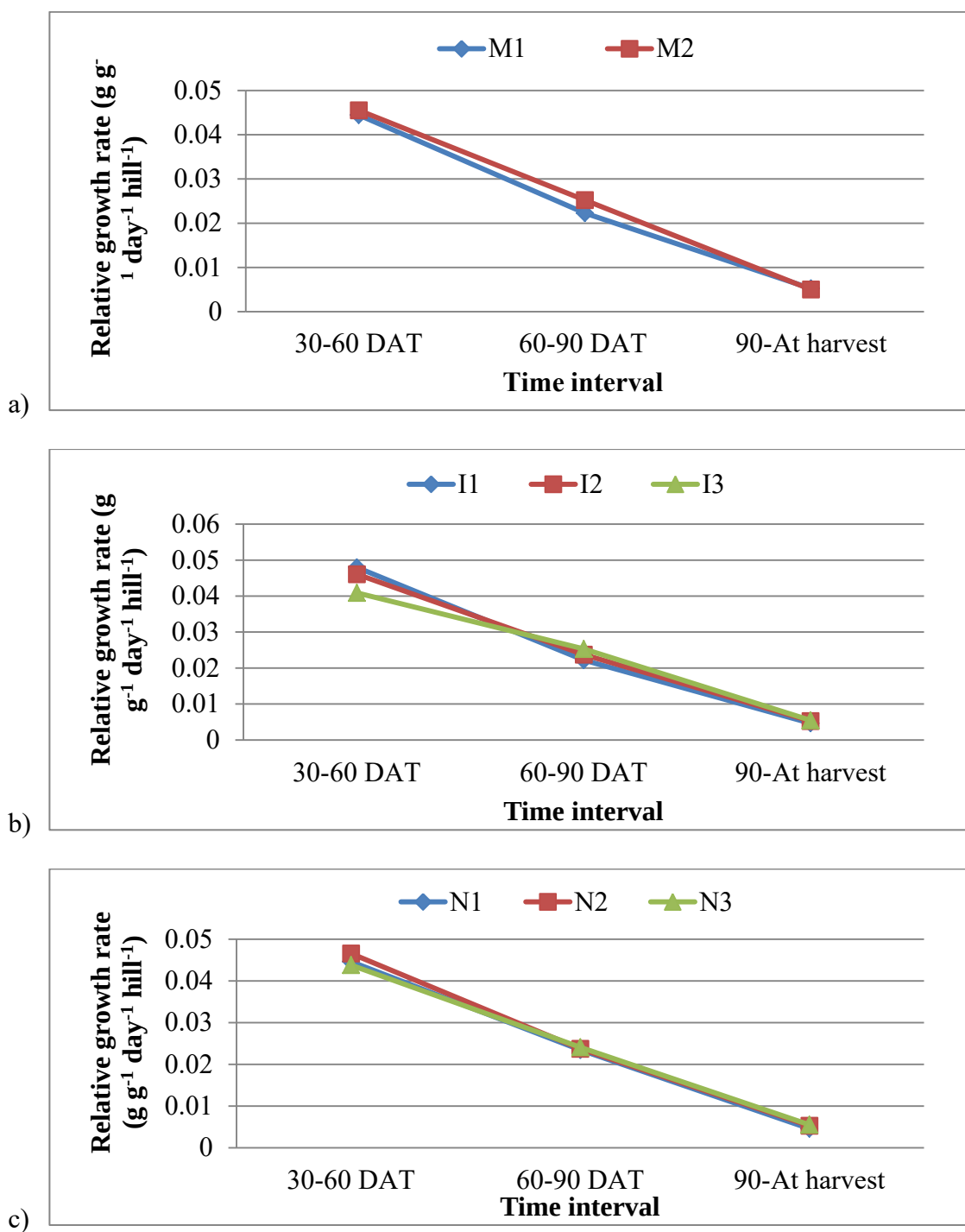


Figure 4.3: Relative growth rate of rice as influenced by (a) establishment methods, (b) water regimes and (c) nutrient levels (*kharif* mean data)

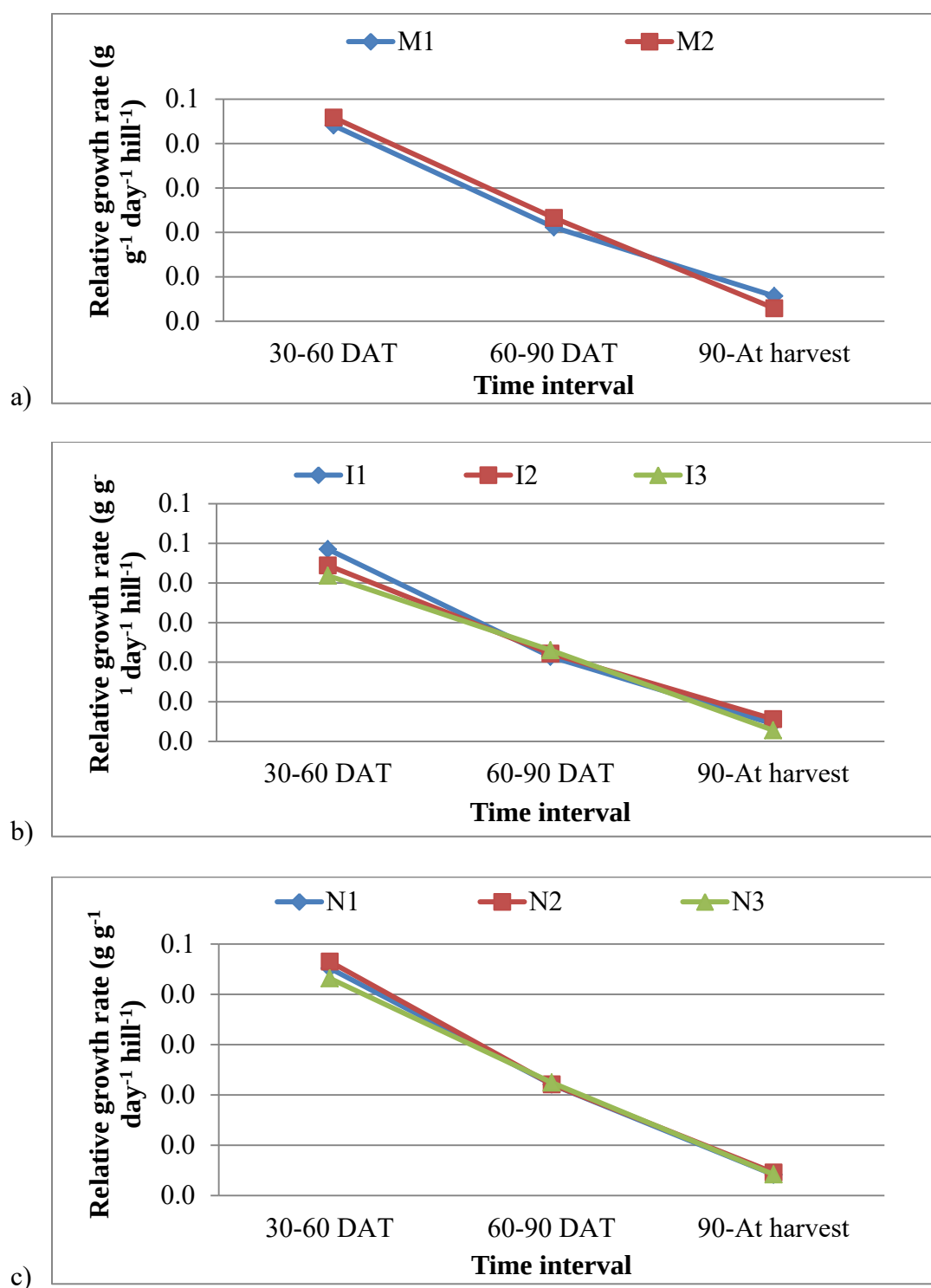


Figure 4.4: Relative growth rate of rice as influenced by (a) establishment methods, (b) water regimes and (c) nutrient levels (*rabi* mean data)

Table 4.9(a): Root length of *kharif* rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	Root length (cm)							
	<i>Kharif</i>							
	30 DAT				60 DAT			
	2015	2016	mean	2015	2016	mean	2015	2016
Establishment methods								
M1	16.7	17.0	16.9	24.3	24.2	24.3	26.7	24.8
M2	19.8	20.2	20.0	26.4	28.3	27.3	29.0	29.7
SEm±	0.3	0.4	0.3	0.3	0.2	0.2	0.4	0.3
CD (P=0.05)	1.5	2.3	1.9	2.0	1.3	1.2	2.3	1.9
Water regimes								
I1	17.5	18.4	17.9	23.7	24.7	24.2	26.1	25.6
I2	18.4	19.4	18.9	26.1	26.8	26.0	27.6	28.2
I3	18.8	18.1	18.5	28.2	27.2	27.2	30.0	27.8
SEm±	0.5	0.4	0.4	0.4	0.2	0.2	0.5	1.1
CD (P=0.05)	NS	NS	NS	1.7	0.9	1.0	1.9	NS
Nutrient levels								
N1	18.3	18.5	18.4	25.1	25.3	25.2	27.6	27.1
N2	18.4	18.5	18.5	25.9	26.9	26.4	28.5	27.9
N3	18.0	18.9	18.4	25.0	26.5	25.7	27.5	26.7
SEm±	0.2	0.3	0.2	0.5	0.5	0.4	0.6	0.8
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (MxIxN)	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

I1: Saturation;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

M2: Modified system of rice intensification;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

Table 4.9(b): Root length of *rabi* rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	Root length (cm)							
	<i>Rabi</i>							
	30 DAT				60 DAT			
	2015-16	2016-17	mean	2015-16	2016-17	mean	2015-16	2016-17
Establishment methods								
M1	16.8	17.0	16.9	25.0	24.2	24.6	28.5	26.8
M2	20.8	20.3	20.5	28.3	27.8	28.1	31.8	30.9
SEm±	0.1	0.3	0.1	0.5	0.3	0.4	0.5	0.3
CD (P=0.05)	0.6	1.7	0.8	2.8	1.9	2.4	2.8	1.9
Water regimes								
I1	18.2	18.0	18.1	25.0	24.0	24.5	28.5	26.6
I2	19.2	19.0	19.1	27.4	26.9	27.2	30.9	29.9
I3	19.1	18.9	19.0	27.6	27.1	27.3	31.1	30.1
SEm±	0.5	0.7	0.6	0.4	0.6	0.5	0.4	0.7
CD (P=0.05)	NS	NS	NS	1.6	2.4	1.8	1.6	2.6
Nutrient levels								
N1	18.2	18.0	18.1	25.0	24.0	24.5	29.9	28.7
N2	19.2	19.0	19.1	27.6	27.1	27.3	30.4	29.1
N3	19.1	18.9	19.0	27.4	26.9	27.2	30.2	28.8
SEm±	0.5	0.7	0.6	0.4	0.6	0.5	0.4	0.3
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (MxIxN)								
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting; M2: Modified system of rice intensification;
I1: Saturation; I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;
I3: irrigation at 10 cm water level depletion in PWT from soil surface;
N1: 100% RDN through inorganic; N2: 125% RDN through inorganic; N3: 50% through inorganic + 50% through organic

perched water tube from soil surface (27.2 and 28.9 cm in *kharif*; 27.3 and 30.6 cm in *rabi* mean data, respectively) recorded significantly longer root length except during *kharif* 2016 and was also found at par with irrigation at 5 cm water level depletion in perched water tube from soil surface (26.2 and 27.9 cm in *kharif*; 27.2 and 30.4 cm in *rabi* mean data, respectively). On the other hand significantly lower root length was recorded under waster regime of saturation through the life cycle

The interaction effect between establishment methods, water regimes and nutrient levels on root length was non-significant at any of the stages of the crop growth period during both the seasons and years.

4.1.1.12 Root volume (cm³)

The data on root volume was taken at 30 days interval from 30, 60 and 90 DAT revealed that it was influenced significantly by establishment methods and water regimes at variable stages and seasons; however effect of nutrient levels was not observed during both the seasons and years as depicted in Table 4.11(a and b). Root volume of rice increased gradually from 30 DAT up to 90 DAT. As regards to establishment methods, higher root volume was recorded under modified SRI at 30, 60 and 90 DAT (15.1, 34.2 and 35.8 cm³ in *kharif*; 14.6, 36.2 and 39.5 cm³ in *rabi* mean data, respectively) as compared to normal transplanting (11.0, 20.4, 23.1 cm³ in *kharif*; 9.9, 22.4 and 26.1 cm³ in *rabi* mean data, respectively).

On perusal of the data related to water regimes it was observed that root volume was not influenced significantly at initial stage of 30 DAT due to water regimes. However, at 60 and 90 DAT, irrigation at 10 cm water level depletion in perched water tube from soil surface (28.6 and 30.8 cm³ in *kharif*; 31.0 and 35.1 cm³ in *rabi* mean data, respectively) recorded significantly higher root volume except during *kharif* 2016 and was also found at par with irrigation at 5 cm water level depletion in perched water tube from soil surface (29.2 and 34.3cm in *kharif*; 27.2 and 30.4 cm in *rabi* mean data, respectively).

The interaction effect of establishment methods, water regimes and nutrient levels on root volume during both the seasons and years and in pooled mean data of two years was not significant at any stages of the crop growth period.

Table 4.10(a): Root volume of *kharif* rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	Root volume (cm ³)								
	kharif								
	30 DAT			60 DAT			90 DAT		
	2015	2016	mean	2015	2016	mean	2015	2016	mean
Establishment methods									
M1	10.6	11.4	11.0	20.8	20.1	20.4	24.3	21.9	23.1
M2	12.5	17.7	15.1	34.3	34.0	34.2	36.0	35.6	35.8
SEm±	0.2	0.2	0.2	0.5	0.5	0.2	0.5	0.6	0.3
CD (P=0.05)	1.0	1.0	1.0	2.8	3.2	1.0	2.9	3.5	1.7
Water regimes									
I1	11.0	14.6	12.8	25.9	25.3	25.6	28.3	27.1	27.7
I2	11.7	14.8	13.2	27.3	27.8	27.7	29.9	29.9	29.9
I3	11.9	14.3	13.1	29.4	28.0	28.6	32.2	29.9	30.8
SEm±	0.3	0.3	0.3	0.5	0.5	0.4	0.6	1.2	0.7
CD (P=0.05)	NS	NS	NS	2.1	2.1	1.8	2.2	NS	2.4
Nutrient levels									
N1	11.6	14.4	13.0	27.2	26.6	26.9	29.8	28.6	29.2
N2	11.6	14.7	13.2	28.1	27.7	27.9	30.8	29.5	30.1
N3	11.4	14.7	13.0	27.3	26.9	27.1	29.9	28.3	29.1
SEm±	0.1	0.2	0.2	0.6	0.6	0.6	0.7	1.0	0.7
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (MxIxN)	NS	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

M2: Modified system of rice intensification;

I1: Saturation; I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

Table 4.10(b): Root volume of *rabi* rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	Root volume (cm ³)							
	<i>Rabi</i>							
	30 DAT		60 DAT		90 DAT			
	2015-16	2016-17	mean	2015-16	2016-17	mean	2015-16	2016-17
Establishment methods								
M1	9.9	9.9	9.9	24.0	20.7	22.4	28.7	23.5
M2	13.5	15.8	14.6	34.6	37.7	36.2	42.6	40.5
SEm±	0.3	0.2	0.3	0.3	0.8	0.6	0.3	0.8
CD (P=0.05)	2.1	1.0	1.5	2.1	5.0	3.5	2.1	5.0
Water regimes								
I1	11.3	12.5	11.9	28.6	26.5	27.6	33.9	29.3
I2	11.9	12.8	12.3	28.7	29.7	29.2	34.0	32.5
I3	12.0	13.3	12.7	30.5	31.5	31.0	36.0	34.3
SEm±	0.5	0.2	0.3	0.3	0.5	0.3	0.3	0.5
CD (P=0.05)	NS	NS	NS	1.2	1.9	1.0	1.1	1.9
Nutrient levels								
N1	11.5	12.5	12.0	29.2	28.8	29.0	34.3	31.6
N2	12.4	13.1	12.8	29.6	29.7	29.7	35.2	32.5
N3	11.2	13.0	12.1	29.0	29.2	29.1	34.3	32.0
SEm±	0.3	0.4	0.3	0.3	1.1	0.7	0.4	1.1
CD (P=0.05)	1.2	NS	NS	NS	NS	NS	NS	NS
Interaction (MxIxN)	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

I1: Saturation;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

M2: Modified system of rice intensification;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

4.1.1.13 Days to 50% panicle exertion (days)

Days to 50 % panicle exertion (PE) was significantly influenced by establishment methods during both the seasons and years and water regimes influenced it during rabi seasons only in both the years; however, nutrient levels failed to affect days to 50% panicle exertion during both the years as depicted in Table 4.9. The data pertaining to establishment methods revealed that modified SRI (75.0 and 73.6 days in *kharif* and *rabi* mean data, respectively) took significantly lower number of days to attain 50% panicle exertion as compared to normal transplanting (78.1 and 78.5 days in *kharif* and *rabi* mean data, respectively).

As regards to water regimes, less number of days were required to attain 50 % PE under irrigation at 10 cm water level depletion in perched water tube from soil surface during *rabi* seasons of both the years and in mean data although days required to attain 50% PE was not influenced significantly due to various water regimes in *kharif* seasons of both the years. However, irrigation at 10 cm water level depletion in perched water tube from soil surface (I_3) (74.4 days) took significantly lower number of days to attain 50% PE during both the rabi seasons and in mean data.

Nutrient levels behaved similarly to attain 50% PE in both the seasons and years. Similarly the interaction effect of all the factors i.e. establishment methods, water regimes and nutrient levels was not significant at any of the seasons and year.

4.1.1.14 Days to 50% flowering (days)

Data recorded on days to 50% flowering presented in Table 4.9 revealed that days to 50 % flowering was significantly influenced by establishment methods during both the seasons and years where as water regimes influenced it during rabi seasons only however, nutrient levels did not showed any significant variation during both the years. The data pertaining to establishment methods revealed that modified SRI (88.3 and 88.5 days in *kharif* and *rabi* mean data, respectively) took significantly less number of days to attain 50% flowering as compared to normal transplanting (91.7 and 93.6 days in *kharif* and *rabi* mean data, respectively).

Table 4.11: Days to 50% panicle initiation and days to 50% flowering of *rabi* rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	Days to 50% panicle initiation					Days to 50% flowering				
	Kharif			Rabi		Kharif			Rabi	
	2015	2016	mean	2015-16	2016-17	2015	2016	mean	2015-16	2016-17
Establishment methods										
M1	78.1	78.1	78.1	78.2	78.8	78.5	90.8	91.7	91.9	93.5
M2	75.0	75.1	75.0	73.4	73.9	73.6	87.7	88.3	87.6	88.5
SEm±	0.5	0.2	0.4	0.7	0.5	0.2	0.4	0.4	0.7	0.7
CD (P=0.05)	3.1	1.3	2.2	4.4	3.2	1.2	2.5	2.5	4.2	4.4
Water regimes										
I1	76.9	77.2	77.1	76.8	77.8	77.5	89.9	90.6	90.5	92.0
I2	76.2	76.7	76.4	75.1	76.6	76.3	89.4	89.9	89.2	90.2
I3	76.4	75.9	76.2	74.0	74.7	74.4	88.5	89.5	88.5	89.1
SEm±	0.4	0.8	0.3	0.3	0.3	0.2	0.8	0.3	0.2	0.3
CD (P=0.05)	NS	NS	NS	1.0	1.3	0.7	NS	NS	0.8	1.0
Nutrient levels										
N1	76.8	77.3	77.0	76.4	77.0	76.7	90.0	90.5	90.1	91.6
N2	76.4	76.2	76.3	76.0	76.5	76.2	88.8	89.7	89.9	91.2
N3	76.4	76.3	76.4	75.0	75.6	75.3	88.9	89.8	89.3	90.2
SEm±	0.3	0.5	0.4	0.5	0.3	0.4	0.6	0.4	0.6	0.5
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (MxIxN)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

M2: Modified system of rice intensification;

I1: Saturation;

I2: Irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

I3: Irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

Water at 10 cm water level depletion in perched water tube from soil surface (74.4 days) took significantly lower number of days to attain 50% flowering during both the *rabi* seasons over other water regimes.

The effect of nutrient levels on days to 50% flowering was not significant at any of the seasons and years

Interaction between establishment methods, water regimes and nutrient levels were found non-significant towards days to 50% flowering at both the seasons and years.

Discussion on influence of establishment methods, water regimes and nutrient levels on growth parameters

Temperature, rainfall, sunlight and soil are important abiotic components in the ecosystem which influence productivity. The meteorological data (Figure 3.1 to 3.4 and Appendix I to IV) revealed that the seasonal conditions during the crop growth periods varied during *kharif* seasons but were similar during *rabi* seasons.

As regards to climatic conditions, *kharif* season of 2016 was superior and received 785.9 mm rainfall against 331.5 mm during 2015 with higher rainy days (41 and 20 days, respectively). Other climatic parameters were almost similar. Transplanting of rice was earlier during *kharif* 2016 as compared to *kharif* 2015 (last week of June in *kharif* 2016 and 1st fortnight of September in *kharif* 2015) which was optimum for the growth and development of rice hence, reflected well in grain yield during *kharif* 2016. There were no severe incidence of pests and diseases during both the *kharif* seasons. Kar *et al.* (2005) also supported that growth and yield of any grain crop under a particular environment are largely determined by soil moisture, nutrients, radiation interception and the efficiency of conversion of intercepted radiation to dry matter and partitioning of dry matter in to grain.

During *rabi* seasons, transplanting of crop during *rabi* 2015-16 was done during 1st fortnight of February as compared to early planting during *rabi* 2016-17 (last week of December to 1st week of January) climatic factors like maximum and minimum temperature, solar radiation, rainfall and relative humidity etc. were similar during both the *rabi* seasons. Rainfall was mostly ineffective during both *rabi* seasons.

In addition, there were no severe incidence of pests and diseases during both the kharif seasons.

The physical properties of soil was near neutral ($\text{pH } 7.8 \pm 0.05$) with low available N and high available P and K. Growth parameters and growth analysis of rice plant height, number of tillers hill^{-1} , number of leaves hill^{-1} , leaf area, SPAD value, leaf area index, leaf area duration, dry matter accumulation, root length and root volume were recorded at periodical intervals [Table 4.1(a) to 4.11(b)].

The results indicated that modified SRI exhibited taller plants over normal transplanting but was comparable at later stages. Also modified SRI produced higher number of tillers hill^{-1} than the normal transplanting during all the growth stages of both the seasons and years. Ginigaddara and Ranamukhaarachchi (2011) also found that transplanting younger seedlings with wider spacing have ability to produce greater number of tillers hill^{-1} than older seedlings with narrow spacing. Lenka and Gulati (2015) observed that when a seedling is transplanted carefully at the initial growth stage, the trauma of root damage caused during uprooting is minimized following a rapid growth with short phyllochrons. Vigorous individual plants with higher number of tillers and functional leaves hill^{-1} in modified SRI (M_2) obtained sufficient leaf area, leaf area index and leaf area duration during the crop flowering leads to superior crop growth rate hill^{-1} from 60 DAT to 90 DAT. Thereby higher leaf number and sufficient LAI and LAD joined together produced at par dry matter accumulation m^{-2} in modified SRI as compared to normal transplanting. The younger seedlings in SRI when carefully transplanted by keeping the roots straight (assuring that the roots do not assume 'j' shape) might have encouraged vigorous and deeper root system. The above statement can also be supported by earlier works, Kavitha *et al.* (2011) and Mohanty *et al.* (2014). Further, the provision of wider spacing between plants in SRI (fewer plants per unit area) and loosening of soil by running of cono-weeder to control weeds might have helped rice seedlings to develop profuse root growth (Mohanty *et al.*, 2014). Wider space availability due to square planting between plant to plant and row to row might have amplified the root spreading extent in the form of root length and root volume in rhizosphere, which eventually utilized the resources such as

nutrients, water, space and light very efficiently. Above elements were found important for plant growth and there by leading to higher tillering and dry matter production as has been reported earlier by Raju and Sreenivas (2008) and Dandeniya and Thies (2012). All the aforesaid growth parameters of rice recorded the lowest values under normal transplanting on hill⁻¹ basis. However on per unit area basis (m⁻²) normal transplanting performed superior over MoSRI. Similar findings were also reported earlier by Styger *et al.* (2011) and Hamid *et al.* (2016). Also a definite positive relationship between seedling age and earliness was observed in modified SRI. Younger seedlings gave early panicle exertion and flowering; leading to entering into early reproductive stage (Upreti, 2006).

As regards to water regimes, plants given saturation maintained throughout the lifecycle of crop obtained higher values for plant growth parameters viz., plant height, number of tillers hill⁻¹, number of leaves hill⁻¹, leaf area, SPAD value, leaf area index, leaf area duration, dry matter accumulation and SPAD value [from Table 4.1(a) to 4.9(b)] recorded at periodical intervals were found superior over other water regimes. In all aforesaid growth parameters, the performance of saturation throughout the lifecycle of crop (I₁) might be due to favorable vegetative growth and development as they received sufficient moisture at appropriate amount and critical stages during entire lifecycle. Since water plays a vital role in the carbohydrate metabolism, protein synthesis, cell division, cell enlargement and partitioning of photosynthates to sink for improved development of growth traits (Yang *et al.*, 2003) the favorable soil water balance maintained under saturation and 5 cm water level depletion in perched water tube from soil surface (I₂) helped the crop plants to put forth improved performance over irrigation at 10 cm water level depletion in perched water tube from soil surface (I₃). The increased growth parameters were attributed to higher frequency of irrigation, favourable soil water balance without any wide fluctuations and higher nutrient uptake due to better availability of nutrients under both saturations [Table 4.17 (a and b)]. These findings are in agreement with Ramakrishna *et al.* (2007) and Sandhu *et al.* (2012).

Therefore, crop plants irrigated with saturation and 5 cm water level depletion in perched water tube from soil surface (I_2) treatments had higher number of tillers [Table 4.2(a and b)] contributing to more canopy building *i.e.* leaf area and LAI. As leaves continue to grow and persist (LAD) until an optimal leaf area index *i.e.*, LAI > 4.0 [Table 4.5(a) and 4.5(b)] is achieved, that get the most out of canopy photosynthesis with high photosynthetic efficiency *i.e.* CGR and RGR resulting in higher dry matter production (Figure 4.1 to 4.4). Several researchers had found similar results of growth parameters (Thompson, 2002; Pandey *et al.*, 2010 and Yang and Zhang, 2010).

The growth and development parameters of rice in 125% of RDN through inorganic and 100% of RDN through inorganic and integrated nutrient management through 50% RDN inorganic and organic were statistically at par with each other but these levels were non-significantly superior over RDN (50 % inorganic and 50 % organic) throughout all the seasons and their pooled mean data. This could be due to the fact that leaf nitrogen status of rice is closely related to photosynthetic rate and biomass production and it is a sensitive indicator of changes in crop nitrogen demand within a growing season of rice. Application of nitrogen through inorganic source alone or in integration with organic source might have helped crop to perform equally better at critical physiological phases and would have led to enhanced assimilation of photosynthates towards grain as sink. Increase in grain and straw yield related attributes can also be attributed to favorable effect in accelerating the growth and yield parameters (Jugseniya, 2012).

4.2 Post-harvest observations

4.2.1 Yield and yield attributes

4.2.1.1 Number of panicles (m^{-2})

Number of panicles (m^{-2}) of rice was significantly affected due to water regimes, however it was not affected significantly in establishment methods and nutrient levels during *kharif* and *rabi* in both the years (Table 4.12). As regard to establishment methods, normal transplanting and modified SRI recorded comparable

number of panicles (m^{-2}) during both the seasons years and in mean data (377.7 and 340.2 panicles m^{-2} , respectively in mean data).

The data pertaining to water regimes, saturation maintained throughout the life cycle of transplanted rice recorded the highest number of panicles (m^{-2}) during *kharif* and *rabi* seasons of both the years and in mean data (393 and 350.5 panicles m^{-2} , respectively in mean data).

Amongst nutrient levels, 125% recommended dose of nitrogen (RDN) applied through inorganic source recorded numerically highest number of panicles (m^{-2}) in both the seasons and in their mean data (377.4 and 336.6 panicles m^{-2} , respectively in mean data), but it was statistically on par with other nutrient levels.

The interaction effect among establishment methods, water regimes and nitrogen levels was found to be non-significant with respect to number of panicles (m^{-2}) during both the years of study and in mean data.

4.2.1.2 Number of panicles (hill^{-1})

Results on number of panicles (hill^{-1}) of rice revealed that number of panicles hill^{-1} was influenced significantly due to establishment methods and water regimes; however it was not affected significantly in nutrient levels during *kharif* and *rabi* in both the years (Table 4.12). Establishment method of modified SRI recorded significantly higher number of panicles hill^{-1} over normal transplanting during both the years and in pooled means (21.65 and 19.33 panicles hill^{-1} , respectively in mean data).

Water regime of saturation maintained throughout the life cycle of transplanted rice observed the highest number of panicles hill^{-1} during *kharif* and *rabi* seasons of both the years and in mean data (16.29 and 14.48 panicles hill^{-1} , respectively in mean data).

The interaction effect between establishment methods, water regimes and nitrogen levels was found to be non-significant with respect to number of panicles (hill^{-1}) during both the years as well as in mean data of two years.

4.2.1.3 Panicle length (cm)

Panicle length of rice was significantly influenced due to establishment methods, however variable findings were obtained with water regimes and nutrient

Table 4.12: Number of panicles and panicle length of rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	Number of panicles (m ⁻²)					Number of panicles (hill ⁻¹)					Panicle length (g)							
	Kharif		Rabi			Kharif		Rabi			Kharif		Rabi					
	2015	2016	mean	2015- 2016		mean	2015	2016	mean		2015- 2016	mean	2015	2016	mean	2015- 2016		
Establishment methods	16	17	16	17		16	17	16	17		16	17	16	17				
M1	342	413	378	366	314	340	7.6	9.2	8.4	8.1	7.0	7.6	22.1	22.5	22.3	21.9	22.0	21.9
M2	323	370	346	334	284	309	20.2	23.1	21.6	20.9	17.8	19.3	23.3	23.6	23.4	23.0	23.0	23.0
SEm±	9.1	7.8	6.3	6.9	5.3	5.8	0.46	0.26	0.34	0.47	0.10	0.24	0.2	0.2	0.2	0.2	0.1	0.1
CD (P=0.05)	NS	NS	NS	NS	NS	NS	2.78	1.57	2.08	2.86	0.59	1.48	1.2	NS	1.1	1.0	0.7	0.8
Water regimes																		
I1	376	410	393	378	323	350	15.8	16.8	16.3	15.7	13.3	14.5	23.3	23.5	23.4	22.8	22.6	22.7
I2	321	392	356	348	299	323	13.3	16.2	14.7	14.4	12.4	13.4	22.7	22.9	22.8	22.6	22.4	22.5
I3	301	372	337	325	276	300	12.7	15.4	14.1	13.5	11.5	12.5	22.2	22.6	22.4	21.8	22.5	22.2
SEm±	5.5	8.3	3.2	6.8	7.4	6.1	0.28	0.28	0.13	0.31	0.26	0.18	0.3	0.2	0.2	0.3	0.5	0.4
CD (P=0.05)	21.4	NS	12.4	26.5	29.0	24.1	1.10	NS	0.53	1.20	1.04	0.70	NS	NS	0.6	1.3	NS	NS
Nutrient levels																		
N1	323	390	356	350	300	325	13.3	16.0	14.7	14.5	12.4	13.4	22.8	23.1	22.9	22.5	22.9	22.7
N2	348	407	377	361	312	337	14.6	16.7	15.7	15.0	12.9	13.9	22.8	23.3	23.0	22.5	22.4	22.5
N3	327	377	352	339	286	313	13.8	15.7	14.8	14.0	11.9	13.0	22.6	22.7	22.7	22.1	22.2	22.2
SEm±	7.8	8.9	3.5	7.7	7.6	6.9	0.35	0.31	0.15	0.34	0.27	0.17	0.3	0.2	0.2	0.4	0.2	0.3
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (MxIxN)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

M2: Modified system of rice intensification;

I1: Saturation;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

levels during *kharif* and *rabi* in both the years as presented in Table 4.12. The data related to establishment methods revealed that modified system of rice intensification (23.4 and 23.0 cm, respectively, over mean data) registered significantly longer panicle length as compared to normal transplanting during *kharif* 2015 and *rabi* seasons of both the years and mean data of both the years and seasons.

Results on water regimes suggested that saturation maintained throughout life cycle of rice recorded longer panicles during both the years and in mean data which was significantly higher over rest of the water regimes except *kharif* 2015 and *rabi* 2016-17 and mean data of 2016-17 where all the water regimes behaved similar towards panicle length.

With respect to nutrient levels, 125% recommended dose of nitrogen (RDN) applied through inorganic source recorded longer panicles during both the years and in mean data which was found significantly higher during *kharif* 2016.

With reference to interaction effect between establishment methods, water regimes and nitrogen levels, non-significant differences were recorded with respect to panicle length during both the seasons and years.

4.2.1.4 Panicle weight (g)

Data recorded on panicle weight revealed that establishment methods and water regimes significantly influenced the panicle weight. However, effect due to nutrient levels was non-significant over both the seasons and years as depicted in Table 4.13. The data related to establishment methods indicated that panicle weight of rice was significantly heavier in modified system of rice intensification than normal transplanting.

Irrigation maintained at saturation throughout life cycle of rice during both the seasons and years of study registered maximum panicle weight however at par values were registered under irrigation at 5 cm water level depletion in perched water tube from soil surface during both the years and their means except during *kharif* 2016 where all the water regimes behaved similarly towards panicle weight. The lowest panicle weight was recorded under irrigation at 10 cm water level depletion in perched water tube from soil surface during both the years and mean data.

Table 4.13: Panicle weight and grains panicle⁻¹ of rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	Panicle weight (g)					Grains panicle ⁻¹ (No.)						
	Kharif		Rabi			Kharif		Rabi				
	2015	2016	mean	2015-16	2016-17	mean	2015	2016	mean	2015-16	2016-17	mean
Establishment methods												
M1	2.35	2.45	2.40	2.25	2.18	2.21	93.9	98.0	96.0	93.7	92.4	93.1
M2	3.02	2.77	2.90	2.95	2.51	2.73	120.9	110.7	115.8	125.6	109.4	117.5
SEm±	0.09	0.05	0.04	0.06	0.04	0.02	3.8	1.9	1.7	1.9	1.6	1.6
CD (P=0.05)	0.57	0.29	0.26	0.34	0.27	0.15	22.9	11.4	10.6	11.3	9.6	9.8
Water regimes												
I1	2.87	2.74	2.80	2.79	2.49	2.64	116.7	109.5	112.1	117.5	107.3	112.4
I2	2.66	2.57	2.62	2.59	2.31	2.49	106.5	103.0	104.7	109.2	99.4	104.3
I3	2.53	2.51	2.52	2.42	2.23	2.32	101.1	100.6	100.8	102.2	95.9	99.1
SEm±	0.06	0.05	0.05	0.05	0.05	0.04	2.4	1.9	1.9	2.1	1.8	0.8
CD (P=0.05)	0.23	NS	0.18	0.21	0.19	0.17	9.4	NS	7.4	8.4	7.2	3.2
Nutrient levels												
N1	2.68	2.62	2.65	2.60	2.36	2.48	107.1	104.8	105.9	109.6	101.3	105.4
N2	2.71	2.64	2.68	2.67	2.34	2.50	108.4	105.6	107.0	112.6	101.7	107.1
N3	2.67	2.57	2.62	2.53	2.34	2.43	106.7	102.6	104.7	106.8	99.7	103.2
SEm±	0.04	0.05	0.01	0.03	0.05	0.03	1.7	2.3	0.6	2.2	2.2	1.5
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (MxIxN)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

I1: Saturation;

I3: Irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

M2: Modified system of rice intensification;

I2: Irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

As regards to nitrogen levels, statistically equal performance was recorded in respect of panicle weight. Nutrient level of 125% recommended dose of nitrogen (RDN) applied through inorganic source recorded numerically higher values during both the seasons and years.

Combined effect of establishment methods, water regimes and nitrogen levels was non-significant with respect to panicle weight during both the seasons and years along with mean data.

4.2.1.5 Number of grains panicle⁻¹

The number of grains panicle⁻¹ of rice was significantly influenced by establishment methods and water regimes; however nitrogen levels failed to influence this parameter significantly during both the seasons and years of study (Table 4.13). The data pertaining to number of grains panicle⁻¹ of rice was significantly higher in modified system of rice intensification (115.8 and 117.9 grains panicle⁻¹, in mean data of kharif and rabi, respectively) than normal transplanting (96.0 and 93.1 grain panicle⁻¹, in mean data of kharif and rabi, respectively).

Among the water regimes, saturation maintained throughout lifecycle (I₁) produced significantly higher number of grains panicle⁻¹ (112.1 and 112.4 grains panicle⁻¹, respectively in the mean data) during both the seasons and years as well as on the basis of mean data.

The interaction effect amongst establishment methods, water regimes and nitrogen levels was non-significantly influenced with respect to number grains of panicle⁻¹ during both the seasons and years.

4.2.1.6 Sterility percentage (%)

Sterility percentage of rice was significantly influenced by water regimes; however establishment methods and nitrogen levels did not influence this parameter significantly during both the seasons years of study except in *rabi* 2015 (Table 4.14). The data concerning to establishment methods showed non-significant values of sterility percentage of grains in rice in all the years and over mean data except during *rabi* 2015 where, normal transplanting showed significantly higher sterile grains over modified SRI.

Table 4.14: Sterility percentage and panicle length of rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	Sterility percentage (%)										Test weight (g)			
	Kharif					Rabi					Kharif			
	2015	2016	mean	2015-16	2016-17	2015	2016	mean	2015	2016	mean	2015-16	2016-17	mean
Establishment methods														
M1	15.0	11.9	13.5	15.2	12.1	12.9	23.4	23.9	23.7	23.4	23.3	23.3	23.3	23.3
M2	14.9	11.7	13.3	13.7	11.7	13.5	24.1	23.6	23.9	23.9	24.0	24.0	24.0	24.0
SEm±	0.5	0.4	0.3	0.2	0.3	0.1	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Water regimes														
I1	13.1	11.2	12.2	13.4	9.8	11.5	23.7	23.8	23.7	23.4	23.4	23.4	23.4	23.4
I2	15.5	11.8	13.7	14.4	11.9	13.1	23.7	23.4	23.5	23.6	23.7	23.7	23.7	23.7
I3	16.3	12.4	14.3	15.8	13.9	14.9	23.9	24.1	24.0	23.8	23.8	23.8	23.8	23.8
SEm±	0.2	0.8	0.4	0.4	0.4	0.2	0.2	0.2	0.2	0.5	0.5	0.5	0.5	0.5
CD (P=0.05)	0.6	NS	1.4	1.6	1.5	0.8	NS	NS	NS	NS	NS	NS	NS	NS
Nutrient levels														
N1	14.9	12.4	13.6	14.5	12.3	13.4	23.9	23.6	23.7	23.7	23.7	23.7	23.7	23.7
N2	15.4	11.1	13.2	15.0	11.8	13.4	23.7	23.8	23.7	23.7	23.7	23.7	23.7	23.7
N3	14.6	12.0	13.3	13.9	11.5	12.7	23.7	23.9	23.8	23.5	23.5	23.5	23.5	23.5
SEm±	0.5	1.2	0.5	0.5	0.3	0.3	0.1	0.2	0.1	0.3	0.3	0.3	0.3	0.3
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (MxIxN)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

M2: Modified system of rice intensification;

I1: Saturation;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

Further, data related to water regimes revealed that saturation maintained throughout the lifecycle of rice produced lowest percentage of sterile grains over other water regimes of 5 cm and 10 cm water level depletion in perched water tube from soil surface.

Nutrient levels indicated non-significant differences in sterility percentage of grains in rice over all the seasons and years and in mean data.

Interaction between establishment methods, water regimes and nitrogen levels, was found non-significant for the character during both the seasons and years.

4.2.1.7 Test weight (g)

Test weight of rice grain during *kharif* and *rabi* seasons of both the years did not influenced significantly due to establishment methods, water regimes and nutrient levels. The interaction effect of these factors on test weight was also not significant at both the seasons and years (Table 4.14).

4.2.1.8 Grain yield (t ha⁻¹)

Grain yield of rice was significantly influenced due to water regimes, however it was not affected significantly with establishment methods and variable findings were obtained with nutrient levels during *kharif* and *rabi* seasons in both the years [Table 4.15(a) and 4.15(b)]. The data pertaining to effect of establishment methods on grain yield of rice indicated that normal transplanting (4.97 t ha⁻¹ and 4.67 t ha⁻¹, respectively over mean data of *kharif* and *rabi* seasons of both the years) and modified SRI (5.55 t ha⁻¹ and 5.23 t ha⁻¹, respectively in mean data of *kharif* and *rabi* of both the years) did not differed significantly during *kharif* and *rabi* sown rice during both the years as well as in mean data for grain yield.

As regards to water regimes saturation maintained throughout the life cycle of transplanted rice recorded the highest grain yield during *kharif* and *rabi* seasons of both the years and in mean data (5.37 and 5.23 t ha⁻¹, respectively in mean data of *kharif* and *rabi* of both the years) and it was *at par* with irrigation at 5 cm water level depletion in perched water tube from soil

Table 4.15(a): Grain yield, straw yield and harvest index of *kharif* rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	<i>Kharif</i>							
	Grain yield (t ha ⁻¹)				Straw yield (t ha ⁻¹)			
	2015	2016	mean	2015	2016	mean	2015	2016
Establishment methods								
M1	5.36	5.56	5.46	6.68	6.92	6.80	44.60	43.90
M2	4.92	5.01	4.97	6.08	6.39	6.23	44.86	43.11
SEm±	0.08	0.12	0.08	0.22	0.10	0.12	1.11	0.85
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Water regimes								
I1	5.50	5.59	5.55	6.82	6.92	6.87	44.76	43.84
I2	5.18	5.27	5.23	6.39	6.65	6.52	44.88	43.52
I3	4.74	4.99	4.87	5.93	6.38	6.15	44.54	43.17
SEm±	0.10	0.19	0.10	0.14	0.15	0.09	0.47	1.11
CD (P=0.05)	0.39	NS	0.41	0.53	NS	0.35	NS	NS
Nutrient levels								
N1	5.16	5.32	5.24	6.40	6.60	6.50	44.70	43.88
N2	5.31	5.36	5.34	6.42	6.73	6.58	45.68	43.98
N3	4.96	5.17	5.06	6.32	6.63	6.48	43.80	42.67
SEm±	0.06	0.22	0.10	0.24	0.10	0.13	0.67	1.33
CD (P=0.05)	0.23	NS	NS	NS	NS	NS	NS	NS
Interaction (MxIxN)	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

I1: Saturation;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

M2: Modified system of rice intensification;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

Table 4.15(b): Grain yield, straw yield and harvest index of *rabi* rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	<i>Rabi</i>									
	Grain yield (t ha ⁻¹)					Straw yield (t ha ⁻¹)				
	2015-16	2016-17	mean	2015-16	2016-17	2015-16	2016-17	mean	2015-16	2016-17
Establishment methods										
M1	5.27	4.83	5.05	6.80	6.30	6.55	43.7	43.0	43.3	43.8
M2	4.89	4.46	4.67	6.42	5.61	6.02	43.1	44.4	43.8	43.8
SEm±	0.09	0.11	0.09	0.16	0.20	0.17	0.63	0.31	0.39	0.39
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Water regimes										
I1	5.48	4.98	5.23	7.02	6.44	6.73	43.7	43.4	43.5	43.5
I2	5.05	4.68	4.90	6.65	6.03	6.34	43.2	43.6	43.4	43.4
I3	4.70	4.28	4.49	6.17	5.41	5.79	43.2	44.1	43.7	43.7
SEm±	0.15	0.05	0.09	0.10	0.11	0.09	0.81	0.43	0.57	0.57
CD (P=0.05)	0.57	0.21	0.35	0.37	0.42	0.34	NS	NS	NS	NS
Nutrient levels										
N1	5.10	4.66	4.88	6.63	6.06	6.34	43.5	43.3	43.4	43.4
N2	5.23	4.80	5.02	6.82	6.13	6.47	43.4	43.9	43.6	43.6
N3	4.79	4.47	4.68	6.40	5.69	6.04	43.2	43.9	43.6	43.6
SEm±	0.12	0.15	0.07	0.15	0.20	0.14	1.09	1.31	0.89	0.89
CD (P=0.05)	0.43	NS	0.25	NS	NS	NS	NS	NS	NS	NS
Interaction (MxIxN)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

I1: Saturation;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

M2: Modified system of rice intensification;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

surface (5.05 and 4.90 t ha⁻¹, respectively in mean data of *kharif* and *rabi* of both the years). However, in *kharif* grown rice crop the grain yield of rice was statistically at par in all the water regime during *kharif* 2016 and in pooled mean data of *kharif* two years.

Result on grain yield of rice also indicated that among the nutrient levels, 125% recommended dose of nitrogen (RDN) applied through inorganic source recorded the highest grain yield in both the seasons and in their mean data. However, significant differences were observed in *kharif* 2015 and *rabi* 2015-16 and in *rabi* mean data. 100% RDN through inorganic source produced comparable grain yield of rice with 125% RDN during both the seasons and years of experimentations.

The interaction effect between combination of establishment methods, water regimes and nitrogen levels was found to be non-significant with respect to grain yield during both the seasons and years of study.

4.2.1.9 Straw yield (t ha⁻¹)

Straw yield of rice was considerably influenced due to water regimes, however it was not affected significantly with establishment methods and variable findings were obtained with nutrient levels during *kharif* and *rabi* seasons in both the years as depicted in Table 4.15(a) and 4.15(b). Regarding establishment methods, normal transplanting recorded comparable straw yield during *kharif* and *rabi* seasons of both the years and also in mean data.

The data pertaining to water regimes saturation maintained throughout the life cycle recorded the highest straw yield during *kharif* and *rabi* seasons of both the years and in mean data (5.37 and 5.23 t ha⁻¹, respectively in mean data).

Nutrient levels did not influence the straw yield significantly during both the seasons and years of study.

The interaction effect among establishment methods, water regimes and nitrogen levels was found to be non-significant with respect to straw yield during both the seasons and years of study and over mean data.

4.2.1.10 Harvest index (%)

Data on harvest index of rice are presented in Table 4.15(a) and 4.15(b) showed that establishment methods, water regimes and nutrient levels did not influenced the harvest index of rice during kharif and rabi seasons of both the years and in their mean data. The interaction effect of these factors was also nono-significant for harvest index.

Discussion on influence of establishment methods, water regimes and nutrient levels on yield and yield parameters of rice

Among the different establishment methods, normal transplanting (M_1) recorded higher values of grain and straw yield over modified SRI (M_2) during both the seasons and years and in pooled data. However, the difference in yield was not significant. Normal transplanting provided higher plant population m^{-2} which helped to fetch higher grain and straw yield. However, MoSRI establishment method provides better aeration, wider spacing and less competition, which enabled the plants to grow vigorously. Modification in age of seedling of SRI gave a chance to establish the crop little later in the season. The competitive grain and straw yield under MoSRI could be attributed to the higher root growth which enabled them to access nutrients from much greater volume of soil. It helped to capture all the essential nutrient elements important for plant growth and there by leading to higher tillering and dry matter production as has been reported earlier by Raju and Sreenivas (2008) and Dandeniya and Thies (2012). The yield attributing characters such as panicle length, panicle weight and grains $panicle^{-1}$ were higher in MoSRI method than in normal transplanting, which were responsible for the competitive grain and straw yield (Belder *et al.*, 2002 and Diproshan *et al.*, 2015). It was found that all the crop establishment methods were comparable to each other in recording number of panicles m^{-2} , test weight and sterility percentage but with respect to number of panicles $hill^{-1}$, number of total grains $panicle^{-1}$, panicle weight and panicle length, modified SRI recorded significantly highest values. However, better yield parameters in modified SRI could not compensate the yield over normal transplanting due to less plant population (Bommayasamy *et al.*, 2010). In support to the above findings, Turmel

(2011) found significant evidence that SRI increases rice yields in regions with low fertility soils and has no effect on yields in moderate to high fertility soils.

The improved growth performance in the form of number of tillers, LAI, LAD, CGR and dry matter production by the crop at saturation throughout the lifecycle (I_1) and irrigation at 5 cm water level depletion in perched water tube from soil surface (I_2) might have been responsible for more number of panicles with longer panicle length in these treatments (Table 4.12 and Table 4.14). These attributes in turn contributed to higher number of grains panicle⁻¹ and panicle weight (Table 4.13). Similar results were reported by Shi *et al.* (2002) and Chowdhury *et al.* (2014). They suggested that in saturation throughout the lifecycle and irrigation at 5 cm water depletion in perched water tube provide continuous supply of moisture and nutrients without any moisture deficit resulted in better growth and yields. When moderate AWD is adopted, soil drying is controlled properly and photosynthesis is not severely inhibited as plants rehydrate overnight, such a regime not only save water but also increase grain yield (Yang *et al.*, 2007). The lowest grain and straw yield was recorded in 10 cm water level depletion in perched water tube from soil surface (I_3), where plants suffered due to moisture stress in which photosynthesis is severely inhibited and plants cannot rehydrate overnight during the soil drying period markedly decreased grain yield (Yang *et al.*, 2017). The grain yield of a crop is the combined effect of various growth and development parameters. In the present investigation almost all the growth and development characters seemed to be affected by the increasing levels of irrigation while at the moisture stress condition for a long period, the photosynthetic activities were reduced owing to the closure of stomata which resulted the supply of CO₂ and the capacity of protoplasm to carry on photosynthetic efficiency and reduced translocation might have hindered further accumulation of the end products (Yoshida, 1972). While it was reverse in the case of the treatment receiving sufficient water throughout the growing period. Hence, plants were unable to extract more water and

nutrients from deeper layers of soil under moisture deficit conditions which ultimately led to poor growth and yield attributes.

Nitrogen fertilization quantity had a crucial role in improving morpho-physiological characteristics of rice, which may perhaps upsurge leaf and root growth to appropriate LAI for obtaining higher grain and straw yield (Larijani and Hoseini, 2012). The highest grain and straw yield of rice under 125% of RDN through inorganic could be attributed to adequate N availability. The favorable conditions experienced by the crop in 125% of RDN through inorganic and 100% of RDN through inorganic in turn helped the plants to put forth improved performance over RDN through integrated sources.

Thus improved growth performance in the form of number of tillers, number of leaves, leaf area, LAI, LAD, CGR and dry matter by the crop in 125% of RDN through inorganic and 100% of RDN through inorganic might have been responsible for more number of panicles in these treatments [Table 4.2(a and b), 4.3(a and b), 4.4(a and b), 4.5(a and b), 4.6(a and b), 4.8(a and b), Figure 4.1 and 4.2]. These in turn contributed to higher number of grains panicle⁻¹ and panicle weight (Table 4.13). Lastly the adequate stream of nitrogen conferring to the crop needs might have giving rise to more vigorous and extensive root system [Table 4.18 and 4.19 (a and b)] of crop leading to increased vegetative growth, means more competent sink formation and greater sink size, greater carbohydrate translocation from vegetative plant parts to the grains, ultimately reflected in higher grain and straw yield in these treatments Bezbaruha *et al.* (2011) and Ehsanullah *et al.* (2012).

Application of 125% of RDN through inorganic and 100% of RDN through inorganic were found effective to maintain optimal leaf nitrogen which resulted in better crop growth and higher grain and straw yield (Sarwa *et al.*, 2011). Combined application of inorganic (50%) and organic (50%) would promote positive soil biological processes and enhance the availability of nutrients over a longer period that

led to better growth and grain and straw yield as it showed on par results with 125% of RDN through inorganic source (Kaushal *et al.* (2010) and Chowdhury *et al.* (2014).

There was positive correlation between number of tillers (hill^{-1}), number of leaves (hill^{-1}), leaf area, leaf area index, leaf area duration, SPAD value and dry matter accumulation and also they were positively correlated with grain yield of rice in both the year's mean data [Table 4.28 (a and b)]. It confirms the beneficial effect of yield deciding growth parameters on yield of rice.

In case of yield attributes, test weight was found non-significantly correlated with grain and other yield attributes. Further, sterility percentage was found negatively correlated with grain yield and number of panicles (m^{-2}), panicle length, panicle length, number of grains was found positively correlated with the grain yield [Table 4.30 (a and b)]. From this we can come up to the conclusion that the treatment which can enhance above positively correlated yield attributes will lead to better and higher grain yield.

4.3 Nutrient content and uptake in rice

4.3.1 Nutrient content in rice

4.3.1.1 Nutrient content in grain

The data presented in Table 4.16 (a and b) revealed that nutrient content *i.e.* N, P and K was not influenced significantly due to different establishment methods, water regimes and nutrient levels during *kharif* and *rabi* season rice in both the years. Similarly, no interaction effect of establishment methods, water regimes and nutrient levels was noticed for above mentioned nutrients.

4.3.1.2 Nutrient content in straw

N, P and K content in rice straw was analyzed and presented in 4.17 (a and b) revealed that it was not influenced significantly with establishment methods, water regimes and nutrient levels in both the seasons and years of investigation. Similarly, no interaction effect of these factors was noticed for above mentioned nutrients.

Table 4.16(a): N, P and K content of grain in *kharif* as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	<i>Kharif</i>							
	Grain N content (%)				Grain P content (%)			
	2015	2016	mean		2015	2016	mean	
Establishment methods								
M1	1.23	1.24	1.24		0.35	0.37	0.36	
M2	1.27	1.30	1.28		0.37	0.38	0.38	
SEm±	0.01	0.02	0.01		0.01	0.01	0.01	
CD (P=0.05)	NS	NS	NS		NS	NS	NS	
Water regimes								
I1	1.24	1.25	1.24		0.36	0.37	0.36	
I2	1.24	1.27	1.25		0.36	0.38	0.37	
I3	1.28	1.30	1.29		0.37	0.38	0.37	
SEm±	0.01	0.02	0.01		0.02	0.02	0.01	
CD (P=0.05)	NS	NS	NS		NS	NS	NS	
Nutrient levels								
N1	1.27	1.29	1.28		0.35	0.37	0.36	
N2	1.26	1.30	1.28		0.37	0.38	0.37	
N3	1.22	1.22	1.22		0.37	0.38	0.37	
SEm±	0.02	0.01	0.01		0.01	0.01	0.01	
CD (P=0.05)	NS	NS	NS		NS	NS	NS	
Interaction (MxIxN)	NS	NS	NS		NS	NS	NS	

M1: Normal transplanting;

I1: Saturation;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

M2: Modified system of rice intensification;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

Table 4.16(b): N, P and K content of grain in *rabi* as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	<i>Rabi</i>							
	Grain N content (%)				Grain P content (%)			
	2015-16	2016-17	mean		2015-16	2016-17	mean	
Establishment methods								
M1	1.22	1.23	1.22		0.35	0.35	0.36	
M2	1.27	1.29	1.28		0.37	0.37	0.37	
SEm±	0.01	0.01	0.01		0.02	0.02	0.02	
CD (P=0.05)	NS	NS	NS		NS	NS	NS	
Water regimes								
I1	1.23	1.25	1.24		0.37	0.37	0.37	
I2	1.25	1.29	1.25		0.35	0.35	0.35	
I3	1.25	1.25	1.27		0.37	0.37	0.37	
SEm±	0.01	0.01	0.01		0.01	0.01	0.01	
CD (P=0.05)	NS	NS	NS		NS	NS	NS	
Nutrient levels								
N1	1.22	1.25	1.24		0.36	0.35	0.36	
N2	1.28	1.28	1.28		0.36	0.37	0.37	
N3	1.24	1.24	1.24		0.34	0.37	0.36	
SEm±	0.01	0.01	0.00		0.01	0.01	0.01	
CD (P=0.05)	NS	NS	NS		NS	NS	NS	
Interaction (MxIxN)	NS	NS	NS		NS	NS	NS	

M1: Normal transplanting;

I1: Saturation;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

M2: Modified system of rice intensification;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

Table 4.17(a): N, P and K content of straw in *kharif* as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	<i>Kharif</i>							
	Straw N content (%)		Straw P content (%)		Straw K content (%)		mean	mean
	2015	2016	mean	2015	2016	mean	2015	2016
Establishment methods								
M1	0.41	0.42	0.42	0.22	0.23	0.22	1.44	1.60
M2	0.45	0.44	0.44	0.23	0.23	0.23	1.46	1.63
SEm±	0.00	0.01	0.00	0.00	0.00	0.00	0.03	0.04
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Water regimes								
I1	0.41	0.42	0.42	0.22	0.23	0.23	1.41	1.59
I2	0.43	0.43	0.43	0.22	0.22	0.23	1.46	1.61
I3	0.45	0.44	0.44	0.22	0.22	0.23	1.48	1.65
SEm±	0.01	0.01	0.00	0.01	0.01	0.01	0.02	0.02
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Nutrient levels								
N1	0.44	0.44	0.44	0.22	0.23	0.22	1.44	1.60
N2	0.44	0.44	0.44	0.22	0.24	0.23	1.48	1.65
N3	0.40	0.42	0.41	0.23	0.22	0.23	1.44	1.62
SEm±	0.01	0.00	0.00	0.01	0.01	0.01	0.02	0.04
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (MxIxN)	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

I1: Saturation;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

M2: Modified system of rice intensification;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

Table 4.17(b): N, P and K content of straw in *rabi* as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	<i>Rabi</i>							
	Straw N content (%)				Straw P content (%)			
	2015-16	2016-17	mean		2015-16	2016-17	mean	
Establishment methods								
M1	0.43	0.47	0.45	0.22	0.22	0.22	0.22	1.52
M2	0.43	0.49	0.46	0.23	0.23	0.23	0.23	1.58
SEm±	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.03
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Water regimes								
I1	0.42	0.45	0.44	0.23	0.22	0.22	0.23	1.52
I2	0.43	0.49	0.46	0.22	0.22	0.22	0.22	1.56
I3	0.44	0.50	0.47	0.23	0.23	0.23	0.23	1.58
SEm±	0.00	0.02	0.00	0.01	0.01	0.01	0.01	0.03
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Nutrient levels								
N1	0.43	0.46	0.44	0.22	0.23	0.23	0.22	1.51
N2	0.44	0.50	0.47	0.24	0.23	0.23	0.23	1.58
N3	0.43	0.48	0.45	0.22	0.22	0.22	0.22	1.56
SEm±	0.01	0.02	0.00	0.01	0.01	0.01	0.01	0.02
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (MxIxN)	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

M2: Modified system of rice intensification;

I1: Saturation;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

Table 4.18(a): N, P and K uptake of grain in *kharif* as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	<i>Kharif</i>							
	Grain N uptake (kg ha ⁻¹)		Grain P uptake (kg ha ⁻¹)		Grain K uptake (kg ha ⁻¹)		mean	mean
	2015	2016	mean	2015	2016	mean	2015	2016
Establishment methods								
M1	65.9	68.9	67.7	18.8	20.6	19.7	25.2	28.9
M2	62.5	65.1	63.6	18.2	19.0	18.9	23.6	26.1
SEm±	1.40	2.31	1.64	0.51	0.82	0.65	0.54	0.39
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Water regimes								
I1	68.2	69.9	68.8	19.8	20.7	20.0	25.9	29.1
I2	64.2	66.9	65.4	18.6	20.0	19.4	24.9	27.9
I3	60.7	64.9	62.8	17.5	19.0	18.0	22.8	25.9
SEm±	1.55	2.91	1.42	1.20	1.11	0.52	0.39	0.85
CD (P=0.05)	6.07	NS	5.6	NS	NS	NS	1.55	2.99
Nutrient levels								
N1	65.5	68.6	67.1	18.1	19.7	18.9	24.8	27.7
N2	66.9	69.7	68.4	19.6	20.4	19.8	25.5	27.3
N3	60.5	63.1	61.7	18.4	19.6	18.7	22.8	27.4
SEm±	1.20	2.73	1.43	0.51	1.3	0.7	0.41	1.07
CD (P=0.05)	4.70	NS	5.5	NS	NS	NS	1.62	NS
Interaction (MxIxN)	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

I1: Saturation;

I3: Irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

M2: Modified system of rice intensification;

I2: Irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

Table 4.18(b): N, P and K uptake of grain in *rabi* as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	<i>Rabi</i>							
	Grain N uptake (kg ha ⁻¹)				Grain P uptake (kg ha ⁻¹)			
	2015-16	2016-17	mean		2015-16	2016-17	mean	
Establishment methods								
M1	64.3	59.4	61.6	18.4	16.9	18.2	26.1	27.3
M2	62.1	57.5	59.8	18.1	16.5	17.3	24.5	25.7
SEm±	0.72	0.94	0.69	0.97	0.91	1.01	0.67	0.69
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Water regimes								
I1	67.4	62.3	64.9	20.3	18.4	19.4	27.4	28.8
I2	63.1	60.4	61.3	17.7	16.4	17.2	24.8	26.0
I3	58.8	53.5	57.0	17.4	15.8	16.6	23.5	24.7
SEm±	1.14	0.45	0.63	0.75	0.64	0.72	0.52	0.83
CD (P=0.05)	4.4	1.7	2.5	NS	NS	NS	2.06	3.11
Nutrient levels								
N1	62.2	58.3	60.5	18.4	16.3	17.6	25.2	26.4
N2	66.9	61.4	64.3	18.8	17.8	18.6	25.4	27.1
N3	59.4	55.4	58.0	16.3	16.5	16.8	24.1	25.3
SEm±	1.73	1.71	1.78	0.9	1.1	0.9	0.93	0.3
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (MxIxN)	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

I1: Saturation;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

M2: Modified system of rice intensification;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

4.3.2 Nutrient uptake in rice

4.3.2.1 N, P and K uptake in grain

It is obvious from the data given in Table 4.18 (a and b) that N, P and K uptake remained unaffected due to establishment methods; but in case of water regimes and nutrient levels it showed variable results during both the seasons and years of study.

Among establishment methods, normal transplanting (M_1) recorded comparable N (67.7 and 61.6 kg ha⁻¹ in kharif and rabi mean data, respectively), P (19.7 and 18.2 kg ha⁻¹, respectively in kharif and rabi mean data) and K (26.8 and 27.3 kg ha⁻¹ in kharif and rabi mean data, respectively) uptake as in modified SRI (M_2) (63.6 and 59.8 kg ha⁻¹ of N; 18.9 and 17.3 kg ha⁻¹ of P and 24.9 and 25.7 kg ha⁻¹ of K in kharif and rabi mean data, respectively).

Saturation throughout the lifecycle of crop were found significantly higher in N (68.8 and 64.9 kg ha⁻¹ in kharif and rabi mean data, respectively) and K (29.6 and 28.8 kg ha⁻¹ in kharif and rabi mean data, respectively) uptake which was also at par with irrigation at 5 cm water level depletion in perched water tube from soil surface (I_2) (65.4 and 61.3 kg ha⁻¹ of N and 26.2 and 26.0 kg ha⁻¹ of K in kharif and rabi mean data, respectively). The lowest value of grain N uptake was found under irrigation at 10 cm water level depletion in perched water tube from soil surface (I_3) (60.5 and 56.0 kg ha⁻¹ of N and 60.5 and 56.0 kg ha⁻¹ of K in kharif and rabi mean data, respectively). However, P uptake by grains was found to be non-significant due to water regimes.

Nitrogen uptake by grain related to nutrient levels was found significantly higher under 125% RDN through inorganic sources during *kharif* 2015 (66.9 kg ha⁻¹) and in *kharif* mean data (68.4 kg ha⁻¹); however, it was found comparable during *kharif* 2016 and *rabi* seasons of both the years (69.7 and 64.3 kg ha⁻¹, respectively during *kharif* 2016 and *rabi* mean data). Similarly, 125% RDN through inorganic recorded comparable grain P (19.8 and 18.6 kg ha⁻¹, respectively, in *kharif* and *rabi* mean data) and K (26.7 and 27.1 kg ha⁻¹, respectively, in *kharif* and *rabi* mean data) uptake over other nutrient levels during both the years and in mean data.

As regards to interaction effect of establishment methods, water regimes and nitrogen levels, N, P and K uptake by grain was found non-significant during both the seasons of both the years and in mean data.

4.3.2.2 N, P and K uptake in straw

Nitrogen uptake by rice straw was significantly influenced by water regimes and was not much affected by establishment methods and nutrient levels during both the years of study as given in Table 4.19(a and b). The data of establishment methods revealed that normal transplanting was statistically comparable to modified SRI.

Among water regimes, nitrogen uptake by straw differ significantly at harvest and was found higher under saturation throughout lifecycle of crop (30.8 and 31.4 kg ha⁻¹, in *kharif* and *rabi* mean data, respectively) however, during *kharif* 2016, it was found *at par* in all the water regimes. The lowest straw N uptake was recorded under irrigation at 10 cm water level depletion in perched water tube from soil surface (26.2 and 25.3 kg ha⁻¹, in *kharif* and *rabi* mean data, respectively).

As regards to nutrient levels, non-significantly highest straw N uptake was recorded under application of 125% RDN through inorganic source (29.0 and 30.4 kg ha⁻¹, in *kharif* and *rabi* mean data, respectively) but it was not significantly affected due to different levels of nutrients. On the other hand, P and K uptake in straw was not influenced significantly during both the seasons and years of study at any of the establishment, water regime and nutrient levels.

The interaction effect of establishment methods, water regimes and nutrient levels was found non-significant during both the seasons and years as well as in mean data in N, P and K uptake by straw.

4.3.2.3 Total N, P and K uptake by grain and straw

It is obvious from the data given in Table 4.20 (a and b) that total N, P and K uptake by rice plant remained unaffected due to establishment methods; but in case of water regimes and nutrient levels it showed variable results during both the seasons years of study.

Among establishment methods, normal transplanting (M₁) recorded comparable total N (96.6 and 92.0 kg ha⁻¹ in *kharif* and *rabi* mean data, respectively), P (35.0 and 33.2 kg ha⁻¹, respectively in *kharif* and *rabi* mean data) and K (134.0 and 128.2 kg ha⁻¹ in *kharif* and *rabi* mean data, respectively) uptake followed by modified

Table 4.19(a): N, P and K uptake of straw in *kharif* as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	Kharif								
	Straw N uptake (kg ha ⁻¹)			Straw P uptake (kg ha ⁻¹)			Straw K uptake (kg ha ⁻¹)		
	2015	2016	mean	2015	2016	mean	2015	2016	mean
Establishment methods									
M1	27.6	30.1	28.9	14.5	16.1	15.3	97.7	116.2	107.0
M2	27.4	29.0	28.2	13.9	15.5	14.7	87.8	105.8	96.8
SEm±	0.65	0.37	0.51	0.42	0.15	0.2	5.00	3.94	2.7
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Water regimes									
I1	30.2	31.4	30.8	16.2	16.6	16.7	99.5	115.1	107.3
I2	27.7	29.4	28.6	15.9	16.1	16.7	95.1	113.1	104.1
I3	24.6	27.9	26.2	15.3	15.3	15.1	83.7	104.8	94.2
SEm±	0.24	0.97	0.44	0.97	0.61	0.33	2.25	2.48	2.01
CD (P=0.05)	0.94	NS	1.71	NS	NS	NS	8.83	NS	7.96
Nutrient levels									
N1	28.2	29.0	28.6	14.1	15.2	14.3	92.2	105.6	98.8
N2	28.2	29.6	29.0	14.5	16.2	15.1	95.0	111.0	103.3
N3	25.3	27.8	26.6	14.1	14.6	14.9	91.0	107.4	98.5
SEm±	0.86	0.36	0.52	0.28	0.34	0.64	3.63	1.93	2.25
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (MxIxN)	NS	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

I1: Saturation;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

M2: Modified system of rice intensification;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

Table 4.19(b): N, P and K uptake of straw in *rabi* rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	<i>Rabi</i>							
	Straw N uptake (kg ha ⁻¹)				Straw P uptake (kg ha ⁻¹)			
	2015-16	2016-17	mean	2015-16	2016-17	mean	2015-16	2016-17
Establishment methods								
M1	29.5	30.8	30.1	15.1	13.9	14.5	105.6	95.9
M2	27.6	26.6	27.1	14.6	12.7	13.6	102.0	89.0
SEm±	0.78	1.00	0.92	0.38	0.44	0.41	5.84	4.56
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Water regimes								
I1	30.8	32.0	31.4	14.7	15.2	16.2	112.4	101.6
I2	28.8	29.5	29.1	13.3	14.0	15.9	103.6	93.9
I3	26.1	24.5	25.3	12.9	13.0	15.3	95.4	81.9
SEm±	0.15	0.63	0.32	0.39	0.32	0.97	3.09	2.11
CD (P=0.05)	0.62	2.2	1.12	NS	NS	NS	11.8	8.25
Nutrient levels								
N1	28.5	27.9	27.9	14.6	13.9	13.9	102.1	91.5
N2	30.0	30.7	30.4	16.4	14.1	14.9	109.1	96.9
N3	27.5	27.3	27.2	14.1	12.5	13.3	100.5	88.8
SEm±	0.54	1.14	0.6	0.66	0.60	0.28	3.65	3.41
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (MxIxN)	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

M2: Modified system of rice intensification;

I1: Saturation;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

Table 4.20(a): Total N, P and K uptake during *kharif* by rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	<i>Kharif</i>					
	Total N uptake (kg ha ⁻¹)			Total P uptake (kg ha ⁻¹)		
	2015	2016	mean	2015	2016	mean
Establishment methods						
M1	93.6	99.6	96.6	33.5	36.6	35.0
M2	90.0	94.2	92.1	32.1	34.6	33.4
SEm±	0.8	2.3	1.4	0.5	0.9	0.7
CD (P=0.05)	NS	NS	NS	NS	NS	NS
Water regimes						
I1	100.4	104.3	102.3	34.7	36.7	35.7
I2	91.9	96.1	94.0	33.1	35.8	34.5
I3	83.2	90.2	86.7	30.6	34.3	32.5
SEm±	1.7	3.2	1.5	1.9	2.0	1.1
CD (P=0.05)	6.8	NS	5.8	NS	NS	NS
Nutrient levels						
N1	94.1	98.9	96.5	32.1	34.8	33.5
N2	94.9	99.7	97.3	33.6	36.2	34.9
N3	86.4	92.0	89.2	32.7	35.8	34.3
SEm±	1.7	2.6	1.4	0.9	1.4	0.9
CD (P=0.05)	6.6	NS	5.5	NS	NS	NS
Interaction (MxIxN)	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

I1: Saturation;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

M2: Modified system of rice intensification;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

Table 4.20(b): Total N, P and K uptake during *rabi* by rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	<i>Rabi</i>							
	Total N uptake (kg ha ⁻¹)				Total P uptake (kg ha ⁻¹)			
	2015-16	2016-17	mean		2015-16	2016-17	mean	
Establishment methods								
M1	93.7	90.2	92.0		34.7	31.7	33.2	
M2	89.8	84.0	86.9		32.2	28.6	30.4	
SEm±	1.1	2.0	1.5		1.2	1.3	1.3	
CD (P=0.05)	NS	NS	NS		NS	NS	NS	
Water regimes								
I1	98.5	94.3	96.4		36.0	32.9	34.5	
I2	91.8	89.5	90.7		32.6	29.8	31.2	
I3	85.0	77.6	81.3		31.6	27.8	29.7	
SEm±	1.0	0.7	0.8		0.9	0.8	0.8	
CD (P=0.05)	4.0	2.8	3.0		NS	NS	NS	
Nutrient levels								
N1	91.7	88.6	90.2		34.0	31.1	32.5	
N2	95.7	90.8	93.2		34.0	30.8	32.4	
N3	87.8	82.1	84.9		32.4	28.6	30.5	
SEm±	1.6	2.2	1.7		1.3	1.5	1.3	
CD (P=0.05)	NS	NS	NS		NS	NS	NS	
Interaction (MxIxN)	NS	NS	NS		NS	NS	NS	

M1: Normal transplanting;

I1: Saturation;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

M2: Modified system of rice intensification;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

SRI (M₂) (92.1 and 86.9 kg ha⁻¹ of N; 33.4 and 30.4 kg ha⁻¹ of P and 121.7 and 120.5 kg ha⁻¹ of K in kharif and rabi mean data, respectively).

Data on water regimes revealed that in saturation throughout the lifecycle of crop were found significantly superior in N (102.3 and 96.4 kg ha⁻¹ in kharif and rabi mean data, respectively) and K (134.6 and 135.5 kg ha⁻¹ in kharif and rabi mean data, respectively) uptake and was at par with irrigation at 5 cm water level depletion in perched water tube from soil surface (94.0 and 90.7 kg ha⁻¹ of N and 130.3 and 124.6 kg ha⁻¹ of K in kharif and rabi mean data, respectively). The lowest value of grain N uptake was found under irrigation at 10 cm water level depletion in perched water tube from soil surface (86.7 and 81.3 kg ha⁻¹ of N and 118.6 and 113.1 kg ha⁻¹ of K in kharif and rabi mean data, respectively). However, total P uptake by rice plant was found non-significant under water regimes.

Total nitrogen uptake by rice plant was found significantly higher under 125% RDN through inorganic sources during *kharif* 2015 (94.9 kg ha⁻¹) and in *kharif* mean data (97.3 kg ha⁻¹). However, total nitrogen uptake during rabi; and total phosphorus and total potassium uptake by rice plants were found non-significant under nutrient levels during both the seasons and years.

Interaction effect of establishment methods, water regimes and nitrogen levels on total N, P and K uptake rice plant was found non-significant during both the seasons and years.

Discussion on influence of establishment methods, water regimes and nutrient levels on plant nutrient content and uptake by rice

Scanning of data revealed that nitrogen, phosphorus and potassium content in grains and straw was not influenced significantly due to various establishment methods, water regimes and nutrient levels. However, their uptake showed marked variation due to water regimes. The content of N and P were more in grains as compared to straw however, K content, was higher in straw as against in grains. Use of younger age seedling (18-20 days) *i.e.* modified SRI proved comparable in increasing N, P and K content in grain and straw over 25-28 days old seedling with

normal transplanting during both the years and seasons. Worth mentioning, more removal of K by straw mainly associated with luxury consumption of this nutrient during crop cycles than grains.

The uptake being the product of content and dry matter production, normal transplanting with 50 hills m^{-2} recorded the higher N, P and K uptake at harvest over modified SRI with 16 hills m^{-2} , as was evident from its dry matter production and ultimately higher grain and straw yields. Profuse and robust root system under modified SRI due to early seedling vigour might have facilitated greater ability to mobilize more nutrients, concomitant higher absorption and translocation of nutrients hill^{-1} . A well developed and healthy root system plays an important role in uptake and translocation of nutrients from soil in SRI particularly with planting younger seedlings (Uphoff, 2005).

This might be due to the fact that, under individual hill wider spacing showed superior growth and yield contributing characters than closer spacing. Further, closer spacings resulted in higher inter plant competition for the resources thus resulting in lesser development of yield characters hill^{-1} . These results are in agreement with the findings of Chandrapala *et al.* (2010). Higher nutrient uptake observed with 2-3 seedlings hill^{-1} might be due to maintenance of optimum number of seedlings which helped the crop in increasing the growth especially dry matter production there by contributing to greater nutrient uptake (Padmanabham, 2006). This might also be due to better exploitation of the nutrients from the soil due to higher number of tillers per unit area in the closer spacing. These results were in close agreement with those of Lourduraj and Rajagopal (1999) and Gunri *et al.* (2004). Higher uptake of N P K was noticed with increase in planting density. The better root proliferation under higher planting density might have resulted in higher N uptake and consequent increase in the efficient utilization of added N (Verma *et al.*, 1988). Higher P uptake might be due to increased root surface area as a result of higher N uptake, which might have resulted in increased P absorption and hence P uptake by the crop. Higher K uptake by high planting densities at different stages of crop growth might be because of increased root

surface area and with increased N and P uptake, thereby replacement of K^+ by NK^{+4} which are similar in ionic radii and valency (Vimala and Subramanian, 1994).

Crop under saturation throughout lifecycle recorded higher nutrient uptake as compared to irrigation at 5 and 10 cm water level depletion in perched water tube from soil surface. The higher level of nutrient supply is conducive for extensive root proliferation, to explore a greater volume of soil and absorb larger quantities of nutrients that often tend to correlate positively with dry matter production and concentration of nutrients in the plant under higher level of nutrient supply (Aruna *et al.* 2016). Greater amount of N, P and K uptake by rice at higher irrigation levels are may be due to the fact that higher frequency of irrigation under saturated condition was more conducive for uptake of nutrients by the roots of plants without stress on root hairs (Chowdhury *et al.*, 2014). Water loving nature of rice plant and its growth behavior may also be responsible for higher nutrient uptake as it is more vigorous under water regime of saturation affecting the availability of nutrients towards sink from the source (soil). Also In saturated condition NH_4-N are reported to be always higher than NO_3-N and vice-versa under dry and alternated wet and dry condition (Gatti *et al.*, 2011). The tendency of NH_4-N (positive charged) to get adsorbed on soil exchange complex is higher over NO_3-N (negatively charged) protected ammonium from severe N losses through leaching from soil clay (negatively charged) layers leading to better uptake of nitrogen in saturated water regime (Weil and Brady, 2013). Same may the case for potassium as it is also absorbed in K^+ .

Application of organic manure along with chemical fertilizer accelerates the microbial activity, increases nutrients use efficiency and enhances the availability of the native nutrients to the plants resulting higher nutrients uptake (Bezbaruha *et al.* 2011). Higher nutrients uptake with the application of inorganic fertilizer might be due to comparable nutrient concentration along with higher biomass production (Bezbaruha *et al.* 2011). Higher nutrient uptake here was associated with superior yield attributing parameters ultimately giving rise to higher yield due to continuous availability of water and nutrients that resulted in higher uptake of nutrients, which

may have helped in production of higher dry matter. Enhanced moisture availability through irrigation should be supplemented by optimum nitrogen or nutrients to improve use efficiency of both the resources and harvest higher yield. (Halli *et al.* 2016).

4.4 Soil nutrient status

4.4.1 Available N, P and K in soil (kg ha^{-1})

The data presented in Table 4.21 (a and b) revealed that available nutrient in soil *i.e.* N, P and K was not influenced significantly due to different establishment methods, water regimes and nutrient levels during *kharif* and *rabi* season rice in both the years. Similarly, interaction effect of these factors was not noticed for above mentioned soil nutrients.

Discussion on influence of establishment methods, water regimes and nutrient levels on available N, P and K in soil

Post-harvest soil fertility status in terms of available N, available P and available K, immediately after the harvest of rice crop was not significantly influenced by different establishment methods, water regimes and nutrient levels. However, long term application of organic matter in combination with inorganic fertilizers gave comparable but higher results at later seasons. Naidu *et al.* (2013) also found similar results.

Previous meta-analysis of SRI trials had also concluded that establishment method of SRI had similar soil nutrient uptake as in normal transplanted crop in countries other than Madagascar. The above trend might be due to considerable similar quantities of nutrients left in the soil after meeting crop requirement (McDonald *et al.*, 2006). However, Turmel (2011) observed that SRI increases rice yields in regions other than Madagascar and SRI increases rice yields on low fertility soils but had no effect on yields in moderate to high fertility soils and so SRI may not affect nutrient status of soil significantly.

Turmel (2011) reported that soil macronutrient availability are consistent in response of available soil N to mineral fertilizer addition in both the flooded and

Table 4.21(a): Available N, P and K status in soil as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	<i>Kharif</i>							
	Available N in soil				Available P in soil			
	2015	2016	mean	2015	2016	mean	2015	2016
Establishment methods								
M1	177.3	174.4	175.9	42.1	39.9	41.0	524.2	520.7
M2	181.6	180.3	180.9	42.7	41.0	41.9	520.3	528.1
SEm±	2.7	4.6	0.9	0.1	0.4	0.2	3.9	5.1
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Water regimes								
I1	179.5	181.0	180.3	40.5	39.6	39.5	515.2	513.1
I2	178.6	177.6	178.2	42.9	40.6	41.7	521.4	527.3
I3	175.3	176.0	175.6	43.9	42.1	43.0	530.1	533.0
SEm±	1.9	4.7	3.3	0.8	0.7	0.6	5.3	4.7
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Nutrient levels								
N1	176.0	174.5	175.2	41.2	39.4	40.3	519.9	518.1
N2	178.0	175.6	178.8	42.8	40.4	41.6	521.1	522.6
N3	180.4	179.4	179.9	43.2	41.6	42.4	525.8	532.6
SEm±	1.5	2.1	1.8	0.6	0.9	0.6	4.4	4.0
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (MxIxN)	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

I1: Saturation;

I3: Irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

M2: Modified system of rice intensification;

I2: Irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

Table 4.21(b): Available N, P and K status in soil as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	Rabi									
	Available N in soil			Available P in soil			Available K in soil			mean
	2015-16	2016-17	mean	2015-16	2016-17	mean	2015-16	2016-17	mean	
Establishment methods										
M1	174.8	177.1	178.9	43.4	40.7	42.0	522.0	524.1	523.1	
M2	178.4	182.2	182.8	43.7	41.4	42.6	529.4	537.8	533.6	
SEm±	1.4	4.3	2.8	0.5	0.6	0.5	2.5	4.6	3.2	
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	
Water regimes										
I1	180.5	182.2	181.4	42.6	39.4	41.0	518.4	524.0	521.2	
I2	178.6	179.3	178.9	43.7	41.4	42.5	528.3	532.3	530.3	
I3	170.6	176.1	174.3	44.4	42.4	43.4	530.5	536.5	533.5	
SEm±	3.7	2.0	2.8	0.4	0.6	0.4	2.7	2.4	2.0	
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	
Nutrient levels										
N1	175.2	176.1	179.2	43.2	40.4	41.8	521.8	527.5	524.7	
N2	178.6	176.9	177.9	43.4	41.0	42.2	524.9	529.1	527.0	
N3	181.5	183.5	182.5	44.1	41.8	42.9	530.4	536.2	533.3	
SEm±	2.4	1.9	2.2	0.6	0.9	0.7	1.5	2.8	1.8	
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	
Interaction (MxIxN)	NS	NS	NS	NS	NS	NS	NS	NS	NS	

M1: Normal transplanting;

I1: Saturation;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

M2: Modified system of rice intensification;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

intermittently flooded water regimes. However, by the end of the second season, only compost had a significant positive effect on the soil N availability. Soil P was increased significantly by compost application in both field seasons. They further concluded that water regime and mineral fertilizer had no effect on the soil available K.

Vermicompost applied plots built-up residual soil fertility because of slow release of nutrients and reduction of nutrient losses (Bezbaruha *et al.* 2011). The increase in soil N and P after vermicompost application might be due to the direct addition of N and P through decomposition of the vermicompost added to the soil. Bodruzzaman *et al.* (2010) stated that vermicompost application on a preceding rice crop had a residual effect on the yield of a succeeding crop. The available soil N nutrient in the present study revealed that much of the nitrogen was removed from the soil with the application of inorganic N either 100% or 125%, both resulting in a negative soil N balance. Combined application of both FYM and inorganic N and P sources mostly resulted in a non-significant but positive balance of soil N and P nutrients. Thus, improvements in soil N and P nutrient status due to vermicompost application could sustain high rice crop yields ensuring long term sustainability of the system (Tadesse 2013). According to soil total nitrogen ratings of Hazeltonan and Murphy (2007), FYM application raised the soil N to the highest rate. Aziz *et al.* (2010) and Thamaraiselvi *et al.* (2012) noted upsurges in soil total N due to organic manures application. Integrated application of inorganic fertilizers and organic manures helped in increasing the availability of N in sustaining and restoring soil fertility in its available nutrients (Singhal *et al.*, 2011).

4.5 Quality parameters of rice

4.5.1 Effect of establishment methods, water regimes and nutrient levels on quality parameters of rice

Quality parameters *i.e.* hulling, milling and head rice recovery percentage were not influenced significantly due to establishment methods, water regimes and nutrient levels during *kharif* seasons of both the years [Table 4.22(a)]. Similarly in *rabi*

Table 4.22(a): Hulling percentage, milling percentage and head rice recovery of *kharif* rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	<i>Kharif</i>							
	Hulling percentage (%)		Milling percentage (%)		Head rice recovery (%)		mean	mean
	2015	2016	mean	2015	2016	mean	2015	2016
Establishment methods								
M1	76.4	75.0	75.7	67.9	66.4	67.2	52.7	55.8
M2	76.7	75.4	76.1	68.1	66.8	67.3	53.1	56.1
SEm±	0.5	0.4	0.3	0.4	0.4	0.2	0.2	0.3
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Water regimes								
I1	78.0	75.5	76.7	68.7	66.9	67.8	53.3	56.2
I2	76.2	75.3	75.8	68.1	66.6	67.3	52.5	56.0
I3	75.5	74.8	75.2	67.3	66.2	66.7	52.8	55.6
SEm±	0.7	0.3	0.5	0.5	0.2	0.2	0.4	0.2
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Nutrient levels								
N1	76.4	75.1	75.8	68.7	66.6	67.7	52.6	56.0
N2	76.9	75.3	76.0	67.8	66.5	67.1	52.5	55.9
N3	76.4	75.2	75.8	67.6	66.6	67.1	53.4	55.9
SEm±	0.7	0.4	0.5	0.4	0.4	0.3	0.1	0.3
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (MxIxN)	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

M2: Modified system of rice intensification;

I1: Saturation;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

Table 4.22(b): Hulling percentage, milling percentage and head rice recovery of *rabi* rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	Rabi								
	Hulling percentage (%)		Milling percentage (%)		Head rice recovery (%)		mean	mean	
	2015-16	2016-17	mean	2015-16	2016-17	mean			2015-16
Establishment methods									
M1	73.6	75.5	74.6	62.6	63.7	63.4	52.6	53.5	53.2
M2	73.6	75.9	74.8	63.1	64.1	63.6	53.0	53.9	53.4
SEm±	0.19	0.32	0.19	0.15	0.18	0.19	0.20	0.14	0.18
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Water regimes									
I1	74.3	76.8	75.5	63.4	64.8	64.1	53.3	54.5	53.9
I2	73.8	75.6	74.7	63.1	64.1	63.6	53.0	53.8	53.4
I3	72.8	74.8	73.8	62.1	62.9	62.5	52.2	52.8	52.5
SEm±	0.24	0.37	0.31	0.19	0.20	0.16	0.19	0.18	0.15
CD (P=0.05)	0.9	1.6	1.1	0.8	0.8	0.6	0.7	0.7	0.5
Nutrient levels									
N1	73.5	75.7	74.8	62.7	64.1	63.4	52.6	53.8	53.2
N2	73.8	76.3	74.9	63.4	64.1	63.8	53.3	53.9	53.6
N3	73.6	75.2	74.4	62.6	63.5	63.1	52.6	53.4	53.0
SEm±	0.22	0.28	0.24	0.22	0.18	0.14	0.17	0.19	0.13
CD (P=0.05)	NS	NS	NS	0.7	NS	0.5	0.6	NS	0.4
Interaction (MxIxN)	NS	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

I1: Saturation;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

M2: Modified system of rice intensification;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

seasons establishment methods did not had any significant variation on these quality parameters. Whereas, impact of water regimes on quality parameters revealed that, hulling, milling and head rice recovery percentage were significantly higher under saturation which was comparable with irrigation at 5 cm water depletion in perched tube from soil surface and superior over irrigation at 10 cm water levels depletion in PWT from soil surface.

As regards to nutrient levels, hulling percentage was not influenced significant due to nutrient levels, whereas milling percentage was higher in 125% RDN in *rabi* 2015-16, and it was not significant during 2016-17. Similar trend was noticed with head rice recovery.

The interaction effects due to establishment methods, water regimes and nutrient levels were found to be statistically non-significant during both the seasons of both the years and in their mean data.

Discussion on effect of establishment methods, water regimes and nutrient levels on quality parameters of rice

Grain milling quality has been shown to be affected significantly by growing and environmental conditions, such as water availability, temperature, fertilizer application and drought stresses (Chen *et al.* 2012). Appearance is one of the crucial properties appealing consumers after milling. Milling quality of the grain determines the final yield and the broken kernel rate of the milled rice percentage and head rice recovery. Amylose content and the chain structure of amylopectin were found to be significantly correlated with hardness of rice grains (Gill and Walia, 2013). Post-harvest milling quality aspect of rice is of prime importance for growers as well as consumers (Anonymous, 1998). Post-harvest rice quality parameters i.e. hulling percentage, milling percentage and head rice recovery, was not significantly influenced by different establishment methods water regimes and nutrient levels during *khariif*. However, during *rabi* water regimes and nutrient levels gave significant results. The improvement in these quality parameters in water regimes and nutrient levels might be the result of better utilization of nutrient and water as well as, light and

other inputs (Kumar *et al.*, 2002) which ultimately favored development of heavy panicles and healthy and plump grains.

Significantly lower head rice recovery under irrigation at 10 cm water level depletion in perched water tube from soil surface can be ascribed to incomplete grain filling due to impairment of photosynthates and translocation of assimilates towards sink. This observation is further supported with significantly higher sterility percentage in irrigation at 10 cm water level depletion in perched water tube from soil surface than saturation throughout lifecycle (Brar *et al.*, 2015). The decrease in moisture content of the grains leads to the reduction in milling recovery percentage. The same trend was found by Nour *et al.* (1994) and Refaee (1997). Frequent irrigation during *rabi* as compared to *kharif* seasons might have created the difference along with the climatic factors which favored better performance of water regime of saturation throughout lifecycle of crop. Ying *et al.* (2005) reported that saturation increased the rate of milled and head milled rice, and reduced the percentage of chalky kernel and chalkiness. They also reported that saturation recorded higher chlorophyll content, resulting to higher photosynthetic rate and photosynthate contents, slow senescence and high rate of transport of dry matter from source to sink during grain filling period resulted better quality parameters. The lowest milling recovery in the treatment irrigation at 10 cm water level depletion in perched water tube from soil surface might also be due to early drying of the grains before the completion of ripening. That may result in low moisture content in grain during day and in night some amount of moisture is re-absorbed by the deposition of dew. Such alternate drying and wetting cycles cause mechanical stress which may result in the development of fissures and ultimately higher percentage of broken rice. The results are in agreement with those obtained by Uppal and Bali (1994) and Refaee (2007).

Perez *et al.* (1996) reported that application of N in higher dose at flowering had a large effect on development of rice grain than hull and this increase grain firmness with increasing doses of nitrogen might have improved the hulling rice recovery. Leesawatwong *et al.* (2005) also reported that higher inorganic fertilizer

application gave firm grain rice was more resistant to abrasive milling than lower doses.

4.6 Water use studies of rice

4.6.1 Effect establishment methods, water regimes and nutrient levels on water use studies of rice

The data regarding irrigation water applied, effective rainfall, total water applied and irrigation water productivity are presented in Table 4.22 and 4.23. The applied water was 37.74 % higher in *kharif* 2015 as compared to *kharif* 2016 and 3.89 % higher in *rabi* 2016-17 as compared to *rabi* 2015-16. The irrigation water applied was in general was higher during different seasons due to variable effective rainfall received and evaporation demand of the crop due to climatic conditions. The total irrigation water applied was higher during *rabi* as compared to *kharif* due to huge variation in rainfall received and irrigation water applied and lower irrigation water productivity mainly due to higher amount of irrigation that was given during *rabi* seasons (Figures 3.1 to 3.4 and Table 4.23 and 4.24).

Among establishment methods, slightly higher irrigation water was applied in normal transplanting over modified SRI during both *kharif* and *rabi* seasons of both the years (760 and 1381 mm ha⁻¹, respectively in mean data).

Regarding water regimes, higher irrigation water was applied under saturation throughout lifecycle of the crop followed by irrigation at 5 cm water depletion in perched water tube (PWT) from soil surface and irrigation at 10 cm water depletion in PWT from soil surface during both the seasons and years of experimentation. Effective rainfall was similar in all the treatments of water regimes during both the seasons and years.

In case of nutrient levels, irrigation water applied and effective rainfall was similar in all the levels. Further, regarding total water applied, similar trend was observed in establishment methods, water regimes and nutrient levels during both the seasons and years.

Table 4.23: Irrigation water applied and effective rainfall in rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	Irrigation water applied (mm ha ⁻¹)						Effective rainfall (mm)					
	Kharif			Rabi			Kharif			Rabi		
	2015	2016	mean	2015-16	2016-17	mean	2015	2016	mean	2015-16	2016-17	mean
Establishment methods												
M1	878	642	760	1405	1358	1381	266	552	409	30.6	15.6	24.6
M2	808	582	695	1325	1278	1301	314	571	442	30.6	15.6	24.6
SEm±	-	-	-	-	-	-	-	-	-	-	-	-
CD (P=0.05)	-	-	-	-	-	-	-	-	-	-	-	-
Water regimes												
I1	970	725	847.5	1545	1475	1510	275	561	418	30.6	15.6	24.6
I2	810	585	697.5	1345	1275	1310	275	561	418	30.6	15.6	24.6
I3	750	525	637.5	1205	1205	1205	275	561	418	30.6	15.6	24.6
SEm±	-	-	-	-	-	-	-	-	-	-	-	-
CD (P=0.05)	-	-	-	-	-	-	-	-	-	-	-	-
Nutrient levels												
N1	843	612	727.5	1365	1318	1341	275	561	418	30.6	15.6	24.6
N2	843	612	727.5	1365	1318	1341	275	561	418	30.6	15.6	24.6
N3	843	612	727.5	1365	1318	1341	275	561	418	30.6	15.6	24.6
SEm±	-	-	-	-	-	-	-	-	-	-	-	-
CD (P=0.05)	-	-	-	-	-	-	-	-	-	-	-	-

M1: Normal transplanting;

I1: Saturation;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

M2: Modified system of rice intensification;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

Table 4.24: Total water applied and Irrigation water productivity in rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	Total water applied (mm ha ⁻¹)						Irrigation water productivity (kg ha ⁻¹ mm ⁻¹)					
	<i>Kharif</i>			<i>Rabi</i>			<i>Kharif</i>			<i>Rabi</i>		
	2015	2016	mean	2015-16	2016-17	mean	2015	2016	mean	2015-16	2016-17	mean
Establishment methods												
M1	1144	1194	1169	1436	1374	1406	4.80	4.75	4.78	3.79	3.63	3.71
M2	1122	1153	1137	1356	1294	1326	4.41	4.28	4.35	3.51	3.35	3.43
SEm±	-	-	-	-	-	-	0.08	0.11	0.06	0.07	0.08	0.07
CD (P=0.05)	-	-	-	-	-	-	NS	NS	0.34	NS	NS	NS
Water regimes												
I1	1245	1286	1266	1576	1491	1535	4.42	4.35	4.38	3.48	3.34	3.41
I2	1085	1146	1116	1376	1291	1335	4.78	4.60	4.69	3.67	3.62	3.65
I3	1025	1086	1056	1236	1221	1230	4.63	4.60	4.61	3.80	3.50	3.65
SEm±	-	-	-	-	-	-	0.08	0.16	0.09	0.09	0.04	0.05
CD (P=0.05)	-	-	-	-	-	-	NS	NS	NS	NS	0.20	NS
Nutrient levels												
N1	1118	1173	1146	1396	1334	1366	4.62	4.55	4.58	3.67	3.50	3.59
N2	1118	1173	1146	1396	1334	1366	4.76	4.58	4.67	3.76	3.60	3.68
N3	1118	1173	1146	1396	1334	1366	4.44	4.42	4.43	3.51	3.36	3.44
SEm±	-	-	-	-	-	-	0.05	0.19	0.09	0.09	0.10	0.05
CD (P=0.05)	-	-	-	-	-	-	0.21	NS	0.35	NS	NS	NS
Interaction (MxIxN)	-	-	-	-	-	-	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

M2: Modified system of rice intensification;

I1: Saturation;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

Irrigation water productivity (IWP) was not affected significantly during both the seasons and years due to establishment methods. Similarly, irrigation water productivity was comparable in all the water regimes during *kharif* and *rabi* both the seasons and years except during *rabi* 2016-17 where highest irrigation water productivity was recorded under irrigation at 5 cm water level depletion in PWT from soil surface. Among nutrient levels, significantly higher IWP was observed in irrigation at 5 cm water level depletion in PWT from soil surface which was comparable with saturation maintained throughout the lifecycle of the crop during *kharif* 2015. Whereas, in rest of the seasons and years all the nutrient levels behaved similarly for IWP.

The interaction effect of irrigation water productivity due to establishment methods, water regimes and nitrogen levels on irrigation water productivity was found to be non-significant during both the years and in mean data.

Discussion on effect of establishment methods, water regimes and nutrient levels on water use studies of rice

The evaluation of effective rainfall involves measuring rainfall and/or irrigation, losses through surface runoff, percolation losses beyond the root zone and the soil moisture uptake by the crop for evapotranspiration. Dastane *et al.* (1974) considers effective rainfall as useful or utilizable rainfall and argues that it is not necessary that all rainfall received at a time, rate or amount will be effective. Some of it may be unavoidably wasted (in this experiment during *kharif* 2016; Appendix II) while some may be destructive (during *Rabi* 2015-16; Appendix III). These rains cannot be considered as effective. In present experiment modified SRI nursery is transplanted 8-10 days earlier than normal transplanting. Hence, they may get the chances of getting higher duration to enjoy rainfall effectively. Lack of rainfall will need more frequent irrigation which will increase irrigation water applied in field and will reduce irrigation water productivity as happened in present investigation. Here, *kharif* crops gave higher irrigation water productivity over *rabi* crops.

Nour *et al.* (1997) also reported significant decrease in irrigation water productivity also known as WUE as the irrigation frequency increased. However, Hussain *et al.* (2007) found that prolonging the period of irrigation frequency adversely affected paddy yield in sandy loam soil, but was not so in clay loam soil. Similar benefits of full irrigation over deficit irrigation or partial root zone irrigation have also been reported by Wang *et al.* (2016).

Kar *et al.* (2005) concluded that growth and yield of any grain crops under a particular environment are largely determined by soil moisture, nutrients, radiation interception and the efficiency of conversion of intercepted radiation to dry matter which decides the efficiency of water use. Applied nitrogen was influenced by availability of soil water which should be close to the field capacity (Quaye, 2009).

Deficit irrigation and partial root deficit irrigation are methods to save water, but compared to deficit irrigation, well watered with recommended dose of fertilizer, performed better than deficit irrigation, which are reflected in terms of leaf area, leaf area index ultimately helping to gain higher water use efficiency. The fully irrigated plants accumulated significantly higher amount of N owing to higher dry matter resulting in higher WUE as compared to partial root zone irrigation and deficit irrigation (Lie *et al.*, 2007). In integrated nutrient source and organic and inorganic source results were at par.

Water and nutrients are complimentary inputs, thus depend on each other for the combined and cumulative effect on crops to improve WUE and NUE (Halli *et al.*, 2016). Wang *et al.* (2011) concluded that plants which have adequately supplied with fertilizers may also show higher drought tolerance and show higher water productivity. Yang and Zhang (2010) stated that integrated nutrient management is the best approach to supply adequate and balanced nutrients and increase crop productivity in an efficient and environmentally benign manner, without sacrificing water use efficiency.

4.7 Economics of rice

4.7.1 Effect establishment methods, water regimes and nutrient levels on economics of rice

The data regarding cost of cultivation, gross return, net return and B:C ratio of rice as influenced by different establishment methods, water regimes and nitrogen levels are presented in Table 25(a and b) and 4.26(a and b). The modified SRI method of rice establishment recorded lower cost of cultivation (36,124 and 38,234 ₹ ha⁻¹ in *kharif* and *rabi* mean data, respectively), gross return (74,430 and 68,874 ₹ ha⁻¹ in *kharif* and *rabi* mean data, respectively) and net return (38,305 and 30,641 ₹ ha⁻¹ in *kharif* and *rabi* mean data, respectively) as compared to normal transplanting (cost of cultivation of 41,671 and 43,603 ₹ ha⁻¹; gross return of 81,853 and 76,680 ₹ ha⁻¹ and net return of 40,183 and 33,077 ₹ ha⁻¹ in *kharif* and *rabi* mean data, respectively). However, B:C ratio of establishment methods was recorded higher under MoSRI (2.10 and 1.83 in *kharif* and *rabi* mean data, respectively) as compared to normal transplanting (1.99 and 1.78 in *kharif* and *rabi* mean data, respectively).

Among water regimes, saturation throughout lifecycle of crop incurred highest cost of cultivation (39,440 and 41,974 ₹ ha⁻¹ in *kharif* and *rabi* mean data, respectively), gross return (83,093 and 78,187 ₹ ha⁻¹ in *kharif* and *rabi* mean data, respectively), net return (43,653 and 36,213 ₹ ha⁻¹ in *kharif* and *rabi* mean data, respectively) and B:C ratio (2.14 and 1.89 in *kharif* and *rabi* mean data, respectively) as compared to other water regimes.

In case of nutrient levels, 50% RDN through inorganic + 50% through organic source (45,696 and 47,607 ₹ ha⁻¹ in *kharif* and *rabi* mean data, respectively) incurred highest cost of cultivation over rest of the treatments. However, 125% RDN through inorganic sources gave higher gross return (79,885 and 75,101 ₹ ha⁻¹ in *kharif* and *rabi* mean data, respectively), net return (44,211 and 37,334 ₹ ha⁻¹ in *kharif* and *rabi* mean data, respectively) and B:C ratio (2.24 and 1.99 in *kharif* and *rabi* mean data, respectively) over other nutrient levels.

Table 4.25(a): Cost of cultivation and gross return of rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	Cost of cultivation (₹ ha ⁻¹)						Gross return (₹ ha ⁻¹)					
	Kharif			Rabi			Kharif			Rabi		
	2015	2016	mean	2015-16	2016-17	mean	2015	2016	mean	2015-16	2016-17	mean
Establishment methods												
M1	41217	42124	41671	42384	44821	43603	78927	84780	81853	77702	75658	76680
M2	35826	36423	36124	36992	39475	38234	72449	76411	74430	71998	65751	68874
SEm±	-	-	-	-	-	-	-	-	-	-	-	-
CD (P=0.05)	-	-	-	-	-	-	-	-	-	-	-	-
Water regimes												
I1	38910	39969	39440	40910	43037	41974	80944	85242	83093	80697	75677	78187
I2	38410	38999	38705	39410	42037	40724	76288	80377	78333	74405	71221	72813
I3	38244	38853	38548	38744	41370	40057	69831	76167	72999	69447	65215	67331
SEm±	-	-	-	-	-	-	-	-	-	-	-	-
CD (P=0.05)	-	-	-	-	-	-	-	-	-	-	-	-
Nutrient levels												
N1	35305	35342	35323	36472	38289	37380	75900	81134	78517	75224	70984	73104
N2	35655	35692	35673	36822	38712	37767	78032	81738	79885	77233	72969	75101
N3	44605	46787	45696	45771	49443	47607	73131	78914	76023	72092	68159	70125
SEm±	-	-	-	-	-	-	-	-	-	-	-	-
CD (P=0.05)	-	-	-	-	-	-	-	-	-	-	-	-

M1: Normal transplanting;

I1: Saturation;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

M2: Modified system of rice intensification;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

Table 4.25(b): Cost of cultivation and gross return of rice as influenced by interaction of water regimes and nutrient management under transplanting and modified SRI

Treatments	Cost of cultivation (₹ ha ⁻¹)						Gross return (₹ ha ⁻¹)					
	Kharif			Rabi			Kharif			Rabi		
	2015	2016	mean	2015-16	2016-17	mean	2015	2016	mean	2015-16	2016-17	mean
M1I1N1	37945	38417	38181	39945	41407	40676	83308	92889	88099	85712	80109	82911
M1I1N2	38295	38767	38531	40295	41830	41062	87663	92814	90239	86572	82563	84568
M1I1N3	47245	49862	48554	49245	52561	50903	82418	87253	84836	79595	77098	78347
M1I2N1	37945	37977	37961	38945	40907	39926	80481	83377	81929	74551	75061	74806
M1I2N2	38295	38327	38311	39295	41330	40312	82652	85134	83893	80107	79855	79981
M1I2N3	47245	49422	48334	48245	52061	50153	74265	81908	78087	74431	73209	73820
M1I3N1	38112	38184	38148	38612	40573	39592	72444	82589	77517	74657	73767	74212
M1I3N2	38462	38534	38498	38962	40996	39979	74972	78904	76938	73828	69863	71846
M1I3N3	47412	49629	48521	47912	51727	49819	72138	78151	75145	69862	69395	69629
M2I1N1	33442	33658	33550	35442	36950	36196	78106	78855	78481	76287	70307	73297
M2I1N2	33793	34008	33901	35793	37373	36583	78780	81111	79946	80695	74703	77699
M2I1N3	42742	45104	43923	44742	48104	46423	75389	78529	76959	75323	69281	72302
M2I2N1	32442	32158	32300	33442	35450	34446	74638	77825	76232	72668	68685	70677
M2I2N2	32793	32508	32651	33793	35873	34833	76532	77694	77113	74920	68908	71914
M2I2N3	41742	43604	42673	42742	46604	44673	69157	76327	72742	69755	61609	65682
M2I3N1	31942	31658	31800	32442	34450	33446	66422	71268	68845	67470	57979	62725
M2I3N2	32293	32008	32151	32793	34873	33833	67591	74770	71181	67279	61926	64603
M2I3N3	41242	43104	42173	41742	45604	43673	65422	71319	68371	63584	58362	60973

M1: Normal transplanting;

I1: Saturation;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

M2: Modified system of rice intensification;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

Table 4.26(a): Net return and B:C ratio of rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	Net return (₹ ha ⁻¹)										B:C ratio			
	Kharif					Rabi					Kharif			
	2015	2016	mean	2015-16	2016-17	mean	2015	2016	mean	2015-16	2016-17	mean	2015-16	2016-17
Establishment methods														
M1	37710	42656	40183	35318	30836	33077	1.94	2.05	1.99	1.85	1.71	1.78	1.85	1.71
M2	36623	39988	38305	35005	26276	30641	2.05	2.14	2.10	1.97	1.70	1.83	1.97	1.70
SEm±	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CD (P=0.05)	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Water regimes														
I1	42034	45273	43653	39787	32639	36213	2.11	2.17	2.14	2.00	1.79	1.89	2.00	1.79
I2	37877	41378	39628	34995	29184	32089	2.02	2.11	2.06	1.92	1.73	1.82	1.92	1.73
I3	31588	37314	34451	30703	23845	27274	1.86	2.00	1.93	1.82	1.60	1.71	1.82	1.60
SEm±	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CD (P=0.05)	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nutrient levels														
N1	40595	45792	43194	38753	32695	35724	2.16	2.30	2.23	2.07	1.85	1.96	2.07	1.85
N2	42377	46046	44211	40412	34257	37334	2.19	2.30	2.24	2.10	1.88	1.99	2.10	1.88
N3	28527	32127	30327	26320	18716	22518	1.64	1.69	1.66	1.58	1.38	1.48	1.58	1.38
SEm±	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CD (P=0.05)	-	-	-	-	-	-	-	-	-	-	-	-	-	-

M1: Normal transplanting; M2: Modified system of rice intensification;
 I1: Saturation; I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;
 I3: irrigation at 10 cm water level depletion in PWT from soil surface;
 N1: 100% RDN through inorganic; N2: 125% RDN through inorganic; N3: 50% through inorganic + 50% through organic

Table 4.26(b): Net return and B:C ratio of rice as influenced by interaction of water regimes and nutrient management under transplanting and modified SRI

Treatments	Net return (₹ ha ⁻¹)										B:C ratio							
	Kharif					Rabi					Kharif				Rabi			
	Kharif					Rabi					Kharif				Rabi			
	2015	2016	mean	2015-16	2016-17	2015	2016	mean	2015-16	2016-17	2015	2016	mean	2015-16	2016-17	mean		
M1I1N1	45363	54472	49918	45767	38702	42235	2.20	2.42	2.31	2.15	1.93	2.04	2.04	1.93	2.04	2.04		
M1I1N2	49367	54047	51707	46277	40733	43505	2.29	2.39	2.34	2.15	1.97	2.06	2.06	1.97	2.06	2.06		
M1I1N3	35173	37391	36282	30350	24537	27444	1.74	1.75	1.75	1.62	1.47	1.55	1.55	1.47	1.55	1.55		
M1I2N1	42536	45400	43968	35606	34154	34880	2.12	2.20	2.16	1.91	1.83	1.87	1.87	1.83	1.87	1.87		
M1I2N2	44357	46807	45582	40812	38525	39669	2.16	2.22	2.19	2.04	1.93	1.99	1.99	1.93	1.99	1.99		
M1I2N3	27020	32485	29753	26186	21148	23667	1.57	1.66	1.62	1.54	1.41	1.48	1.48	1.41	1.48	1.48		
M1I3N1	34333	44406	39370	36045	33193	34619	1.90	2.16	2.03	1.93	1.82	1.88	1.88	1.82	1.88	1.88		
M1I3N2	36510	40371	38441	34866	28866	31866	1.95	2.05	2.00	1.89	1.70	1.80	1.80	1.70	1.80	1.80		
M1I3N3	24726	28522	26624	21951	17667	19809	1.52	1.57	1.55	1.46	1.34	1.40	1.40	1.34	1.40	1.40		
M2I1N1	44664	45197	44931	40845	33357	37101	2.34	2.34	2.34	2.15	1.90	2.03	2.03	1.90	2.03	2.03		
M2I1N2	44988	47103	46046	44902	37330	41116	2.33	2.39	2.36	2.25	2.00	2.13	2.13	2.00	2.13	2.13		
M2I1N3	32647	33425	33036	30581	21178	25880	1.76	1.74	1.75	1.68	1.44	1.56	1.56	1.44	1.56	1.56		
M2I2N1	42195	45667	43931	39226	33235	36231	2.30	2.42	2.36	2.17	1.94	2.06	2.06	1.94	2.06	2.06		
M2I2N2	43740	45186	44463	41127	33036	37082	2.33	2.39	2.36	2.22	1.92	2.07	2.07	1.92	2.07	2.07		
M2I2N3	27415	32723	30069	27013	15006	21010	1.66	1.75	1.71	1.63	1.32	1.48	1.48	1.32	1.48	1.48		
M2I3N1	34479	39610	37045	35028	23529	29279	2.08	2.25	2.17	2.08	1.68	1.88	1.88	1.68	1.88	1.88		
M2I3N2	35299	42762	39031	34486	27053	30770	2.09	2.34	2.22	2.05	1.78	1.92	1.92	1.78	1.92	1.92		
M2I3N3	24179	28216	26198	21842	12758	17300	1.59	1.65	1.62	1.52	1.28	1.40	1.40	1.28	1.40	1.40		

M1: Normal transplanting;

M2: Modified system of rice intensification;

I1: Saturation;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

As regards to interaction effect of establishment methods, water regimes and nitrogen levels on cost of cultivation [Table 4.25(b)], highest value was noted under normal transplanting x saturation throughout lifecycle of crop x 50% RDN through inorganic + 50% through organic source ($M_1I_1N_3$) (48,554 and 50,903 ₹ ha⁻¹, in *kharif* and *rabi* mean data, respectively). Further, it was followed by, normal transplanting x irrigation at 5 cm water level depletion in perched water tube from soil surface x 50% RDN through inorganic + 50% through organic source ($M_1I_2N_3$) (48,334 and 50,153 ₹ ha⁻¹, in *kharif* and *rabi* mean data, respectively).

The highest gross return [Table 4.25(b)] (90,239 and 84,568 ₹ ha⁻¹, in *kharif* and *rabi* mean data, respectively) and net return (51,707 and 43,505 ₹ ha⁻¹, in *kharif* and *rabi* mean data, respectively) was obtained under normal transplanting x saturation throughout lifecycle of crop x 125% RDN through inorganic ($M_1I_1N_2$).

Similarly, the higher B:C ratio [Table 4.26(b)] was found under modified SRI x irrigation at 5 cm water level depletion in perched water tube from soil surface x 125% RDN through inorganic ($M_2I_2N_2$) (2.36 and 2.07, in *kharif* and *rabi* mean data, respectively) followed by, modified SRI x irrigation at 5 cm water level depletion in perched water tube from soil surface x 100% RDN through inorganic ($M_2I_2N_1$) (2.36 and 2.06, in *kharif* and *rabi* mean data, respectively) and normal transplanting x saturation throughout lifecycle x 125% RDN through inorganic ($M_1I_1N_2$) (2.34 and 2.06 in *kharif* and *rabi* mean data, respectively).

Discussion on effect of establishment methods, water regimes and nutrient levels on economics of rice

In progressive countries like India, economic feasibility is very important to be discussed as it directly affects the social and economic conditions of the farmers. Any value greater than 2.0 is considered safe as the farmers get ₹. 2.00 for every rupee invested (Reddy and Reddy, 2002). On the other hand, minimum B:C ratio of 1.5 for the agricultural sector is to be fixed for any enterprises to be economically viable.

In present investigation, modified SRI recorded lower cost of cultivation over normal transplanting due to lower monetary requirement in management practices viz. seed rate, nursery management cost, labour requirement for transplanting, lower investment in weed control (only 4 time cono-weeding was done) etc. However, due to lower yield compared to normal transplanting, it grossed lower gross and net return. In contrary to this, many of the former researchers have found SRI as higher gross and net return giving technique (Reddy *et al.*, 2008; Shekhar *et al.*, 2009 and Vishwakarma, 2015). But then also MoSRI managed to give higher B:C ratio over normal transplanting. Similar findings were also observed by Kewat *et al.* (2002) and Babu *et al.* (2014).

In case of water regimes, saturation throughout life cycle received higher number of irrigations during all the seasons which was the major cause of higher cost of cultivation. However, labour involved in weeding were higher in case of irrigation at 5 and 10 cm water level depletion in perched water tube from soil surface which lowered down the advantage of monetary savings due to lower irrigation. Higher grain and straw yield managed to get higher gross and net return as well as B:C ratio in saturation throughout lifecycle of crop over irrigation at 5 cm and 10 cm water level depletion in perched water tube from soil surface. The above findings are in agreement with those of Subramaniam *et al.* (2007) Rahaman and Sinha (2013) and Kumar *et al.* (2013).

Concerning to nutrient levels, 50% through inorganic + 50% through organic was found highest in cost of cultivation. This was mainly due to requirement of bulk amount of organic manure (here; vermicompost). The requirement of tonnes of vermicompost needed higher monetary input when compared to inorganic fertilizer. Similar finding was also reported by Chowdhary *et al.* (2014). The trend was followed by 125% RDN through inorganic and 100% RDN though inorganic. This cost of organic manure can be minimized if vermicompost of any other organic manure can be produced from own farm and household waste. If this is achieved, farmer can save that major monetary investment and scenario can be viewed in a complete different

way. These findings can further be supported by the works of Sultan *et al.* (2007) Mohanty *et al.* (2014) and Aruna *et al.* (2016) also.

4.8 Energetics of rice

4.8.1 Effect establishment methods, water regimes and nutrient on energetics of rice

The data regarding energy input, gross energy output, energy output: input ratio, energy productivity, net energy output and energy intensity in economic terms in rice as influenced by establishment methods, water regimes and nitrogen levels are presented in Table 4.27(a and b), 4.28(a and b) and 4.29(a and b). As regards to establishment methods, modified SRI method of rice (15.27 and 16.53 GJ ha⁻¹ in *kharif* and *rabi* mean data, respectively) received lower energy input as compared to normal transplanting (M₁) (15.97 and 16.53 GJ ha⁻¹ in *kharif* and *rabi* mean data, respectively). However, in return to the input applied, higher gross energy output (164.4 and 160.8 GJ ha⁻¹ in *kharif* and *rabi* mean data, respectively), energy output: input ratio (10.21 and 9.34 in *kharif* and *rabi* mean data, respectively), energy productivity (0.74 and 0.70 kg MJ⁻¹ in *kharif* and *rabi* mean data, respectively) and net energy output (147.4 and 143.6 GJ ha⁻¹ in *kharif* and *rabi* mean data, respectively) were recorded under normal transplanting as compared to MoSRI. (gross energy output of 150.5 and 148.7 GJ ha⁻¹, energy output: input ratio of 9.80 and 9.01, energy productivity of 0.74 and 0.68 kg MJ⁻¹ and net energy output of 133.9 and 132.9 GJ ha⁻¹ in *kharif* and *rabi* mean data, respectively). Further, modified SRI method of rice (4.21 and 3.74 MJ ₹⁻¹ in *kharif* and *rabi* mean data) gave higher energy intensity as compared to normal transplanting (4.03 and 3.74 MJ ₹⁻¹ in *kharif* and *rabi* mean data, respectively).

The data pertaining to water regimes revealed that, saturation throughout lifecycle of crop received higher energy input (16.22 and 17.79 GJ ha⁻¹ in *kharif* and *rabi* mean data, respectively), gross energy output (166.7 and 165.1 GJ ha⁻¹ in *kharif* and *rabi* mean data, respectively), energy output: input ratio (10.18 and 9.29 in *kharif* and *rabi* mean data, respectively), energy productivity (0.77 and 0.70 kg MJ⁻¹ in *kharif*

Table 4.27(a): Energy input and energy output of rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	Energy input (GJ ha ⁻¹)						Energy output (GJ ha ⁻¹)					
	Kharif			Rabi			Kharif			Rabi		
	2015	2016	mean	2015-16	2016-17	mean	2015	2016	mean	2015-16	2016-17	mean
Establishment methods												
M1	16.55	15.40	15.97	17.29	17.18	17.23	161.8	164.9	163.3	162.3	159.3	160.8
M2	15.84	14.69	15.27	16.58	16.47	16.53	148.1	150.2	149.1	148.4	149.1	148.7
SEm±	-	-	-	-	-	-	-	-	-	-	-	-
CD (P=0.05)	-	-	-	-	-	-	-	-	-	-	-	-
Water regimes												
I1	16.69	15.74	16.22	17.95	17.63	17.79	165.6	165.7	165.7	166.1	164.1	165.1
I2	16.10	14.84	15.47	16.73	16.73	16.73	155.8	157.1	156.5	156.1	152.0	154.0
I3	15.81	14.55	15.18	16.12	16.12	16.12	143.5	149.7	146.6	143.9	146.6	145.2
SEm±	-	-	-	-	-	-	-	-	-	-	-	-
CD (P=0.05)	-	-	-	-	-	-	-	-	-	-	-	-
Nutrient levels												
N1	15.48	14.33	14.91	16.22	16.11	16.17	155.2	158.4	156.8	155.8	154.4	155.1
N2	17.30	16.15	16.72	18.04	17.93	17.98	160.6	160.1	160.4	157.1	159.7	158.4
N3	15.81	14.65	15.23	16.54	16.44	16.49	149.1	154.0	151.5	153.2	148.5	150.8
SEm±	-	-	-	-	-	-	-	-	-	-	-	-
CD (P=0.05)	-	-	-	-	-	-	-	-	-	-	-	-

M1: Normal transplanting;

I1: Saturation;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

M2: Modified system of rice intensification;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

Table 4.27(b): Energy input and energy output of rice as influenced by interaction of water regimes and nutrient management under transplanting and modified SRI

Treatments	Energy input (GJ ha ⁻¹)						Energy output (GJ ha ⁻¹)					
	Kharif			Rabi			Kharif			Rabi		
	2015	2016	mean	2015-16	2016-17	mean	2015	2016	mean	2015-16	2016-17	mean
M1I1N1	16.30	15.35	15.69	17.42	16.96	17.19	170.2	175.6	172.9	170.8	170.5	170.7
M1I1N2	18.11	17.17	17.51	19.24	18.77	19.01	182.0	181.2	181.6	172.7	172.8	172.8
M1I1N3	16.62	15.68	16.01	17.74	17.28	17.51	166.2	169.2	167.7	176.6	160.3	168.5
M1I2N1	15.74	14.48	14.91	16.17	16.02	16.10	164.1	164.2	164.2	160.9	147.3	154.1
M1I2N2	17.56	16.30	16.72	17.98	17.84	17.91	169.2	167.0	168.1	166.7	166.3	166.5
M1I2N3	16.07	14.81	15.23	16.49	16.34	16.42	153.0	157.9	155.5	160.9	151.6	156.3
M1I3N1	15.48	14.22	14.60	15.54	15.40	15.47	149.8	163.1	156.5	150.3	160.9	155.6
M1I3N2	17.29	16.03	16.42	17.36	17.21	17.29	154.8	153.3	154.1	150.4	156.3	153.4
M1I3N3	15.80	14.54	14.92	15.87	15.72	15.80	146.8	152.5	149.7	151.6	148.2	149.9
M2I1N1	15.66	14.71	14.98	16.71	16.28	16.50	159.6	155.4	157.5	162.3	158.1	160.2
M2I1N2	17.47	16.53	16.80	18.53	18.10	18.32	162.8	158.3	160.6	156.6	166.1	161.4
M2I1N3	15.98	15.03	15.30	17.03	16.60	16.82	152.6	154.7	153.7	157.4	156.6	157.0
M2I2N1	15.03	13.77	14.19	15.45	15.34	15.40	151.7	151.1	151.4	154.4	150.9	152.7
M2I2N2	16.84	15.58	16.01	17.27	17.15	17.21	154.0	152.9	153.5	154.5	155.3	154.9
M2I2N3	15.35	14.09	14.51	15.77	15.66	15.72	142.9	149.6	146.3	139.0	140.4	139.7
M2I3N1	14.71	13.45	13.87	14.82	14.71	14.77	135.5	141.2	138.4	135.9	138.9	137.4
M2I3N2	16.53	15.27	15.69	16.64	16.52	16.58	141.1	148.2	144.7	141.5	141.6	141.6
M2I3N3	15.03	13.77	14.20	15.14	15.03	15.09	133.0	140.0	136.5	133.5	133.9	133.7

M1: Normal transplanting;

M2: Modified system of rice intensification;

I1: Saturation;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

Table 4.28(a): Energy output : input and energy productivity of rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	Energy output : input ratio										Energy productivity (kg MJ ⁻¹)				
	Kharif					Rabi					Kharif				
	2015	2016	mean	2015-16	2016-17	mean	2015	2016	mean	2015-16	2016-17	mean	2015-16	2016-17	mean
Establishment methods															
M1	9.69	10.73	10.21	9.40	9.28	9.34	0.73	0.81	0.77	0.70	0.70	0.70	0.70	0.70	0.70
M2	9.36	10.24	9.80	8.96	9.05	9.01	0.70	0.78	0.74	0.66	0.69	0.68	0.66	0.69	0.68
SEm±	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CD (P=0.05)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Water regimes															
I1	9.82	10.54	10.18	9.27	9.31	9.29	0.74	0.80	0.77	0.69	0.71	0.70	0.69	0.69	0.69
I2	9.69	10.61	10.15	9.34	9.09	9.21	0.72	0.80	0.76	0.69	0.69	0.69	0.69	0.69	0.69
I3	9.09	10.31	9.70	8.93	9.11	9.02	0.68	0.78	0.73	0.66	0.69	0.68	0.66	0.69	0.68
SEm±	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CD (P=0.05)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nutrient levels															
N1	9.92	11.05	10.48	9.60	9.58	9.59	0.74	0.84	0.79	0.71	0.73	0.72	0.71	0.73	0.72
N2	9.27	9.91	9.59	8.70	8.90	8.80	0.69	0.75	0.72	0.64	0.67	0.66	0.64	0.67	0.66
N3	9.42	10.50	9.96	9.24	9.03	9.13	0.70	0.80	0.75	0.69	0.68	0.69	0.69	0.68	0.69
SEm±	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CD (P=0.05)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

M1: Normal transplanting; M2: Modified system of rice intensification;
I1: Saturation; I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;
I3: irrigation at 10 cm water level depletion in PWT from soil surface;
N1: 100% RDN through inorganic; N2: 125% RDN through inorganic; N3: 50% through inorganic + 50% through organic

Table 4.28(b): Energy output : input ratio and energy productivity of rice as influenced by interaction of water regimes and nutrient management under transplanting and modified SRI

Treatments	Energy output : input ratio										Energy productivity			
	Kharif					Rabi					Kharif			
	2015	2016	mean	2015-16	2016-17	mean	2015	2016	mean	2015-16	2016-17	mean	2015-16	2016-17
M1I1N1	10.44	11.44	10.94	9.73	9.89	9.81	0.78	0.86	0.82	0.72	0.75	0.74	0.72	0.75
M1I1N2	10.05	10.55	10.30	8.91	9.07	8.99	0.75	0.80	0.78	0.66	0.69	0.68	0.66	0.69
M1I1N3	10.00	10.80	10.40	9.88	9.12	9.50	0.74	0.82	0.78	0.74	0.69	0.72	0.74	0.69
M1I2N1	10.42	11.34	10.88	9.83	9.00	9.42	0.78	0.86	0.82	0.73	0.68	0.71	0.73	0.68
M1I2N2	9.64	10.24	9.94	9.17	9.14	9.16	0.72	0.78	0.75	0.68	0.69	0.69	0.68	0.69
M1I2N3	9.52	10.67	10.10	9.64	9.08	9.36	0.71	0.81	0.76	0.72	0.69	0.71	0.72	0.69
M1I3N1	9.68	11.48	10.58	9.52	10.19	9.86	0.72	0.87	0.80	0.71	0.77	0.74	0.71	0.77
M1I3N2	8.95	9.56	9.26	8.54	8.87	8.71	0.67	0.72	0.70	0.63	0.67	0.65	0.63	0.67
M1I3N3	9.29	10.49	9.89	9.41	9.19	9.30	0.69	0.79	0.74	0.70	0.70	0.70	0.70	0.70
M2I1N1	10.20	10.56	10.38	9.60	9.52	9.56	0.76	0.80	0.78	0.71	0.72	0.72	0.71	0.72
M2I1N2	9.31	9.58	9.45	8.36	9.02	8.69	0.69	0.72	0.71	0.62	0.68	0.65	0.62	0.68
M2I1N3	9.55	10.29	9.92	9.13	9.25	9.19	0.71	0.78	0.75	0.68	0.70	0.69	0.68	0.70
M2I2N1	10.10	10.97	10.54	9.86	9.64	9.75	0.75	0.83	0.79	0.73	0.73	0.73	0.73	0.73
M2I2N2	9.14	9.81	9.48	8.84	8.89	8.87	0.68	0.74	0.71	0.65	0.67	0.66	0.65	0.67
M2I2N3	9.31	10.62	9.97	8.70	8.79	8.75	0.69	0.80	0.75	0.64	0.67	0.66	0.64	0.67
M2I3N1	9.21	10.50	9.86	9.05	9.25	9.15	0.69	0.80	0.75	0.67	0.70	0.69	0.67	0.70
M2I3N2	8.53	9.70	9.12	8.40	8.41	8.41	0.64	0.74	0.69	0.62	0.64	0.63	0.62	0.64
M2I3N3	8.85	10.16	9.51	8.69	8.73	8.71	0.66	0.77	0.72	0.64	0.66	0.65	0.64	0.66

M1: Normal transplanting;

M2: Modified system of rice intensification;

I1: Saturation;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

Table 4.29(a): Net energy output and energy intensity of interaction of water regimes and nutrient management under transplanting and modified SRI in rice

Treatments	Net energy output (GJ ha ⁻¹)									
	Kharif					Rabi				
	2015	2016	mean	2015-16	2016-17	mean	2015	2016	mean	2015-16 2016-17
Establishment methods										
M1	145.2	149.5	147.4	145.0	142.2	143.6	3.95	4.11	4.03	3.84
M2	132.3	135.5	133.9	131.8	132.6	132.2	4.17	4.25	4.21	4.04
SEm±	-	-	-	-	-	-	-	-	-	-
CD (P=0.05)	-	-	-	-	-	-	-	-	-	-
Water regimes										
I1	148.9	150.0	149.5	148.1	146.4	147.3	4.29	4.31	4.30	4.08
I2	139.7	142.3	141.0	139.3	135.2	137.3	4.11	4.21	4.16	4.00
I3	127.7	135.2	131.5	127.7	130.5	129.1	3.79	4.03	3.91	3.75
SEm±	-	-	-	-	-	-	-	-	-	-
CD (P=0.05)	-	-	-	-	-	-	-	-	-	-
Nutrient levels										
N1	139.7	144.1	141.9	139.5	138.3	138.9	4.38	4.59	4.49	4.25
N2	143.3	144.0	143.7	139.0	141.8	140.4	4.48	4.60	4.54	4.25
N3	133.3	139.4	136.4	136.6	132.1	134.3	3.33	3.35	3.34	3.33
SEm±	-	-	-	-	-	-	-	-	-	-
CD (P=0.05)	-	-	-	-	-	-	-	-	-	-

M1: Normal transplanting;

I1: Saturation;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

M2: Modified system of rice intensification;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

Table 4.29(b): Net energy output and energy intensity of rice as influenced by interaction of water regimes and nutrient management under transplanting and modified SRI

Treatments	Net energy output (GJ ha ⁻¹)						Energy intensity in economic terms (MJ ₹ ⁻¹)					
	Kharif			Rabi			Kharif			Rabi		
	2015	2016	mean	2015-16	2016-17	mean	2015	2016	mean	2015-16	2016-17	mean
M1I1N1	153.9	160.3	157.1	153.2	153.3	153.3	4.46	4.73	4.60	4.25	4.15	4.20
M1I1N2	163.9	164.0	164.0	153.3	153.8	153.6	4.73	4.83	4.78	4.26	4.16	4.21
M1I1N3	149.6	153.6	151.6	158.8	142.7	150.8	3.50	3.48	3.49	3.57	3.07	3.32
M1I2N1	148.3	149.7	149.0	144.5	130.9	137.7	4.30	4.47	4.39	4.11	3.63	3.87
M1I2N2	151.6	150.7	151.2	148.6	148.1	148.4	4.39	4.51	4.45	4.22	4.06	4.14
M1I2N3	137.0	143.1	140.1	144.2	134.9	139.6	3.22	3.28	3.25	3.32	2.93	3.13
M1I3N1	134.3	148.9	141.6	134.5	145.1	139.8	3.91	4.42	4.17	3.87	4.00	3.94
M1I3N2	137.5	137.2	137.4	132.8	138.7	135.8	4.00	4.11	4.06	3.84	3.84	3.84
M1I3N3	131.0	137.9	134.5	135.5	132.1	133.8	3.08	3.15	3.12	3.15	2.88	3.02
M2I1N1	144.0	140.7	142.4	145.4	141.5	143.5	4.74	4.67	4.71	4.55	4.32	4.44
M2I1N2	145.3	141.7	143.5	137.9	147.7	142.8	4.79	4.71	4.75	4.35	4.48	4.42
M2I1N3	136.6	139.7	138.2	140.2	139.6	139.9	3.55	3.46	3.51	3.50	3.28	3.39
M2I2N1	136.7	137.3	137.0	138.8	135.2	137.0	4.65	4.75	4.70	4.59	4.30	4.45
M2I2N2	137.1	137.3	137.2	137.0	137.8	137.4	4.66	4.76	4.71	4.54	4.37	4.46
M2I2N3	127.5	135.6	131.6	123.0	124.4	123.7	3.40	3.46	3.43	3.24	3.03	3.14
M2I3N1	120.8	127.7	124.3	120.9	123.9	122.4	4.21	4.51	4.36	4.16	4.07	4.12
M2I3N2	124.5	132.9	128.7	124.7	124.7	124.7	4.34	4.68	4.51	4.29	4.10	4.20
M2I3N3	118.0	126.2	122.1	118.1	118.6	118.4	3.21	3.28	3.25	3.18	2.96	3.07

M1: Normal transplanting;

M2: Modified system of rice intensification;

I1: Saturation;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

and *rabi* mean data, respectively), net energy output (149.4 and 147.3 GJ ha⁻¹ in *kharif* and *rabi* mean data, respectively) and energy intensity in economic terms (4.30 and 4.00 MJ ₹⁻¹ in *kharif* and *rabi* mean data, respectively) when compared to other water regimes.

Similar data on nutrient levels revealed that, 125% RDN through inorganic source acknowledged higher energy input (16.72 and 17.98 GJ ha⁻¹ in *kharif* and *rabi* mean data, respectively) and was closely followed by 50% RDN through inorganic + 50% through organic source (15.23 and 16.49 in *kharif* and *rabi* mean data, respectively) and 100% RDN through inorganic source (14.91 and 16.17 GJ ha⁻¹ in *kharif* and *rabi* mean data). The higher values of gross energy output (158.8 and 158.4 GJ ha⁻¹ in *kharif* and *rabi* mean data, respectively), net energy output (149.4 and 147.3 GJ ha⁻¹ in *kharif* and *rabi* mean data, respectively) and energy intensity in economic terms (4.54 and 4.21 MJ ₹⁻¹ in *kharif* and *rabi* mean data) were found under 125% RDN through inorganic source as compared to other nutrient levels.

Among interactions of establishment methods, water regimes and nitrogen levels, higher energy input [Table 4.27(b)] was found under normal transplanting x saturation throughout lifecycle of crop x 125% RDN through inorganic (M₁I₁N₂) (17.51 and 19.01 GJ ha⁻¹, in *kharif* and *rabi* mean data, respectively) followed by modified SRI x saturation throughout lifecycle of crop x 125% RDN through inorganic (M₂I₁N₂) (16.80 and 18.32 GJ ha⁻¹, in *kharif* and *rabi* mean data, respectively). As regards to gross energy output [Table 4.27(b)], higher value was found under normal transplanting x saturation throughout lifecycle of crop x 125% RDN through inorganic (M₁I₁N₂) (181.6 and 172.8 GJ ha⁻¹, in *kharif* and *rabi* mean data, respectively) followed by normal transplanting x saturation throughout lifecycle of crop x 100% RDN through inorganic (M₁I₁N₁) (172.9 and 170.7 GJ ha⁻¹, in *kharif* and *rabi* mean data, respectively). On the other hand, energy output : input ratio [Table 4.28(b)], was higher under normal transplanting x irrigation at 5 cm water level depletion in perched water tube from soil surface x 100% RDN through inorganic (M₁I₂N₁) (10.94 and 9.81, in *kharif* and *rabi* mean data, respectively) followed by

normal transplanting x saturation throughout lifecycle of crop x 50% RDN through inorganic and 50% through organic ($M_1I_1N_3$) (10.88 and 9.42, in *kharif* and *rabi* mean data). Regarding energy productivity [Table 4.28 (a and b)] during *kharif* higher productivity was realized under normal transplanting x saturation throughout lifecycle of crop x 100% RDN through inorganic ($M_1I_1N_1$) (0.82 kg MJ^{-1} in mean data, respectively) followed by, normal transplanting x irrigation at 5 cm water level depletion in perched water tube from soil surface x 100% RDN through inorganic ($M_1I_2N_1$) (0.82 MJ^{-1} in mean data). However, during *rabi* seasons, highest energy productivity was recorded under normal transplanting x irrigation at 10 cm water level depletion in perched water tube from soil surface x 100% RDN through inorganic ($M_1I_3N_1$) (0.74 kg MJ^{-1} in mean data) followed by normal transplanting x saturation throughout lifecycle of crop x 100% RDN through inorganic ($M_1I_1N_1$) (0.74 kg MJ^{-1} in mean data).

Net energy output [Table 4.29(b)] was also higher under normal transplanting x saturation throughout lifecycle of crop x 125% RDN through inorganic ($M_1I_1N_2$) (164.0 and 153.6 GJ ha^{-1} , in *kharif* and *rabi* mean data, respectively) followed by normal transplanting x saturation throughout lifecycle of crop x 100% RDN through inorganic ($M_1I_1N_1$) (157.1 and 153.3 GJ ha^{-1} , in *kharif* and *rabi* mean data, respectively) For energy intensity in economic terms during *kharif* seasons higher intensity was brought under normal transplanting x saturation throughout lifecycle of crop x 125% RDN through inorganic ($M_1I_1N_2$) (4.78 MJ ₹^{-1}) followed by modified SRI x saturation throughout lifecycle of crop x 125% RDN through inorganic ($M_2I_1N_2$) (4.75 MJ ₹^{-1}). However, during *rabi* seasons, higher energy intensity in economic terms [Table 4.29(b)] was found under modified SRI x irrigation at 5 cm water level depletion in perched water tube from soil surface x 125% RDN through inorganic ($M_2I_2N_2$) (4.46 MJ ₹^{-1}) followed by modified SRI x irrigation at 5 cm and 10 cm water level depletion in perched water tube from soil surface x 100% RDN through inorganic ($M_2I_2N_1$) (4.45 MJ ₹^{-1}).

Discussion on effect establishment methods, water regimes and nutrient levels on energetics of rice

The comparison of the establishment methods, water regimes and nutrient levels differed in their energy use in all the seasons. Establishment methods of normal transplanting used higher energy input over modified SRI in all the seasons. In line result was also observed by Mohanty *et al.* (2014). This variation in energy input was mainly due to higher energy input viz. seed rate, nursery tillage and management, labour requirement for transplanting, manual weed control (two manual weeding per season) *etc.* used in management practices of normal transplanting. Higher yields in normal transplanting gave higher energy output. This higher energy output with higher input still managed to give higher energy output:input ratio, energy productivity and net energy output. However, higher energy intensity in economic terms was observed under modified SRI. This view of SRI has remained fairly common even though these authors themselves subsequently documented, with a stronger empirical basis, that the labor requirements for practicing SRI in Madagascar diminish as farmers gain skill and confidence in this method; after few years, SRI even becomes labor saving for them (Barrett *et al.*, 2004). However, contrary results were observed by Babu *et al.* (2014).

In case of water regimes, saturation throughout life cycle received higher number of irrigations during all the seasons which was the major cause of higher energy input. However, weeding labour involved were higher in case of irrigation at 5 and 10 cm water level depletion in perched water tube from soil surface which lowered down the advantage of energy savings in irrigation. Higher grain and straw yield managed to get higher energy output. This higher energy output with higher input still managed to give higher energy output : input ratio, energy productivity, net energy output and energy intensity in economic terms also. Saturation throughout lifecycle of crop was followed by irrigation at 5 cm and 10 cm water level depletion in perched water tube from soil surface. The increase in energy output: input ratio was mainly due to higher biomass production and total energy output (Jayadeva and Shetty, 2008). The results obtained in this study are in line with the findings of Padhi

and Sahoo (1996). The increase in energy output: input ratio in application of recommended NPK might be due to reduced energy input for cultivation practices. The results are in line with the findings of Sanjay *et al.* (2006).

Table 4.30(a): Correlation of growth parameters of rice with grain yield during *kharif* seasons

	Grain yield	Number of tillers	Number of leaves	Leaf area	Leaf area index	Leaf area duration	SPAD	Dry matter accumulation
Grain yield	1.000**							
Number of tillers	0.988**	1.000**						
Number of leaves	0.992**	0.997**	1.000**					
Leaf area	0.936**	0.948**	0.933**	1.000**				
Leaf area index	0.964**	0.977**	0.965**	0.994**	1.000**			
Leaf area duration	0.978**	0.996**	0.988**	0.957**	0.983**	1.000**		
SPAD	0.979**	0.994**	0.993**	0.913**	0.913**	0.991**	1.000**	
Dry matter accumulation	0.976**	0.978**	0.989**	0.882**	0.882**	0.959**	0.978**	1.000**

*: Indicates significance at 1% level of significance

**: Indicates significance at 5% level of significance

Table 4.30(b): Correlation of growth parameters of rice with grain yield during *rabi* seasons

	Grain yield	Number of tillers	Number of leaves	Leaf area	Leaf area index	Leaf area duration	SPAD	Dry matter accumulation
Grain yield	1.000**							
Number of tillers	0.992**	1.000**						
Number of leaves	0.992**	0.990**	1.000**					
Leaf area	0.940**	0.927**	0.970**	1.000**				
Leaf area index	0.866**	0.849**	0.913**	0.984**	1.000**			
Leaf area duration	0.862**	0.845**	0.909**	0.983**	1.000**	1.000**		
SPAD	0.907**	0.887**	0.851**	0.730**	0.730**	0.602*	1.000**	
Dry matter accumulation	0.997**	0.995**	0.998**	0.955**	0.955**	0.883**	0.879**	1.000**

*: Indicates significance at 1% level of significance

**: Indicates significance at 5% level of significance

Table 4.31(a): Correlation of yield attributes of rice with grain yield during *kharif* seasons

	Grains yield	Number of panicles (m ⁻²)	Panicle length	Panicle weight	Number of grains panicle ⁻¹	Sterility percentage	Test weight
Grain yield	1.000**						
Number of panicles (m⁻²)	0.956**	1.000**					
Panicle length	0.985**	0.968**	1.000**				
Panicle weight	0.964**	0.966**	0.994**	1.000**			
Number of grains panicle⁻¹	0.960**	0.964**	0.993**	1.000**	1.000**		
Sterility percentage	-0.877**	-0.933**	-0.935**	-0.967**	-0.968**	1.000**	
Test weight	-0.641*	-0.447 ^{NS}	-0.528 ^{NS}	-0.476 ^{NS}	-0.476 ^{NS}	0.357 ^{NS}	1.000**

*: Indicates significance at 1% level of significance

**: Indicates significance at 5% level of significance

Table 4.31(b): Correlation of yield attributes of rice with grain yield during *rabi* seasons

	Grain yield	Number of panicles (m ⁻²)	Panicle length	Panicle weight	Number of grains panicle ⁻¹	Sterility percentage	Test weight
Grain yield	1.000**						
Number of panicles (m⁻²)	0.993**	1.000**					
Panicle length	0.841**	0.811**	1.000**				
Panicle weight	0.976**	0.965**	0.806**	1.000**			
Number of grains panicle⁻¹	0.973**	0.983**	0.789**	0.983**	1.000**		
Sterility percentage	-0.795**	-0.788**	-0.536 ^{NS}	-0.898**	-0.864**	1.000**	
Test weight	-0.562 ^{NS}	-0.585 ^{NS}	-0.256 ^{NS}	-0.706*	-0.706*	0.921**	1.000**

*: Indicates significance at 1% level of significance

**: Indicates significance at 5% level of significance

CHAPTER-V

SUMMARY AND CONCLUSION

Field experiment on “**Evaluation of water regimes and nutrient management on rice-rice cropping system under transplanted and modified system of rice intensification (MoSRI)**” was conducted for consecutive seasons of *kharif* and *rabi* 2015-16 and 2016-17 at the ICAR-Indian Institute of Rice Research, Rajendranagar, Hyderabad (Telangana). The soil of the experimental field was clayey in texture (*Vertisols*) and was near neutral (7.8 ± 0.05) in reaction. The available nitrogen, phosphorus and potassium content were low, high and high, respectively. The climate of the region is semi-arid with an average rainfall of 900 mm yr⁻¹. The crop received 331.5, 177.2, 785.9 and 16.4 mm rainfall during crop period of *kharif* 2015, *rabi* 2015-16, *kharif* 2016 and *rabi* 2016-17, respectively.

The experiment on rice-rice cropping system was undertaken during four consecutive *kharif* and *rabi* seasons of 2015-16 and 2016-17. Treatments comprised of two establishment methods viz. normal transplanting (M_1) and modified system of rice intensification (M_2); three water regimes viz. saturation (I_1), 5 cm water level depletion in perched water tube from soil surface (I_2) and 10 cm water level depletion in perched water tube from soil surface (I_3); and three nutrient levels viz. 100% RDN through inorganic (N_1), 125% RDN through inorganic (N_2) and 50% inorganic + 50% organic (based on % nitrogen content) (N_3). The treatments were replicated thrice. Rice variety 'DRR Dhan 42' was taken as test crop during the course of investigation. Influence of above treatments was studied and their effect on growth behavior and other parameters like yield attributes, yield, soil nutrient availability, nutrient uptake, quality, economics and energetics were assessed and analyzed. The salient findings of the present investigation and the conclusion drawn are summarized as under:

5.1 Growth parameters

The growth parameters of rice *i.e.* number of tillers (hill⁻¹), number of leaves (hill⁻¹), leaf area, leaf area index, leaf area duration, dry matter accumulation, days to

50% panicle exertion, days to 50% flowering, root length and root volume significantly influenced by establishment methods. The significantly higher growth parameters of rice *i.e.* number of tillers (hill^{-1}), number of leaves (hill^{-1}), leaf area, dry matter accumulation, root length and root volume were recorded higher under modified SRI as compared to normal transplanting. However, leaf area index and leaf area duration were recorded higher under normal transplanting over modified SRI at all the stages during both the seasons and years. Days taken for 50% panicle exertion and days to 50% flowering were longer in normal transplanting over modified SRI.

Among water regimes, the growth parameters *i.e.* number of tillers (hill^{-1}), number of leaves (hill^{-1}), leaf area, leaf area index, leaf area duration, dry matter accumulation, days to 50% panicle exertion, days to 50% flowering, root length and root volume were significantly higher under saturation throughout lifecycle as compared to irrigation at 5 and 10 cm water level depletion in perched water tube from soil surface at all the observational stages of growth except initial stage of 30 DAT, where all the water regimes behaved similar for their characters during both the seasons and years. Duration taken for 50% panicle exertion and 50% flowering was also higher under saturation throughout the lifecycle of crop during *kharif* and *rabi* grown rice in both the years. However, root length and root volume were recorded higher under 10 cm water level depletion in perched water tube from soil surface over saturation and 5 cm water level depletion in perched water tube from soil surface at all the growth stages except at 30 DAT during both the seasons and years.

Nutrient levels, did not indicate any significant variation on growth parameters *i.e.* number of tillers hill^{-1} , number of leaves hill^{-1} , leaf area, leaf area index, leaf area duration, SPAD value and dry matter accumulation. Although numerically higher values were observed under 125% RDN through inorganic sources at all the observational stages and was followed by 100% RDN through inorganic sources.

As regards to interaction effect of establishment methods, water regimes and nutrient levels for these growth parameters, they did not differ significantly at any of the stage, seasons and years of experimentation.

5.2 Yield attributes

The yield attributes of rice *i.e.* number of panicles (hill^{-1}), grains panicle $^{-1}$, panicle weight and panicle length were significantly influenced by establishment methods but did not show statistically significant differences for number of panicles (m^{-2}), test weight and sterility percentage. Modified SRI recorded significantly higher value of these yield attributes *viz.* number of panicles (hill^{-1}), number of leaves (hill^{-1}), grains panicle $^{-1}$, panicle weight and panicle length.

Regarding water regimes, the yield attributes *viz.* number of panicles (m^{-2}), number of panicles (hill^{-1}), grains panicle $^{-1}$, panicle weight and sterility percentage were significantly superior under. Saturation maintained throughout lifecycle and they were at par with 5 cm water level depletion in perched water tube from soil surface during both the seasons and years. Sterility percentage was found lower under saturation throughout lifecycle of crop during both the seasons and years.

Nutrient levels did not indicate any significant variation on yield attributes *i.e.* number of panicles (m^{-2} and hill^{-1}), panicle length, panicle weight and number of grains panicle $^{-1}$. However, numerically higher values of these attributes were observed under 125% RDN through inorganic source during both the seasons and years and were followed by 100% RDN through inorganic sources.

As regards to interaction effect of establishment methods, water regimes and nutrient levels, the above yield attributes were non-significant during both the seasons and years.

5.3 Yield

Establishment method of normal transplanting gave higher grain and straw yields over modified SRI during all the seasons and years of experimentation but both the methods were statistically at par. Harvest index remained unaffected due to establishment methods.

Among irrigation regimes, significantly higher grain and straw yield was produced by saturation throughout lifecycle of crop but was at par with irrigation at 5 cm water level depletion in perched water tube from soil surface. Lowest grain and straw yield was recorded under irrigation at 10 cm water level depletion in perched water tube from soil surface during both the seasons and years.

Nutrient levels did not indicate any significant variation on grain and straw yield, however during *kharif* 2015 and *rabi* 2015-16 significantly higher grain yield were observed under 125% RDN through inorganic sources followed by 100% RDN through inorganic sources, both the nutrient levels were comparable with each other and significantly superior over integrated nutrient management during this period. In rest of the seasons and years and grain straw yield did not differ significantly due to nutrient levels.

As regards to interaction effect of establishment methods, water regimes and nutrient levels, the grain yield, straw yield and harvest index were found non-significant during both the seasons and years.

5.4 Nutrient content and uptake

The data recorded N, P and K content in rice grain and straw were not influenced by establishment methods, water regimes, nutrient levels and their combined interaction effect during both the seasons and years.

As regards to establishment methods, the uptake of N, P and K by both grain and straw and the total were found non-significant. Whereas among water regimes, the uptake of N and K by both grain and straw was found significantly higher under saturation throughout lifecycle of crop and was found on par with irrigation at 5 cm water level depletion in perched water tube from soil surface. Regarding P uptake, non-significant differences were observed among water regimes.

Regarding nutrient levels, significantly higher N uptake by grain during *kharif* was recorded under 125% RDN through inorganic and was found at par with 100% RDN through inorganic source.

Interaction of establishment methods, water regimes and nutrient levels did not influenced significantly for N, P and K uptake by grain, straw and total during both the seasons and years of experimentation.

5.5 Available soil nutrient

The data recorded on available soil N, P and K content in soil after rice harvest found non-significant due to establishment methods, water regimes, nutrient levels and their combined interaction effect during both the seasons and years of study.

5.6 Quality studies

The data recorded on quality parameters like hulling percentage, milling percentage and head rice recovery in rice were not influenced significantly by establishment methods, during *kharif* and *rabi* seasons of both the years.

On the other hand water regimes had significant impact on hulling, milling and head rice recovery of rice and these quality parameters were superior under saturation throughout lifecycle which was at par with irrigation at 5 cm water depletion in perched water tube from soil surface.

As regards to influence of nutrient levels on quality parameters, the milling percentage was higher in 125% RDN through inorganic source in *rabi* sown rice during 2015-16 but other parameters were not affected significantly due to nutrient levels.

5.7 Water use studies

The data pertaining to establishment methods revealed that, higher irrigation water applied, total water applied and irrigation water productivity were found higher under normal transplanting over modified SRI during both the seasons and years. However, effective rainfall recorded during both the *kharif* seasons was found higher under modified SRI over normal transplanting.

Water regimes data revealed that, irrigation water applied and total water applied during both the seasons and years and irrigation water productivity during *rabi* seasons of both the years were found higher under saturation throughout lifecycle. However, higher irrigation water productivity was recorded under irrigation at 5 cm water level depletion in perched water tube from soil surface.

Further, among nutrient levels, irrigation water productivity was recorded higher under 125% RDN through inorganic followed by 100% DRN through inorganic source.

5.8 Economics

Among establishment methods, higher cost of cultivation, gross return and net return were recorded under normal transplanting as compared to modified SRI during both the seasons and years. However, with respect to B:C ratio higher

values were obtained under modified SRI in kharif and rabi rice during both the years of experimentation.

With respect to water regimes, higher cost of cultivation, gross return, net return and B:C ratio were recorded under water regime of saturation throughout lifecycle followed by irrigation at 5 cm water level depletion in perched water tube from soil surface during both the seasons and years.

Regarding nutrient levels, higher cost of cultivation, gross return, net return and B:C ratio were recorded under 125% RDN through inorganic sources followed by 100% RDN through inorganic source.

The interaction effect between establishment methods, irrigation regimes and nitrogen levels, observed higher cost of cultivation under normal transplanting x saturation throughout lifecycle of crop x 50% RDN through inorganic + 50% through organic source. The highest gross and net return was obtained under normal transplanting x saturation throughout lifecycle of crop x 125% RDN through inorganic whereas, higher B:C ratio was found under modified SRI x irrigation at 5 cm water level depletion in perched water tube from soil surface x 125% RDN through inorganic.

5.9 Energetics

Among establishment methods, higher energy input, energy output, energy output : input ratio, energy productivity and net energy were recorded under normal transplanting as compared to modified SRI. However, with respect to energy intensity in economic terms higher values were obtained under modified SRI.

As regards to water regimes, higher energy input, energy output, energy output : input ratio, energy productivity, net energy and energy intensity in economic terms were recorded under water regime of saturation throughout lifecycle followed by irrigation at 5 cm water level depletion in perched water tube from soil surface.

Amongst nutrient levels, higher energy input, energy output, net energy and energy intensity in economic terms were recorded under 125% RDN through inorganic sources followed by 100% RDN through inorganic source. However, energy output: input ratio and energy productivity was recorded higher under

100% RDN through inorganic source followed by 125% RDN through inorganic sources.

Interactions of establishment methods, irrigation regimes and nitrogen levels, recorded higher energy input, energy output, energy intensity in economic terms during *kharif* seasons was found under normal transplanting x saturation throughout lifecycle of crop x 125% RDN through inorganic; however, during *rabi* seasons, higher energy intensity in economic terms was found under modified SRI x irrigation at 5 cm water level depletion in perched water tube from soil surface x 125% RDN through inorganic. Higher energy output : input ratio was found under normal transplanting x irrigation at 5 cm water level depletion in perched water tube from soil surface x 100% RDN through inorganic. During *kharif* it was realized under normal transplanting x saturation throughout lifecycle of crop x 100% RDN through inorganic (0.82 kg MJ^{-1} in mean data) followed by, normal transplanting x irrigation at 5 cm water level depletion in perched water tube from soil surface x 100% RDN through inorganic; however, during *rabi* seasons, highest energy productivity was recorded under normal transplanting x irrigation at 10 cm water level depletion in perched water tube from soil surface x 100% RDN through inorganic.

CONCLUSIONS

The findings of present investigation conducted entitled **“Evaluation of water regimes and nutrient management on rice-rice cropping system under transplanted and modified system of rice intensification (MoSRI)”** clearly pictured that

- ❖ Modified SRI and normal transplanting produced comparable grain yield during both the seasons. However, growth parameters as well as yield attributes were significantly superior under modified SRI over normal transplanting but it did not compensate lower number of plant population as compared to normal transplanting resulted in comparable grain and straw yield.
- ❖ Water regime of saturation throughout lifecycle gave higher grain yield indicating no water stress giving plant to thrive well and giving chance to produce best possible growth and yield attributes resulted in higher grain

- yield. Similarly, irrigation at 5 cm water depletion in perched water tube from soil surface was comparable to saturation in growth and yield of rice.
- ❖ Nutrient level of 125% of RDN through inorganic gave higher grain yield, nutrient uptake and water use efficiency followed by 100% RDN through inorganic. The combination of 50% RDN through inorganic and 50% through organic was not able to produce competent yield resulting in lower nutrient uptake, water use efficiency and economic and energy returns.
 - ❖ The modified SRI method of rice establishment recorded lower cost of cultivation, net return and energy input as compared to normal transplanting. However, higher value of B:C ratio and energy intensity were recorded under MoSRI method of establishment, as compared to normal transplanting. Water regimes of saturation throughout lifecycle recorded higher cost of cultivation, net return, B:C ratio, energy output : input ratio, and energy intensity in economic terms over other water regimes. Similarly, 125% RDN through inorganic sources gave higher gross return, net return, B:C ratio, gross energy output, net energy output and energy intensity in economic terms over other nutrient levels.
 - ❖ Interactions of establishment methods, irrigation regimes and nitrogen levels, gave highest gross and net return under normal transplanting x saturation throughout lifecycle of crop x 125% RDN through inorganic. In energy terms, higher energy intensity in economic terms during *kharif* seasons was found under normal transplanting x saturation throughout lifecycle of crop x 125% RDN through inorganic followed by modified SRI x saturation throughout lifecycle of crop x 125% RDN through inorganic. However, during rabi seasons, higher energy intensity in economic terms was found under modified SRI x irrigation at 5 cm water level depletion in perched water tube from soil surface x 125% RDN through inorganic followed by modified SRI x irrigation at 5 cm and 10 cm water level depletion in perched water tube from soil surface x 100% RDN through inorganic

SUGGESTIONS FOR FUTURE RESEARCH WORK

In the light of the experience gained during the investigation and result obtained, it is felt that the following points should be given due consideration in future studies.

- There is need to check different modifications in principles and practices of the performance of SRI to out yield production potential of normal transplanting
- Also there is need to quantify and check different water/irrigation losses due to application practices and for further development of ways to increase water use efficiency which can lead to economically beneficial and energy efficient rice crop production.
- The nutrients applied through inorganic sources are non-renewable resources and therefore renewable and recyclable sources of energy are to be given due importance in further advancement of nutrient use efficiency for an environment friendly, economically viable and energy efficient rice-based cropping system.
- Researchers should concentrate on development of new approaches and advancements in involvement of economically sound and energy productive scientific tools and technologies development which can be used by the farmer themselves.

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Appendix I: Meteorological data of *Kharif*, 2015 (standard weeks)

Standard week No.	Month and date	Temperature (°C)		Relative Humidity		Rainfall (mm week ⁻¹)	Rainy days	Sunshine hours (hr)	Wind speed (kmph)	Evaporation (mm)
		Max.	Min.	I	II					
32	Aug 06-12	31.4	23.9	86.3	61.3	10.6	2	3.7	6.8	5.3
33	13-19	30.3	22.4	89.4	72.1	69	4	3.6	4.4	3.6
34	20-26	31.5	22.6	91.3	64.0	14.6	1	5.4	2.8	4.9
35	27-02	30.1	22.1	84.3	66.7	19.4	2	4.0	3.5	5.2
Average/sum		30.8	22.8	87.8	66.0	113.6	9	4.2	4.4	4.8
36	Sep 03-09	33.1	23.0	86.3	55.1	59.8	4	7.8	2.0	5.7
37	10-16	29.8	21.9	95.4	86.6	101	4	2.4	0.8	2.8
38	17-23	29.3	22.5	90.1	65.3	0	0	3.3	1.3	3.2
39	24-30	32.1	22.1	89.3	55.0	2.8	0	7.5	0.2	4.4
Average/sum		31.1	22.4	90.3	65.5	163.6	8	5.3	1.1	4.0
40	Oct 01-07	31.1	21.6	95.7	59.4	33.8	2	5.4	0.2	3.5
41	08-14	33.1	19.7	89.7	37.7	0	0	7.9	0.2	4.4
42	15-21	32.9	19.1	90.9	41.9	0	0	8.3	0.2	4.3
43	22-28	32.6	18.1	90.6	40.3	1.8	0	9.0	2.0	5.0
44	29-04	31.4	20.5	89.7	52.7	16.5	1	7.8	1.4	3.6
Average/sum		32.2	19.8	91.3	46.4	52.1	3	8.3	1.0	4.3
45	Nov 05-11	31.4	17.5	91.3	67.6	0	0	7.4	1.9	4.3
46	12-18	30.1	16.0	85.3	58.6	0.8	0	6.7	2.5	4.1
47	19-25	29.1	19.1	83.0	53.9	0	0	6.3	1.8	3.9
48	26-2	30.3	17.1	88.4	43.0	1.4	0	7.7	0.5	3.8
Average/sum		30.2	17.4	87.0	55.8	2.2	0	7.0	1.7	4.0
49	Dec 3-9	29.5	15.6	89.9	42.3	0	0	6.9	0.4	3.5
Cumulative average/total		31.1	20.3	89.3	56.9	331.5	20.0	6.2	1.8	4.2

Appendix II: Meteorological data of Rabi, 2015-16 (standard weeks)

Standard week No.	Month and date	Temperature (°C)		Relative Humidity		Rainfall (mm week ⁻¹)	Rainy days	Sunshine hours (hr)	Wind speed (kmph)	Evaporation (mm)
		Max.	Min.	I	II					
2	Jan 8-15	29.2	11.0	78.4	25.6	0	0	9.1	1.2	3.9
3	16-22	29.1	16.6	76.6	36.4	0	0	6.8	1.6	3.7
4	23-29	29.1	15.6	79.4	37.3	0	0	7.2	1.6	3.8
5	30-4	32.9	13.6	70.7	25.6	0	0	9.7	1.2	4.6
Average/sum		30.1	14.2	76.3	31.2	0	0	8.2	1.4	4.0
6	Feb 5-11	31.4	23.9	86.3	61.3	30.6	2	3.7	6.8	5.3
7	12-18	30.3	22.4	89.4	72.1	0	0	3.6	4.4	3.6
8	19-25	31.5	22.6	91.3	64.0	0	0	5.4	2.8	4.9
9	26-3	33.4	21.6	80.9	38.3	0	0	7.0	3.1	6.3
Average/sum		31.7	22.6	87.0	58.9	30.6	2	4.9	4.3	5.0
10	Mar 4-10	34.4	18.6	69.1	26.0	0	0	7.4	1.6	6.2
11	11-17	36.4	21.1	76.3	31.6	0	0	8.0	2.1	6.4
12	18-24	38.1	20.6	67.3	23.7	0	0	9.0	2.0	8.0
13	25-31	37.5	21.6	75.1	31.4	0	0	8.0	2.2	7.2
Average/sum		36.6	20.5	72.0	28.2	0	0	8.1	2.0	7.0
14	Apr 1-7	38.7	22.4	67.7	23.9	3	1	8.4	1.7	7.8
15	8-14	39.8	22.0	55.7	18.9	0	0	9.8	2.1	8.5
16	15-21	40.9	25.4	69.7	21.3	2.6	1	9.3	2.2	8.7
17	22-28	41.5	25.7	45.0	19.3	0	0	9.5	2.6	9.3
18	29-5	40.9	25.1	55.6	24.6	0	0	9.2	3.2	9.1
Average/sum		40.4	24.1	58.7	21.6	5.6	2	9.2	2.4	8.7
19	May 6-12	35.7	21.1	83.3	38.6	130.6	3	8.5	2.8	5.7
20	13-19	37.4	24.9	71.1	40.6	10.4	1.0	7.8	1.4	6.2
Average/sum		36.6	23.0	77.2	39.6	141	4	8.2	2.1	6.0
Cumulative average/total		35.2	20.8	73.1	34.8	177.2	8.0	7.8	2.5	6.3

Appendix III: Meteorological data of *Kharif*, 2016 (standard weeks)

Standard week No.	Month and date	Temperature (°C)		Relative Humidity		Rainfall (mm week ⁻¹)	Rainy days	Sunshine hours (hr)	Evaporation (mm)
		Max.	Min.	I	II				
27	July 2-8	30.6	22.9	84.6	63.9	2.0	0	2.5	3.8
28	9-15	28.7	22.6	88.0	70.3	2.2	0	2.2	3.7
29	16-22	31.7	23.2	84.1	59.6	31.2	2	4.0	4.4
30	23-29	30.0	22.7	95.3	73.6	15.8	2	2.1	2.8
31	30-05	28.6	22.4	92.3	76.7	18.6	3	1.4	3.0
Average/sum		30.1	22.8	90.6	70.0	65.6	7	2.5	3.4
32	Aug 06-12	30.6	22.9	85.6	64.9	1.0	0	5.8	4.5
33	13-19	30.8	22.4	82.9	59.7	39.6	3	7.4	5.1
34	20-26	32.8	23.1	82.1	54.4	88.5	5	9.2	6.8
35	27-02	29.4	23.0	95.0	78.4	11.2	2	3.6	2.6
Average/sum		30.9	22.9	86.4	64.4	140.3	10	6.5	4.8
36	Sep 03-09	29.8	21.6	92.0	61.0	2.2	0	6.1	3.8
37	10-16	28.4	22.1	91.3	79.6	0.0	0	2.3	3.1
38	17-23	28.2	22.1	93.7	81.9	104.8	2	2.3	2.5
39	24-30	27.6	21.9	97.7	81.9	136.6	5	1.3	2.3
Average/sum		28.5	21.9	93.7	76.1	243.6	7	3.0	2.9
40	Oct 01-07	30.1	21.8	91.4	66.7	45.6	3	6.0	3.8
41	08-14	29.8	21.7	92.6	55.6	99.6	5	4.9	3.0
42	15-21	30.6	15.0	94.3	34.9	159	5	9.3	4.0
43	22-28	30.4	15.2	91.9	36.4	3.2	1	8.5	4.1
44	29-04	30.6	19.3	83.7	48.1	29	3	7.1	3.6
Average/sum		30.3	18.6	90.8	48.3	336.4	17	7.2	3.7
45	Nov 05-11	30.4	13.5	88.4	30.0	0.0	0	8.5	3.8
46	12-18	29.8	14.9	88.4	44.3	0.0	0	7.0	3.4
Average		30.1	14.2	88.4	37.2	0.0	0	7.8	3.6
Cumulative average/total		30.0	20.5	90.2	60.4	785.9	41.0	5.4	41.0

Appendix IV: Meteorological data of Rabi, 2016-17 (standard weeks)

Standard week No.	Month and date	Temperature (°C)		Relative Humidity		Rainfall (mm week ⁻¹)	Sunshine hours (hr)	Wind speed (kmph)	Evaporation (mm)
		Max.	Min.	I	II				
49	7-14	28.5	15.1	89.9	42.3	0.2	6.9	0.4	3.5
50	15-22	30.8	16.2	90.9	39.3	0.0	7.5	0.5	3.6
51	23-29	32.6	14.6	92.0	32.7	0.0	7.0	9.0	1.0
52	30-31	29.7	12.1	73.1	26.4	0.0	8.0	8.5	0.8
Average/sum		31.2	13.9	82.6	29.6	0.0	7.5	8.8	0.9
1	Jan 1-7	29.4	11.4	84.1	26.0	0.0	9.6	0.9	3.9
2	8-15	29.2	10.3	78.4	25.6	0.0	9.1	1.2	3.9
3	16-22	29.1	16.6	76.6	36.4	0.0	6.8	1.6	3.7
4	23-29	29.1	15.6	79.4	37.3	0.0	7.2	1.6	3.8
5	30-4	32.9	13.6	70.7	25.6	0.0	9.7	1.2	4.6
Average/sum		30.1	13.7	77.8	30.2	0.0	8.5	1.3	4.0
6	Feb 5-11	32.6	16.9	81.3	32.7	0.0	8.7	1.2	4.8
7	12-18	32.9	17.3	80.4	29.4	15.6	8.6	2.3	6.0
8	19-25	35.4	17.4	78.0	25.4	0.0	9.5	1.9	6.5
9	26-3	33.4	21.6	80.9	38.3	0.0	7.0	3.1	6.3
Average/sum		33.6	18.3	80.2	31.5	15.6	8.5	2.1	5.9
10	Mar 4-10	34.4	18.6	69.1	26.0	0.0	7.4	1.6	6.2
11	11-17	36.4	21.1	76.3	31.6	0.0	8.0	2.1	6.4
12	18-24	38.1	20.6	67.3	23.7	0.0	9.0	2.0	8.0
13	25-31	37.5	21.6	75.1	31.4	0.4	8.0	2.2	7.2
Average/sum		36.6	20.5	72.0	28.2	0.4	8.1	2.0	7.0
14	Apr 1-7	38.7	22.4	67.7	23.9	0.0	8.4	1.7	7.8
15	8-14	39.8	22.0	55.7	18.9	0.0	9.8	2.1	8.5
16	15-21	40.9	25.4	69.7	21.3	0.4	9.3	2.2	8.7
Average/sum		39.8	23.3	64.4	21.4	0.4	9.2	2.0	8.3
Cumulative average/total		34.1	17.8	75.3	28.5	16.4	8.4	2.6	5.5

Appendix V: Crop growth rate of *kharif* rice as influenced water regimes and nutrient management under transplanting and modified SRI

Treatments	Crop growth rate (g day ⁻¹ hill ⁻¹)											
	Kharif											
	0-30 DAT			30-60 DAT			60-90 DAT			90 DAT-At harvest		
	2015	2016	mean	2015	2016	mean	2015	2016	mean	2015	2016	mean
Establishment methods												
M1	0.107	0.110	0.108	0.264	0.360	0.312	0.398	0.372	0.385	0.133	0.112	0.123
M2	0.263	0.271	0.267	0.680	0.900	0.790	1.200	1.158	1.179	0.357	0.309	0.333
SEm±	0.008	0.001	0.003	0.017	0.047	0.015	0.041	0.042	0.027	0.065	0.014	0.037
CD (P=0.05)	0.046	0.007	0.021	0.101	0.288	0.094	0.251	0.256	0.164	NS	0.084	NS
Water regimes												
I1	0.187	0.192	0.190	0.553	0.678	0.615	0.852	0.807	0.830	0.197	0.222	0.210
I2	0.177	0.190	0.183	0.478	0.634	0.556	0.796	0.784	0.790	0.283	0.213	0.248
I3	0.192	0.189	0.190	0.386	0.578	0.482	0.750	0.705	0.727	0.254	0.196	0.225
SEm±	0.007	0.003	0.004	0.023	0.037	0.008	0.051	0.060	0.035	0.101	0.005	0.049
CD (P=0.05)	NS	NS	NS	0.088	NS	0.032	NS	NS	NS	NS	NS	NS
Nutrient levels												
N1	0.190	0.195	0.192	0.485	0.620	0.552	0.799	0.770	0.785	0.205	0.210	0.207
N2	0.186	0.186	0.186	0.496	0.662	0.579	0.849	0.799	0.824	0.270	0.220	0.245
N3	0.180	0.190	0.185	0.436	0.609	0.522	0.750	0.726	0.738	0.260	0.201	0.230
SEm±	0.004	0.002	0.003	0.024	0.035	0.008	0.041	0.013	0.016	0.093	0.003	0.047
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (MxIxN)												
	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

M2: Modified system of rice intensification;

I1: Saturation;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

Appendix VI: Crop growth rate of *rabi* rice as influenced water regimes and nutrient management under transplanting and modified SRI

Treatments	Crop growth rate (g day ⁻¹ hill ⁻¹)											
	Rabi											
	0-30 DAT			30-60 DAT			60-90 DAT			90 DAT-At harvest		
	2015	2016	mean	2015	2016	mean	2015	2016	mean	2015	2016	mean
Establishment methods												
M1	0.104	0.099	0.102	0.296	0.272	0.284	0.358	0.323	0.340	0.073	0.175	0.124
M2	0.253	0.266	0.260	0.825	0.721	0.773	1.037	1.031	1.034	0.153	0.231	0.192
SEm±	0.007	0.004	0.001	0.028	0.017	0.023	0.018	0.012	0.014	0.011	0.050	0.030
CD (P=0.05)	0.041	0.027	0.008	0.171	0.104	0.138	0.107	0.070	0.086	0.066	NS	NS
Water regimes												
I1	0.182	0.187	0.185	0.648	0.583	0.616	0.739	0.711	0.725	0.158	0.213	0.185
I2	0.180	0.187	0.184	0.545	0.478	0.511	0.713	0.654	0.683	0.096	0.300	0.198
I3	0.174	0.173	0.174	0.488	0.429	0.458	0.640	0.665	0.653	0.085	0.097	0.091
SEm±	0.005	0.004	0.003	0.015	0.015	0.015	0.027	0.031	0.026	0.021	0.114	0.064
CD (P=0.05)	NS	NS	NS	0.061	0.060	0.059	NS	NS	NS	NS	NS	NS
Nutrient levels												
N1	0.177	0.186	0.181	0.565	0.498	0.531	0.710	0.664	0.687	0.101	0.238	0.169
N2	0.182	0.181	0.181	0.589	0.529	0.559	0.735	0.702	0.719	0.129	0.175	0.152
N3	0.177	0.181	0.179	0.527	0.463	0.495	0.647	0.665	0.656	0.110	0.196	0.153
SEm±	0.005	0.005	0.004	0.017	0.020	0.019	0.022	0.018	0.018	0.023	0.069	0.038
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (MxIxN)												
	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

I1: Saturation;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

M2: Modified system of rice intensification;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

Appendix VII: Relative growth rate of *khharif* rice as influenced water regimes and nutrient management under transplanting and modified SRI

Treatments	Relative growth rate (g g ⁻¹ day ⁻¹ hill ⁻¹)								
	Kharif								
	30-60 DAT			60-90 DAT			90 DAT-At harvest		
	2015	2016	mean	2015	2016	mean	2015	2016	mean
Establishment methods									
M1	0.0407	0.0482	0.0445	0.0249	0.0197	0.0223	0.0054	0.0050	0.0052
M2	0.0425	0.0486	0.0455	0.0275	0.0230	0.0252	0.0054	0.0047	0.0050
SEm±	0.0002	0.0018	0.0010	0.0013	0.0017	0.0006	0.0006	0.0002	0.0004
CD (P=0.05)	0.0014	NS	NS	NS	NS	NS	NS	NS	NS
Water regimes									
I1	0.0460	0.0500	0.0480	0.0237	0.0207	0.0222	0.0047	0.0046	0.0046
I2	0.0434	0.0488	0.0461	0.0259	0.0216	0.0237	0.0056	0.0049	0.0053
I3	0.0355	0.0464	0.0409	0.0289	0.0217	0.0253	0.0059	0.0050	0.0054
SEm±	0.0010	0.0010	0.0006	0.0014	0.0019	0.0008	0.0016	0.0003	0.0008
CD (P=0.05)	0.0041	0.0023	NS	NS	NS	NS	NS	NS	NS
Nutrient levels									
N1	0.0420	0.0473	0.0446	0.710	0.0216	0.0234	0.0044	0.0048	0.0046
N2	0.0427	0.0504	0.0466	0.735	0.0212	0.0237	0.0059	0.0047	0.0053
N3	0.0401	0.0475	0.0438	0.647	0.0212	0.0241	0.0060	0.0050	0.0055
SEm±	0.0010	0.0009	0.0003	0.022	0.0007	0.0005	0.0013	0.0003	0.0007
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (MxIxN)									
	NS	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

I1: Saturation;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

M2: Modified system of rice intensification;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

Appendix VIII: Relative growth rate of *rabi* rice as influenced water regimes and nutrient management under transplanting and modified SRI

Treatments	Relative growth rate (g g ⁻¹ day ⁻¹ hill ⁻¹)								
	Rabi								
	30-60 DAT			60-90 DAT			90 DAT-At harvest		
	2015	2016	mean	2015	2016	mean	2015	2016	mean
Establishment methods									
M1	0.0445	0.0436	0.0441	0.0213	0.0209	0.0211	0.0030	0.0084	0.0057
M2	0.0481	0.0436	0.0458	0.0225	0.0240	0.0233	0.0022	0.0036	0.0029
SEm±	0.0018	0.0008	0.0009	0.0001	0.0001	0.0000	0.0001	0.0012	0.0006
CD (P=0.05)	NS	NS	NS	0.0005	0.0005	0.0002	0.0004	NS	NS
Water regimes									
I1	0.0497	0.0474	0.0485	0.0213	0.0215	0.0214	0.0032	0.0056	0.0044
I2	0.0464	0.0426	0.0445	0.0224	0.0221	0.0222	0.0024	0.0089	0.0057
I3	0.0429	0.0408	0.0419	0.0222	0.0239	0.0230	0.0022	0.0034	0.0028
SEm±	0.0008	0.0006	0.0005	0.0005	0.0009	0.0006	0.0003	0.0027	0.0015
CD (P=0.05)	0.0033	0.0022	0.0022	NS	NS	NS	NS	NS	NS
Nutrient levels									
N1	0.0471	0.0432	0.0452	0.0222	0.0219	0.0221	0.0022	0.0060	0.0041
N2	0.0476	0.0454	0.0465	0.0220	0.0222	0.0221	0.0030	0.0062	0.0046
N3	0.0443	0.0420	0.0432	0.0216	0.0233	0.0225	0.0026	0.0058	0.0042
SEm±	0.0009	0.0015	0.0011	0.0005	0.0006	0.0005	0.0004	0.0016	0.0007
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (MxIxN)									
	NS	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting;

I1: Saturation;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

M2: Modified system of rice intensification;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

N2: 125% RDN through inorganic;

N3: 50% through inorganic + 50% through organic

Appendix IX: Fixed cost of cultivation of rice during *kharif* and *rabi* 2015-16

Sr. no.	Particulars	Rice		
		Input	Price per unit (Rs)	Total cost (Rs ha ⁻¹)
1	Transplanting			
i	Ploughing (once)	1 Tractor (3 hrs)	650 hr ⁻¹	1950
ii	Puddling and levelling (once)	1 Power tiller (6 hrs)	350 hr ⁻¹	2250
iii	Nutrient management			
	P2O5	60 kg ha ⁻¹	35 kg ⁻¹	2100
	K2O	40 kg ha ⁻¹	18.33 kg ⁻¹	733.2
iv	Plant protection measures			
	Monocrotophos	1100 ml	900 l ⁻¹	990
	Harvesting	20 Woman days	166.67 day ⁻¹	3353.4
v	Threshing and winnowing	Thresher (3 hrs)	600 hr ⁻¹	1800
2	Land revenue		1000 yr ⁻¹	500
A	Common cost			16041.2
B	Miscellaneous	10 % of common cost		1604.1
	Grand Total (A+B)			17654.3

Appendix X: Fixed cost of cultivation of rice during *kharif* and *rabi* 2016

Sr. no.	Particulars	Rice		
		Input	Price per unit (E)	Total cost (E ha ⁻¹)
1	Transplanting			
i	Ploughing (once)	1 Tractor (3 hrs)	700 hr ⁻¹	2100
ii	Puddling and levelling (once)	1 Power tiller (6 hrs)	400 hr ⁻¹	2400
iii	Nutrient management			
	P2O5	60 kg ha ⁻¹	35 kg ⁻¹	2100
	K2O	40 kg ha ⁻¹	18.33 kg ⁻¹	733.2
iv	Plant protection measures			
	Monocrotophos	1100 ml	950 l ⁻¹	1045
	Harvesting	20 Woman days	176.67 day ⁻¹	3553.4
v	Threshing and winnowing	Thresher (3 hrs)	700 hr ⁻¹	1950
2	Land revenue		1000 yr ⁻¹	500
A	Common cost			17246.2
B	Miscellaneous	10 % of common cost		1724.6
	Grand Total (A+B)			18970.8

Appendix XI: Variable cost of cultivation of rice as influenced by establishment methods, irrigation regimes and nutrient levels during *kharif* 2015

Treatment	Nursery seed rate (₹ ha ⁻¹)	Nursery ploughing (₹ ha ⁻¹)	Nursery bed preparation (₹ ha ⁻¹)	Trans-planting labour cost (₹ ha ⁻¹)	Irrigation (nursery+ main field) (₹ ha ⁻¹)	Nutrient (nursery+ main field) (₹ ha ⁻¹)	Weeding (₹ ha ⁻¹)	Total (₹ ha ⁻¹)
M1I1N1	25x40 =1000	0.5x650 =325	12x166.67 =2000	20x166.67 =3333.4	200+(14x500) =7200	120*11.67 =1400.4	20x200 =4000	20299.84
M1I1N2	1000	325	2000	3333.4	7200	150x11.67 =1750.5	4000	20649.94
M1I1N3	1000	325	2000	3333.4	7200	(60x11.67)+ (5x2000)= 10700.2	4000	29599.64
M1I2N1	1000	325	2000	3333.4	200+(12x500) =6200	1400.2	4000	20299.86
M1I2N2	1000	325	2000	3333.4	6200	1750.5	4000	20649.96
M1I2N3	1000	325	2000	3333.4	6200	10700.2	4000	29599.66
M1I3N1	1000	325	2000	3333.4	200+(11x500) =5700	1400.2	4000	20466.54
M1I3N2	1000	325	2000	3333.4	5700	1750.5	4000	20816.64
M1I3N3	1000	325	2000	3333.4	5700	10700.2	4000	29766.34
M2I1N1	5x40 =200	0.2x650 =130	4x166.67 =666.68	12x166.67 =2000	300+(14x500) =7300	1400.2	30x166.67 =5000.1	15797.12
M2I1N2	200	130	666.68	2000	7300	1750.5	5000.1	16147.22
M2I1N3	200	130	666.68	2000	7300	10700.2	5000.1	25096.92
M2I2N1	200	130	666.68	2000	300+(12x500) =6300	1400.2	36x166.67 =6000.1	14797.12
M2I2N2	200	130	666.68	2000	6300	1750.5	6000.1	15147.22
M2I2N3	200	130	666.68	2000	6300	10700.2	6000.1	24096.92
M2I3N1	200	130	666.68	2000	300+(11x500) =5800	1400.2	40x166.67 =6666.8	14297.12
M2I3N2	200	130	666.68	2000	5800	1750.5	6666.8	14647.22
M2I3N3	200	130	666.68	2000	5800	10700.2	6666.8	23596.92

Appendix XII: Variable cost of cultivation of rice as influenced by establishment methods, irrigation regimes and nutrient levels during *rabi* 2015-16

Treatment	Nursery seed rate (₹ ha^{-1})	Nursery ploughing (₹ ha^{-1})	Nursery bed preparation (₹ ha^{-1})	Trans-planting labour cost (₹ ha^{-1})	Irrigation (nursery+ main field) (₹ ha^{-1})	Nutrient (nursery+ main field) (₹ ha^{-1})	Weeding (₹ ha^{-1})	Total (₹ ha^{-1})
M1I1N1	25x40 =1000	0.5x700 =350	12x166.67 =2000	20x166.67 =3333.4	200+(18x500) =9200	120*11.67 =1400.4	20x200 =4000	22299.84
M1I1N2	1000	350	2000	3333.4	9200	150x11.67 =1750.5	4000	22649.94
M1I1N3	1000	350	2000	3333.4	9200	(60x11.67)+ (5x2000)= 10700.2	4000	31599.64
M1I2N1	1000	350	2000	3333.4	200+(14x500) =7200	1400.2	4000	21299.86
M1I2N2	1000	350	2000	3333.4	7200	1750.5	4000	21649.96
M1I2N3	1000	350	2000	3333.4	7200	10700.2	4000	30599.66
M1I3N1	1000	350	2000	3333.4	200+(12x500) =6200	1400.2	4000	20966.54
M1I3N2	1000	350	2000	3333.4	6200	1750.5	4000	21316.64
M1I3N3	1000	350	2000	3333.4	6200	10700.2	4000	30266.34
M2I1N1	5x40 =200	0.2x700 =140	4x166.67 =666.68	12x166.67 =2000	300+(18x500) =9300	1400.2	30x166.67 =5000.1	17797.12
M2I1N2	200	140	666.68	2000	9300	1750.5	5000.1	18147.22
M2I1N3	200	140	666.68	2000	9300	10700.2	5000.1	27096.92
M2I2N1	200	140	666.68	2000	300+(14x500) =7300	1400.2	36x166.67 =6000.1	15797.12
M2I2N2	200	140	666.68	2000	7300	1750.5	6000.1	16147.22
M2I2N3	200	140	666.68	2000	7300	10700.2	6000.1	25096.92
M2I3N1	200	140	666.68	2000	300+(12x500) =6300	1400.2	40x166.67 =6666.8	14797.12
M2I3N2	200	140	666.68	2000	6300	1750.5	6666.8	15147.22
M2I3N3	200	140	666.68	2000	6300	10700.2	6666.8	24096.92

Appendix XIII: Variable cost of cultivation of rice as influenced by establishment methods, irrigation regimes and nutrient levels during *kharif* 2016

Treatment	Nursery seed rate (kg ha^{-1})	Nursery ploughing (kg ha^{-1})	Nursery bed preparation (kg ha^{-1})	Trans-planting labour cost (₹ ha^{-1})	Irrigation (nursery+ main field) (₹ ha^{-1})	Nutrient (nursery+ main field) (kg ha^{-1})	Weeding (₹ ha^{-1})	Total (₹ ha^{-1})
M1I1N1	25x40 =1000	0.5x650 =325	12x176.67 =2120	20x176.67 =3533.4	200+(11x500) =5700	120*11.67 =1400.4	20x210 =4200	19446.04
M1I1N2	1000	325	2120	3533.4	5700	150x11.67 =1750.5	4000	19796.14
M1I1N3	1000	325	2120	3533.4	5700	(60x11.67)+ (5x2000)= 10700.2	4000	30891.64
M1I2N1	1000	325	2120	3533.4	200+(8x500) =4200	1400.2	4000	19006.06
M1I2N2	1000	325	2120	3533.4	4200	1750.5	4000	19356.16
M1I2N3	1000	325	2120	3533.4	4200	10700.2	4000	30451.66
M1I3N1	1000	325	2120	3533.4	200+(7x500) =3700	1400.2	4000	19212.74
M1I3N2	1000	325	2120	3533.4	3700	1750.5	4000	19562.84
M1I3N3	1000	325	2120	3533.4	3700	10700.2	4000	30658.34
M2I1N1	5x40 =200	0.2x650 =130	4x176.67 =706.7	12x176.67 =2120	300+(14x500) =7300	1400.2	30x176.67 =5300.1	14687.12
M2I1N2	200	130	706.7	2120	7300	1750.5	5300.1	15037.22
M2I1N3	200	130	706.7	2120	7300	10700.2	5300.1	26132.72
M2I2N1	200	130	706.7	2120	300+(12x500) =6300	1400.2	36x176.67 =6360.1	13187.12
M2I2N2	200	130	706.7	2120	6300	1750.5	6360.1	13537.22
M2I2N3	200	130	706.7	2120	6300	10700.2	6360.1	24632.72
M2I3N1	200	130	706.7	2120	300+(11x500) =5800	1400.2	40x176.67 =7066.8	12687.12
M2I3N2	200	130	706.7	2120	5800	1750.5	7066.8	13037.22
M2I3N3	200	130	706.7	2120	5800	10700.2	7066.8	24132.72

Appendix XIV: Variable cost of cultivation of rice as influenced by establishment methods, irrigation regimes and nutrient levels during *rabi* 2016-17

Treatment	Nursery seed rate (₹ ha^{-1})	Nursery ploughing (₹ ha^{-1})	Nursery bed preparation (₹ ha^{-1})	Trans-planting labour cost (₹ ha^{-1})	Irrigation (nursery+ main field) (₹ ha^{-1})	Nutrient (nursery+ main field) (₹ ha^{-1})	Weeding (₹ ha^{-1})	Total (₹ ha^{-1})
M1I1N1	25x40 =1000	0.5x650 =325	12x176.67 =2120	20x176.67 =3533.4	200+(17x500) =8700	120*11.67 =1400.4	20x210 =4200	22435.91
M1I1N2	1000	325	2120	3533.4	8700	150x11.67 =1750.5	4000	22858.91
M1I1N3	1000	325	2120	3533.4	8700	(60x11.67)+ (5x2000)= 10700.2	4000	33589.91
M1I2N1	1000	325	2120	3533.4	200+(14x500) =7200	1400.2	4000	21935.93
M1I2N2	1000	325	2120	3533.4	7200	1750.5	4000	22358.93
M1I2N3	1000	325	2120	3533.4	7200	10700.2	4000	33089.93
M1I3N1	1000	325	2120	3533.4	200+(12x500) =6200	1400.2	4000	21602.61
M1I3N2	1000	325	2120	3533.4	6200	1750.5	4000	22025.61
M1I3N3	1000	325	2120	3533.4	6200	10700.2	4000	32756.61
M2I1N1	5x40 =200	0.2x650 =130	4x176.67 =706.7	12x176.67 =2120	300+(17x500) =8700	1400.2	30x176.67 =5300.1	17978.72
M2I1N2	200	130	706.7	2120	8700	1750.5	5300.1	18401.72
M2I1N3	200	130	706.7	2120	8700	10700.2	5300.1	29132.72
M2I2N1	200	130	706.7	2120	300+(14x500) =7300	1400.2	36x176.67 =6360.1	16478.72
M2I2N2	200	130	706.7	2120	7300	1750.5	6360.1	16901.72
M2I2N3	200	130	706.7	2120	7300	10700.2	6360.1	27632.72
M2I3N1	200	130	706.7	2120	300+(12x500) =6300	1400.2	40x176.67 =7066.8	15478.72
M2I3N2	200	130	706.7	2120	6300	1750.5	7066.8	15901.72
M2I3N3	200	130	706.7	2120	6300	10700.2	7066.8	26632.72

Appendix XV: Fixed energy input of rice during all seasons

Particulars		Rice	
	Input	Energy per unit (MJ)	Total Fixed energy (MJ ha ⁻¹)
Transplanting			
i	Ploughing (once)	56.31 MJ lt ⁻¹	675.72
ii	Puddling and levelling (once)	56.31 MJ lt ⁻¹	675.72
vi	Harvesting	1.57 MJ hr ⁻¹	188.4
iii	Nutrient management		
	P ₂ O ₅	11.10 MJ kg ⁻¹	666
	K ₂ O	6.70 MJ kg ⁻¹	268
iv	Plant protection measures		
	Monocrotophos	120 MJ l ⁻¹	132
v	Harvesting	1.57 MJ hr ⁻¹	251.2
vi	Threshing and winnowing	56.31 MJ lt ⁻¹	337.86
Total			3194.9

Appendix XVI: Variable energy of cultivation of rice as influenced by establishment methods, irrigation regimes and nutrient levels during *kharif* 2015

Treatment	Nursery seed rate (MJ ha ⁻¹)	Nursery ploughing (MJ ha ⁻¹)	Nursery bed preparation (MJ ha ⁻¹)	Trans-planting labour cost (MJ ha ⁻¹)	Irrigation (nursery+ main field) (MJ ha ⁻¹)	Nutrient (nursery+ main field) (MJ ha ⁻¹)	Weeding (MJ ha ⁻¹)	Total variable energy (MJ ha ⁻¹)
M11IN1	25x14.7 =367.5	0.5x5x56.31 =325	12x1.57x8 =150.72	20x1.57x8 =251.2	63+(14x315) =4473	120*60.6 =7272	20x1.96x8 =313.6	13101.48
M11IN2	367.5	325	150.72	251.2	4473	150*60.6 =9090	313.6	14919.48
M11IN3	367.5	325	150.72	251.2	4473	(60x60.6)+ (1.98x2000)= 7596	313.6	13425.48
M112N1	367.5	325	150.72	251.2	63+(12x315) =3843	7272	313.6	12546.84
M112N2	367.5	325	150.72	251.2	3843	9090	313.6	14364.84
M112N3	367.5	325	150.72	251.2	3843	7596	313.6	12870.84
M113N1	367.5	325	150.72	251.2	63+(11x315) =3528	7272	313.6	12282.08
M113N2	367.5	325	150.72	251.2	3528	9090	313.6	14100.08
M113N3	367.5	325	150.72	251.2	3528	7596	313.6	12606.08
M21IN1	5x14.7 =73.5	0.2x650 =130	4x1.57x8 =50.24	12x1.57x8 =150.72	94.5+(14x315) =4504.5	7272	30x1.57x8 =376.8	12460.47
M21IN2	73.5	130	50.24	150.72	4504.5	9090	376.8	14278.47
M21IN3	73.5	130	50.24	150.72	4504.5	7596	376.8	12784.47
M212N1	73.5	130	50.24	150.72	94.5+(12x315) =3874.5	7272	36x1.57x8 =6360.1	11830.47
M212N2	73.5	130	50.24	150.72	3874.5	9090	452.16	13648.47
M212N3	73.5	130	50.24	150.72	3874.5	7596	452.16	12154.47
M213N1	73.5	130	50.24	150.72	94.5+(11x315) =3559.5	7272	40x1.57x8 =502.4	11515.47
M213N2	73.5	130	50.24	150.72	3559.5	9090	502.4	13333.47
M213N3	73.5	130	50.24	150.72	3559.5	7596	502.4	11839.47

Appendix XVII: Variable energy of cultivation of rice as influenced by establishment methods, irrigation regimes and nutrient levels during *rabi* 2015-16

Treatment	Nursery seed rate (MJ ha ⁻¹)	Nursery ploughing (MJ ha ⁻¹)	Nursery bed preparation (MJ ha ⁻¹)	Trans-planting labour cost (MJ ha ⁻¹)	Irrigation (nursery+ main field) (MJ ha ⁻¹)	Nutrient (nursery+ main field) (MJ ha ⁻¹)	Weeding (MJ ha ⁻¹)	Total variable energy (MJ ha ⁻¹)
M11IN1	25x14.7 =367.5	0.5x5x56.31 =140.77	12x1.57x8 =150.72	20x1.57x8 =251.2	63+(18x315) =5733	120*60.6 =7272	20x1.96x8 =313.6	14361.48
M11IN2	367.5	140.77	150.72	251.2	5733	150*60.6 =9090	313.6	16179.48
M11IN3	367.5	140.77	150.72	251.2	5733	(60x60.6)+ (1.98x2000)= 7596	313.6	14685.48
M112N1	367.5	140.77	150.72	251.2	63+(14x315) =4473	7272	313.6	13176.84
M112N2	367.5	140.77	150.72	251.2	4473	9090	313.6	14994.84
M112N3	367.5	140.77	150.72	251.2	4473	7596	313.6	13500.84
M113N1	367.5	140.77	150.72	251.2	63+(12x315) =3843	7272	313.6	12597.08
M113N2	367.5	140.77	150.72	251.2	3843	9090	313.6	14415.08
M113N3	367.5	140.77	150.72	251.2	3843	7596	313.6	12921.08
M21IN1	5x14.7 =73.5	0.2x5x56.31 =56.31	4x1.57x8 =50.24	12x1.57x8 =150.72	94.5+(18x315) =5764.5	7272	30x1.57x8 =376.8	13720.47
M21IN2	73.5	56.31	50.24	150.72	5764.5	9090	376.8	15538.47
M21IN3	73.5	56.31	50.24	150.72	5764.5	7596	376.8	14044.47
M212N1	73.5	56.31	50.24	150.72	94.5+(14x315) =4504.5	7272	36x1.57x8 =6360.1	12460.47
M212N2	73.5	56.31	50.24	150.72	4504.5	9090	452.16	14278.47
M212N3	73.5	56.31	50.24	150.72	4504.5	7596	452.16	12784.47
M213N1	73.5	56.31	50.24	150.72	94.5+(12x315) =3874.5	7272	40x1.57x8 =502.4	11830.47
M213N2	73.5	56.31	50.24	150.72	3874.5	9090	502.4	13648.47
M213N3	73.5	56.31	50.24	150.72	3874.5	7596	502.4	12154.47

Appendix XVIII: Variable energy of cultivation of rice as influenced by establishment methods, irrigation regimes and nutrient levels during *kharif* 2016

Treatment	Nursery seed rate (MJ ha ⁻¹)	Nursery ploughing (MJ ha ⁻¹)	Nursery bed preparation (MJ ha ⁻¹)	Trans-planting labour cost (MJ ha ⁻¹)	Irrigation (nursery+ main field) (MJ ha ⁻¹)	Nutrient (nursery+ main field) (MJ ha ⁻¹)	Weeding (MJ ha ⁻¹)	Total variable energy (MJ ha ⁻¹)
M11IN1	25x14.7 =367.5	0.5x5x56.31 =325	12x1.57x8 =150.72	20x1.57x8 =251.2	63+(11x315) =3528	120*60.6 =7272	20x1.96x8 =313.6	12156.48
M11IN2	367.5	325	150.72	251.2	3528	150*60.6 =9090	313.6	13974.48
M11IN3	367.5	325	150.72	251.2	3528	(60x60.6)+ (1.98x2000)= 7596	313.6	12480.48
M112N1	367.5	325	150.72	251.2	63+(8x315) =2583	7272	313.6	11286.84
M112N2	367.5	325	150.72	251.2	2583	9090	313.6	13104.84
M112N3	367.5	325	150.72	251.2	2583	7596	313.6	11610.84
M113N1	367.5	325	150.72	251.2	63+(7x315) =2268	7272	313.6	11022.08
M113N2	367.5	325	150.72	251.2	2268	9090	313.6	12840.08
M113N3	367.5	325	150.72	251.2	2268	7596	313.6	11346.08
M21IN1	5x14.7 =73.5	0.2x650 =130	4x1.57x8 =50.24	12x1.57x8 =150.72	94.5+(11x315) =3559.5	7272	30x1.57x8 =376.8	11515.47
M21IN2	73.5	130	50.24	150.72	3559.5	9090	376.8	13333.47
M21IN3	73.5	130	50.24	150.72	3559.5	7596	376.8	11839.47
M212N1	73.5	130	50.24	150.72	94.5+(8x315) =2614.5	7272	36x1.57x8 =6360.1	10570.47
M212N2	73.5	130	50.24	150.72	2614.5	9090	452.16	12388.47
M212N3	73.5	130	50.24	150.72	2614.5	7596	452.16	10894.47
M213N1	73.5	130	50.24	150.72	94.5+(7x315) =2299.5	7272	40x1.57x8 =502.4	10255.47
M213N2	73.5	130	50.24	150.72	2299.5	9090	502.4	12073.47
M213N3	73.5	130	50.24	150.72	2299.5	7596	502.4	10579.47

Appendix XIX: Variable energy of cultivation of rice as influenced by establishment methods, irrigation regimes and nutrient levels during *rabi* 2016-17

Treatment	Nursery seed rate (MJ ha ⁻¹)	Nursery ploughing (MJ ha ⁻¹)	Nursery bed preparation (MJ ha ⁻¹)	Trans-planting labour cost (MJ ha ⁻¹)	Irrigation (nursery+ main field) (MJ ha ⁻¹)	Nutrient (nursery+ main field) (MJ ha ⁻¹)	Weeding (MJ ha ⁻¹)	Total variable energy (MJ ha ⁻¹)
M1I1N1	25x14.7 =367.5	0.5x5x56.31 =140.77	12x1.57x8 =150.72	20x1.57x8 =251.2	63+(17x315) =5418	120*60.6 =7272	20x1.96x8 =313.6	14046.48
M1I1N2	367.5	140.77	150.72	251.2	5418	150*60.6 =9090	313.6	15864.48
M1I1N3	367.5	140.77	150.72	251.2	5418	(60x60.6)+ (1.98x2000)= 7596	313.6	14370.48
M1I2N1	367.5	140.77	150.72	251.2	63+(14x315) =4473	7272	313.6	13176.84
M1I2N2	367.5	140.77	150.72	251.2	4473	9090	313.6	14994.84
M1I2N3	367.5	140.77	150.72	251.2	4473	7596	313.6	13500.84
M1I3N1	367.5	140.77	150.72	251.2	63+(12x315) =3843	7272	313.6	12597.08
M1I3N2	367.5	140.77	150.72	251.2	3843	9090	313.6	14415.08
M1I3N3	367.5	140.77	150.72	251.2	3843	7596	313.6	12921.08
M2I1N1	5x14.7 =73.5	0.2x5x56.31 =56.31	4x1.57x8 =50.24	12x1.57x8 =150.72	94.5+(17x315) =5449.5	7272	30x1.57x8 =376.8	13405.47
M2I1N2	73.5	56.31	50.24	150.72	5449.5	9090	376.8	15223.47
M2I1N3	73.5	56.31	50.24	150.72	5449.5	7596	376.8	13729.47
M2I2N1	73.5	56.31	50.24	150.72	94.5+(14x315) =4504.5	7272	36x1.57x8 =6360.1	12460.47
M2I2N2	73.5	56.31	50.24	150.72	4504.5	9090	452.16	14278.47
M2I2N3	73.5	56.31	50.24	150.72	4504.5	7596	452.16	12784.47
M2I3N1	73.5	56.31	50.24	150.72	94.5+(12x315) =3874.5	7272	40x1.57x8 =502.4	11830.47
M2I3N2	73.5	56.31	50.24	150.72	3874.5	9090	502.4	13648.47
M2I3N3	73.5	56.31	50.24	150.72	3874.5	7596	502.4	12154.47

Appendix XX: Monetary values and energy constant used for calculation of economic and energy parameters

Source	Monetary values (₹ unit ⁻¹)		Energy constant (MJ unit ⁻¹)
	2015-16	2016-17	
Input calculation			
Adult man	200 ₹ day ⁻¹	210 ₹ day ⁻¹	1.96 MJ hr ⁻¹
Women	166.67 ₹ day ⁻¹	176.67 ₹ day ⁻¹	1.57 MJ hr ⁻¹
Paddy seeds	40 ₹ kg	40 ₹ kg ⁻¹	15.20 MJ kg ⁻¹
Farm machinery (Tractor)	650 ₹ hr ⁻¹	700 ₹ hr ⁻¹	64.80 MJ kg ⁻¹
Self-propelled machines	350 ₹ hr ⁻¹	400 ₹ hr ⁻¹	64.80 MJ kg ⁻¹
Diesel	-	-	56.31 MJ lit ⁻¹
Thresher	600 ₹ hr ⁻¹	700 ₹ hr ⁻¹	10.03 MJ hr ⁻¹
N			60.60 MJ kg ⁻¹
P ₂ O ₅	35 ₹ kg ⁻¹	35 ₹ kg ⁻¹	11.10 MJ kg ⁻¹
K ₂ O	18.33 ₹ kg ⁻¹	18.33 ₹ kg ⁻¹	6.70 MJ kg ⁻¹
Vermicompost	5 ₹ kg ⁻¹	6 ₹ kg ⁻¹	1.98 MJ kg ⁻¹
Monocrotophos	900 ₹ kg ⁻¹	950 ₹ kg ⁻¹	120 l-l
Water	500 ₹ irrigation ⁻¹	500 ₹ irrigation ⁻¹	0.63 MJ 1000 lt ⁻¹
Output calculation			
Paddy grain	1410 ₹ q ⁻¹	1470 ₹ q ⁻¹	14.70 MJ kg ⁻¹
Paddy straw	50 ₹ q ⁻¹	50 ₹ q ⁻¹	12.50 MJ kg ⁻¹

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Signature



Effect of water regimes and nutrient levels on morpho-physiological traits of rice-rice cropping system under transplanting and modified SRI

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ABSTRACT

With increasing labor, water and nutrient scarcity throughout Asia, there is a need to find alternative rice establishment methods, water regimes and nutrient level to the traditional practice of crop management into puddled soil. Therefore, field experiments were conducted for consecutive seasons of kharif and rabi 2015-16 and 2016-17 at the ICAR-Indian Institute of Rice Research, Rajendranagar, Hyderabad (Telangana) with the view of studying the effect of water regimes and nutrient levels on morpho-physiological parameters traits of rice-rice cropping system under transplanting and modified SRI. The experiment was comprised of two establishment methods viz. normal transplanting (M_1) and modified system of rice intensification (M_2); three irrigation regimes viz. saturation (I_1), 5 cm water level depletion in perched water tube from soil surface (I_2) and 10 cm water level depletion in perched water tube from soil surface (I_3); and three nutrient levels viz. 100% RDN through inorganic (N_1), 125% RDN through inorganic (N_2) and 50% inorganic + 50% organic (based on % nitrogen content) (N_3). The treatments were replicated thrice. The influence of plant height was variably influenced by establishment methods, water regimes and nutrient levels during different stages of both the seasons and years. Number of tillers (hill^{-1}) and leaf area index was significantly higher under establishment method of modified SRI (M_2) and water regime of saturation throughout lifecycle during both the seasons and years. However, grain yield of rice was significantly higher under irrigation regime of saturation throughout lifecycle (I_1) but remain unaffected by establishment methods and nutrient levels.

Key words: Modified SRI, alternate wetting and drying, crop growth rate, sensor based water management

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INTRODUCTION

Rice is the world's single most important food crop, being the primary food source for more than a third of the world's population and grown on 11% of the world's cultivated area. Specially, it is important in case of Asians, Africans, and Latin Americans living in the tropics and sub-tropics. In India, the rice consumption demand in 2015-16 was around 99.5 million tonnes and in 2025, the demand will be around 140 million tons and the world demand for rice is projected to increase by as much as 70% over the next 30 years. The SRI, a promising, yet controversial method of rice cultivation, was developed in Madagascar and was first synthesized by [1]. Since 2005, year of introduction of SRI in India, SRI as an alternative method of rice cultivation has received considerable attention both in print as well as from farming communities. SRI shows a great promise to the substantial increase of the irrigated rice yield, its average yield being around 8.0 ton ha^{-1} which is twice more than the world average 3.6 t ha^{-1} [2]. SRI has been reported as a establishment method which incorporates water saving principles during rice production process creating opportunity in many rice production systems which are already stressed as regards to water resources [3]. Still SRI method is not much popular in Indian states where transplanted paddy cultivation is done. The most probable reason may be the delicate age of seedling (8-12 days) which may be overcome by planting seedlings of slight later age (18-20 days) [4][5]. The possible reason may be because many lowland rice cultivars, despite having an ability of internal aeration, are still sensitive to complete submergence. Their leaves and stems moderately elongate under complete submergence to reach the air-water interface, but their elongation growth can exhaust energy reserves and cause death when the flooding depth is deep and the flooding period is long [6]. Irrigated agriculture

contributes 40 per cent of global crop production in 20 per cent of total cultivated land. However, saving water in rice production is crucial for food security in Asia, as more than 75% of the rice comes from the irrigated system. Among the various methods of water-saving irrigation, the most widely adopted is alternate wetting and drying. Cabangon *et al.* (2004) reported that N recovery of rice under AWD (about 20%) was significantly lower than that under submergence (about 40%). Increasing nitrogen use efficiency in AWD will help farmers to reduce the amount of fertilizer inputs, increase their income, and facilitate their adoption of AWD to cope with water scarcity. A combination of AWD and high nitrogen use efficiency management will also benefit the environment by reducing the amount of water used and chemical pollution entering the surroundings. Also, recent findings have shown that optimizing fertilizer N application rates under SRI are important to increase yield as higher N application rate may lead to decrease in grain yield [7]. Keeping these points in view the study was proposed to study the effect of water regimes and nitrogen levels on morpho-physiological traits of rice-rice cropping system under transplanting and modified SRI.

MATERIALS AND METHODS

Field experiments with the view of studying the effect of water regimes and nutrient levels on morpho-physiological parameters traits of rice-rice cropping system under transplanting and modified SRI were conducted for consecutive seasons of *kharif* and *rabi* 2015-16 and 2016-17 at the ICAR-Indian Institute of Rice Research, Rajendranagar, Hyderabad (Telangana). The experiment was comprised of two establishment methods *viz.* normal transplanting (seedling age: 25-28 days and spacing 20 cm x 10 cm) (M₁) and modified system of rice intensification (seedling age: 18-20 days and spacing 25 cm x 25 cm) (M₂); three irrigation regimes *viz.* saturation (I₁), 5 cm water level depletion in perched water tube from soil surface (I₂) and 10 cm water level depletion in perched water tube from soil surface (I₃); and three nutrient levels *viz.* 100% RDN through inorganic (N₁), 125% RDN through inorganic (N₂) and 50% inorganic + 50% organic (based on % nitrogen content) (N₃). The treatments were replicated thrice. The soil of the experimental field was clayey in texture (Vertisols) and was near neutral (7.8±0.05) in reaction. The available nitrogen, phosphorus and potassium content were low, high and high, respectively. The climate of the region is semi-arid with an average rainfall of 900 mm yr⁻¹. The crop received 331.5, 177.2, 785.9 and 16.4 mm rainfall during crop period of *kharif* 2015, *rabi* 2015-16, *kharif* 2016 and *rabi* 2016-17, respectively. The irrigation treatments were imposed after 15 days of transplanting up to grain filling stage of crop in both methods of establishment and 5 cm irrigation was applied based on water level depletion in perched water tube as per treatments (*i.e.* 0 (saturation through lifecycle), 5 and 10 cm depletion of water from soil surface in perched water tubes). The irrigation water was applied through plastic pipe from the source and a water meter was attached for measuring irrigation water. In this experiment, field water tubes crowned with SONAR wave based water level sensor had been used (developed by team of engineers and scientist of WALAMTARI, Rajendranagar, Hyderabad) which are digital electronic devices that can measure real time micro-climate based weather data (temperature and relative humidity) along with water level in the field water tubes. The information was further transmitted to the mobile devices at periodic intervals to take care of field water to achieve maximum water use efficiency (Plate 1). Rice variety 'DRR Dhan 42' was taken as test crops during the course of investigations. Further, the influence of above treatments was studied and their effect on morpho-physiological traits were assessed and analyzed.

RESULTS AND DISCUSSION

Morphological traits: The detail insight growth behavior of morphological traits of plant height and number of tillers of rice as influenced by establishment methods, water regimes and nutrient levels are presented in Table 1 and 2. Among crop establishment methods, modified system of rice intensification (MoSRI) produced significantly taller plants at 60 DAT. However, at 90 DAT and at harvest no significant variation in plant height was observed due to establishment methods in *kharif* seasons, but in *rabi* rice plant height the variation in plant height from 60- DAT to upto at harvest was not significant. As regards to water regimes at 60 and 90 DAT, significantly taller plants were recorded under irrigation at saturation throughout life cycle of crop; and it was statistically at par with irrigation at 5 cm water level depletion in perched water tube from soil surface. Irrigation at 10 cm water level depletion in perched water tube from soil surface exhibited the shortest plant height at all the growth stages during both the years and in mean data. At harvest the plant height of rice crop was not affected due to water regimes in both the years and in *kharif* and *rabi* seasons also. As regards to influence of nutrient levels on plant height, comparable plant of rice was observed under 125% RDN through inorganic source throughout the growth period of crop during both the years and in mean data. The data concerning to establishment methods revealed that significantly higher number of tillers hill⁻¹ at 30, 60, 90 DAT and at harvest stages was recorded under modified SRI (21.6, 25.6 and 24.2 in *kharif*; and 10.2, 20.2, 23.8 and 22.9 during *rabi*, respectively in two years mean) as compared to normal transplanting during both the years and in mean data. [8]

observed that when a seedling is transplanted carefully at the initial growth stage, the trauma of root damage caused during uprooting is minimized following a rapid growth with short phyllochrons. As regards to irrigation regimes, at 60, 90 DAT and at harvest stages, significantly higher number of tillers (hill^{-1}) were observed with irrigation at saturation throughout lifecycle of crop which was statistically at par with irrigation at 5 cm water level depletion in perched water tube from soil surface (I_2). The increased growth parameters were attributed to higher frequency of irrigation, favourable soil water balance without any wide fluctuations due to better availability of nutrients under both saturation and 5 cm water level depletion in perched water tube from soil surface. These findings are in agreement with [9] Irrigation at 10 cm water level depletion in perched water tube from soil surface (I_3) displayed lowest number of tillers hill^{-1} in all the growth stages during both the years and in mean data. The data pertaining to nutrient levels revealed that, number of tillers hill^{-1} of rice was non-significantly influenced by nutrient levels at majority of stages however, in some stages 125% RDN through inorganic source produced higher number of tillers hill^{-1} in mean data of 60 and 90 DAT in *kharif* and *rabi* transplanted rice in both the years.

Physiological traits: The mean value of leaf area index as influenced by treatments of establishment methods, water regimes and nutrient levels is presented in Table 3. The data pertaining to LAI at 60 and 90 DAT was found significantly higher in normal transplanting (mean data viz., 5.00 and 4.11 in *kharif*; 5.10 and 3.75 during *rabi*, respectively) over modified SRI (mean data viz. 3.60 and 3.06 in *kharif*; 4.27 and 2.99 during *rabi*, respectively). This result can be justified by the lower plant population in modified SRI (16 m^2) as compared to normal transplanting (50 m^2). Lower plant population resulted in lower leaf area per unit area of soil coverage resulting into lower LAI in MoSRI over normal transplanting. Among the water regimes, saturation throughout the lifecycle of crop (I_1) (4.74 and 4.07 in *kharif*; 5.00 and 3.59 in *rabi* mean data, respectively) relished significantly higher LAI at both 60 and 90 DAT. The increased LAI were attributed to higher frequency of irrigation giving rise to higher number of tillers under both saturation and 5 cm water level depletion in perched water tube from soil surface. These findings are in agreement with [10] Lowest value of LAI was observed under the water regime of 10 cm water level depletion in perched water tube from soil surface (I_2). Nutrient levels, did not indicate any significant variation on leaf area index, although numerically higher LAI were observed under 125% RDN through inorganic sources at all the observational stages. Crop growth rate (CGR) was computed from 0-30, 30-60, 60-90 and 90 DAT-at harvest and depicted in Figure 1 and 2. Crop growth rate of rice was increased gradually up to 60-90 DAT and decreased thereafter at 90DAT-at harvest. Establishment methods showed significant variation in crop growth rate and higher CGR was observed under modified SRI over normal transplanting at all the stages of observations except at harvest in *kharif* 2015 and *rabi* 2016-17, where both the establishment methods took same pace of growth in both the seasons and years. In case of water regimes at initial stage of 0-30 DAT no significant effect was recorded; however at 30-60 DAT the CGR was significantly higher in saturation throughout lifecycle during both the years and in mean data in *kharif* season but, in *rabi* rice significant variation was seen only in *rabi* 2015-16. Afterwards during 60-90 DAT and 90 DAT- at harvest water regime did not affected the crop growth rate. Nutrient level did not influence the CGR at any of the observational stage during both the seasons and years as well as in mean data. Interaction effect of establishment methods, water regimes and nutrient levels was not significant at all the stages of seasons and years.

Grain yield: Grain yield of rice was significantly influenced due to irrigation regimes, however it was not affected significantly with establishment methods and variable findings were obtained with nutrient levels during *kharif* and *rabi* seasons in both the years (Table 3). The data pertaining to effect of establishment methods on grain yield of rice indicated that normal transplanting (4.97 t ha^{-1} and 4.67 t ha^{-1} , respectively over mean data of *kharif* and *rabi* seasons of both the years) and modified SRI (5.55 t ha^{-1} and 5.23 t ha^{-1} , respectively in mean data of *kharif* and *rabi* of both the years) did not differed significantly during *kharif* and *rabi* own rice during both the years as well as in mean data. Normal transplanting provided higher plant population m^{-2} which helped to fetch higher grain and straw yield. However, MoSRI establishment method provides better aeration, wider spacing and less competition, which enabled the plants to grow vigorously. Modification in age of seedling of SRI gave a chance to establish the crop little later in the season as per remaining SRI principles. It helped to capture all the essential nutrient elements important for plant growth and there by leading to higher tillering as has been reported earlier by [11] As regards to water regimes saturation maintained throughout the life cycle of transplanted rice recorded the highest grain yield during *kharif* and *rabi* seasons of both the years and in mean data (5.37 and 5.23 t ha^{-1} , respectively in mean data of *kharif* and *rabi* of both the years) and it was at par with irrigation at 5 cm water level depletion in perched water tube from soil surface (5.05 and 4.90 t ha^{-1} , respectively in mean data of *kharif* and *rabi* of both the years). The improved growth performance in the form of number of tillers, LAI and CGR by the crop at saturation and irrigation at irrigation at 5 cm

water level depletion in perched water tube from soil surface (I2) treatments might have been responsible for higher grain yield. When moderate AWD is adopted, soil drying is controlled properly and photosynthesis is not severely inhibited as plants rehydrate overnight, such a regime not only save water but also increase grain yield [12]. Result on grain yield of rice also indicated that among the nutrient levels, 125% recommended dose of nitrogen (RDN) applied through inorganic source recorded the highest grain yield in both the seasons and in their mean data. However, significant differences were observed in *kharif* 2015 and *rabi* 2015-16 and in *rabimean* data. 100% RDN through inorganic source produced comparable grain yield of rice with 125% RDN during both the seasons and years of experimentations. The higher grain obtained could be due to the favourable influence of steady, consistent and adequate availability of nutrients during the required stages of crop growth favouring the production of photosynthates coupled with better partitioning to the sink under higher level of nutrition. These results are in accordance with that of [13].

Table 1: Plant height of rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	Plant height (cm)													
	60 DAT							90 DAT						
	<i>Kharif</i>			<i>Rabi</i>				<i>Kharif</i>			<i>Rabi</i>			
	015	016	mean	015-6	016-7	mean	015-6	015-6	016-7	mean	015-6	016-7	mean	016-7
Establishment methods														
M1	63.0	65.4	64.2	67.6	66.1	66.8	88.2	91.5	89.8	89.2	87.8	88.5	95.8	95.8
M2	67.4	70.9	69.1	70.9	69.4	70.1	88.1	92.8	90.4	92.7	91.2	91.9	95.4	96.3
SEm±	0.35	0.46	0.34	0.83	0.83	0.81	0.43	0.64	0.26	2.13	2.08	1.5	0.30	0.68
CD (P=0.05)	2.14	2.82	2.09	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Water regimes														
I1	69.0	70.1	69.5	71.4	69.9	70.7	90.5	92.5	91.5	96.3	94.9	95.6	96.9	96.9
I2	65.0	67.1	66.0	69.8	68.3	69.1	88.6	91.9	90.2	91.0	89.5	90.3	96.1	96.2
I3	61.6	67.2	64.4	66.5	65.0	65.8	85.3	92.1	88.7	85.5	84.1	84.8	93.8	96.5
SEm±	0.97	0.78	0.49	0.80	0.80	0.59	0.80	0.93	0.24	1.80	1.80	1.41	1.04	0.96
CD (P=0.05)	3.79	NS	1.5	3.14	3.14	2.03	3.13	NS	0.7	7.05	7.06	3.4	NS	NS
Nutrient levels														
N1	65.3	66.9	66.1	69.1	67.6	68.3	88.3	92.0	90.1	91.03	89.47	90.3	96.4	96.4
N2	64.9	68.7	66.8	70.3	68.9	69.6	88.4	92.4	90.4	93.45	92.09	92.8	95.5	96.8
N3	65.4	68.7	67.0	68.3	66.9	67.6	87.7	92.1	89.9	88.33	86.87	87.6	94.8	96.5
SEm±	1.43	0.66	0.78	0.59	0.59	0.57	0.81	0.65	0.45	1.32	1.26	0.89	0.90	0.67
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

M1: Normal transplanting; M2: Modified system of rice intensification;

I1: Saturation;

I2: irrigation at 5 cm water level depletion in perched water tube (PWT) from soil surface;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic; N2: 125% RDN through inorganic;

N3: 50% through inorganic +

50% through organic

Table 2: Number of tillers of rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	Number of tillers (hill ⁻¹)													
	60 DAT							90 DAT						
	<i>Kharif</i>			<i>Rabi</i>				<i>Kharif</i>			<i>Rabi</i>			
	015	016	mean	015-6	016-7	mean	015-6	015-6	016-7	mean	015-6	016-7	mean	016-7
Establishment methods														
M1	8.8	9.3	9.0	8.6	7.7	8.1	9.9	10.6	10.2	9.6	9.1	9.4	9.0	10.3
M2	20.8	22.5	21.6	20.6	19.8	20.2	25.2	26.0	25.6	24.9	22.7	23.8	23.3	25.1
SEm±	0.78	0.24	0.27	0.37	0.36	0.36	0.35	0.75	0.43	0.59	0.43	0.51	0.16	0.49
CD (P=0.05)	4.77	1.49	1.64	2.23	2.20	2.17	2.11	4.59	2.61	3.61	2.60	3.09	0.97	2.96
Water regimes														
I1	16.0	17.6	16.8	16.8	14.7	15.4	20.6	19.9	20.3	19.7	17.0	18.0	18.2	19.5
I2	14.9	16.1	15.5	15.1	13.5	14.3	17.6	18.3	17.9	17.3	15.7	16.5	16.2	17.5
I3	13.5	13.9	13.7	12.6	13.1	12.8	14.4	16.7	15.5	15.5	15.1	15.3	14.1	16.1
SEm±	0.64	0.69	0.36	0.51	0.21	0.27	0.30	0.69	0.35	0.27	0.29	0.25	0.60	0.66
CD (P=0.05)	2.11	2.70	1.42	2.00	0.83	1.08	1.17	2.70	1.35	1.07	1.13	0.99	2.36	2.56
Nutrient levels														

N1	14.7	15.6	15.1	14.8	13.8	14.3	17.2	18.5	17.8	17.3	16.0	16.7	15.9	17.6	16.8	16.9	14.9	15.9
N2	15.3	16.5	15.9	14.7	14.3	14.5	19.1	19.2	19.2	17.7	16.5	17.1	17.1	18.7	17.9	17.2	15.2	16.2
N3	14.4	15.5	14.9	14.2	13.2	13.7	16.3	17.2	16.7	16.7	15.2	16.0	15.4	16.8	16.1	16.3	14.4	15.3
SEm±	0.72	0.69	0.50	0.47	0.14	0.28	0.22	0.17	0.13	0.45	0.11	0.22	0.55	0.46	0.37	0.28	0.35	0.30
CD (P=0.05)	NS	NS	NS	NS	NS	NS	0.87	NS	0.53	0.87	NS	0.53	NS	1.79	1.44	NS	1.79	1.44

M1: Normal transplanting;

M2: Modified system of rice intensification;

I1: Saturation;

I2: irrigation at 5 cm water level depletion in perched water tube

(PWT) from soil surface;

I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic; N2: 125% RDN through inorganic;

N3: 50% through inorganic +

50% through organic

Table 3: Leaf area index and grain yield of rice as influenced by water regimes and nutrient management under transplanting and modified SRI

Treatments	Leaf area index										Grain yield (tha ⁻¹)					
	60 DAT					90 DAT										
	Kharif		Rabi		mean	Kharif		Rabi		mean	Kharif		Rabi		mean	
	015	016	015-	016-		015	016	015-	016-		015	016	015-	016-		
	mean		6	7		mean		6	7		mean		6	7	mean	
Establishment methods																
M1	4.67	5.33	5.00	5.39	4.81	5.10	3.97	4.26	4.11	3.79	3.70	3.75	5.36	5.56	5.46	5.27
M2	3.32	3.88	3.60	4.40	4.15	4.27	3.03	3.10	3.06	3.02	2.95	2.99	4.92	5.01	4.97	4.89
SEm±	0.06	0.12	0.04	0.10	0.10	0.10	0.05	0.08	0.03	0.07	0.07	0.01	0.08	0.12	0.08	0.09
CD (P=0.05)	0.39	0.75	0.23	0.64	0.58	0.61	0.31	0.50	0.21	0.44	0.43	0.08	NS	NS	NS	NS
Water regimes																
I1	4.63	4.86	4.74	5.22	4.78	5.00	4.32	3.82	4.07	3.63	3.54	3.59	5.50	5.59	5.55	5.48
I2	3.95	4.63	4.29	4.74	4.34	4.54	3.29	3.63	3.46	3.30	3.22	3.26	5.18	5.27	5.23	5.05
I3	3.40	4.32	3.86	4.73	4.33	4.53	2.89	3.58	3.23	3.29	3.21	3.25	4.74	4.99	4.87	4.70
SEm±	0.07	0.09	0.11	0.08	0.10	0.10	0.11	0.15	0.06	0.07	0.07	0.02	0.10	0.19	0.10	0.15
CD (P=0.05)	0.29	0.38	0.45	0.34	0.38	0.40	0.45	NS	0.23	0.29	0.29	0.08	0.39	NS	0.41	0.57
Nutrient levels																
N1	3.95	4.36	4.16	4.92	4.50	4.71	3.52	3.69	3.60	3.43	3.34	3.38	5.16	5.32	5.24	5.10
N2	4.31	4.81	4.56	5.09	4.66	4.88	3.73	3.79	3.76	3.55	3.46	3.50	5.31	5.36	5.34	5.23
N3	3.72	4.63	4.18	4.67	4.28	4.47	3.25	3.55	3.40	3.25	3.17	3.21	4.96	5.17	5.06	4.79
SEm±	0.16	0.15	0.08	0.08	0.07	0.08	0.16	0.14	0.13	0.06	0.12	0.09	0.06	0.22	0.10	0.12
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.23	NS	NS	0.43

M1: Normal transplanting;

M2: Modified system of rice intensification;

I1: Saturation;

I2: irrigation at 5 cm water level depletion in perched water

tube (PWT) from soil surface;

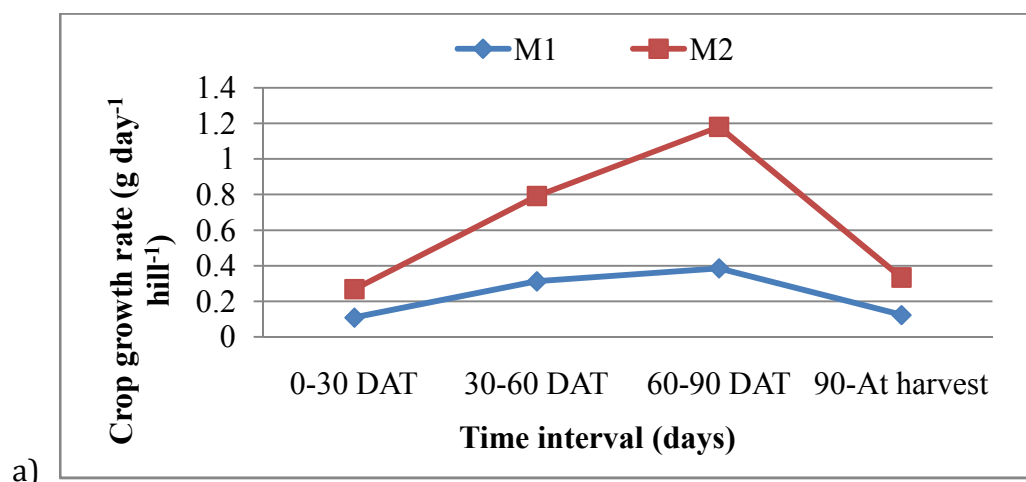
I3: irrigation at 10 cm water level depletion in PWT from soil surface;

N1: 100% RDN through inorganic;

N2: 125% RDN through inorganic;

N3: 50%

through inorganic + 50% through organic



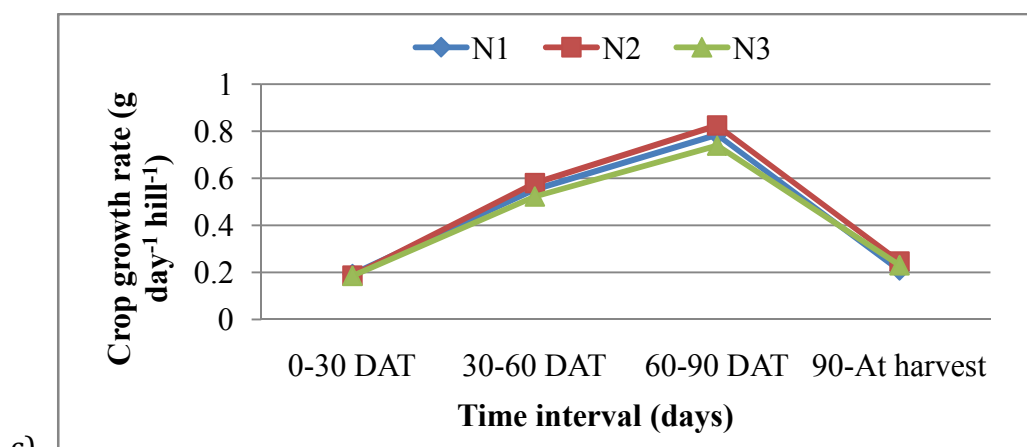
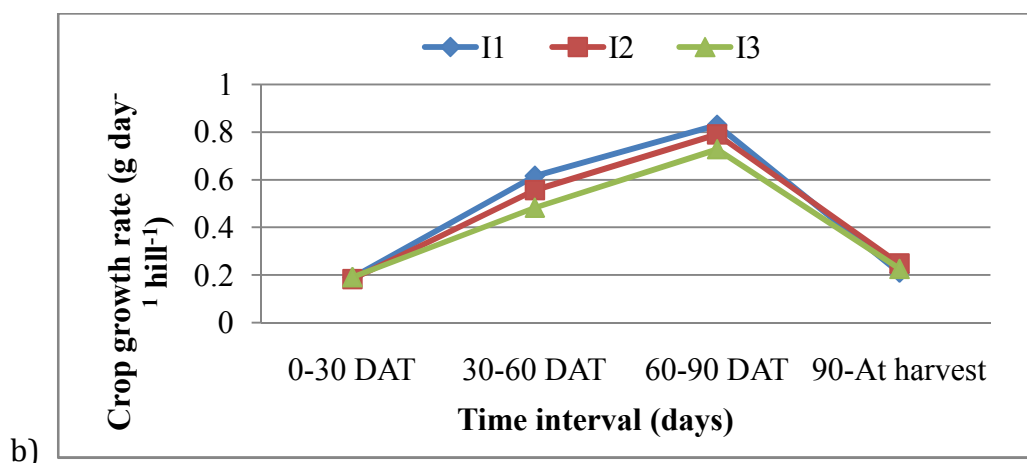
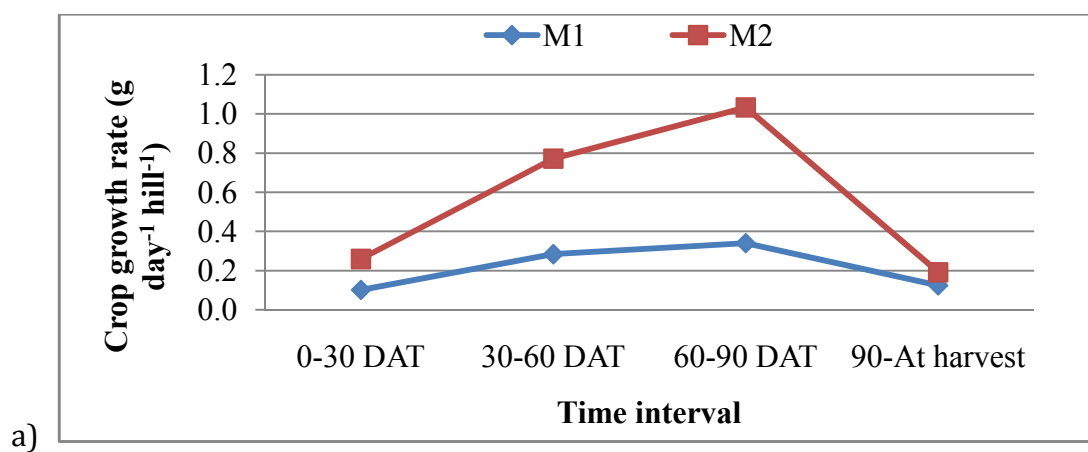


Figure 1: Crop growth rate of rice as influenced by (a) establishment methods, (b) irrigation regimes and (c) nutrient levels (*kharif* mean data)



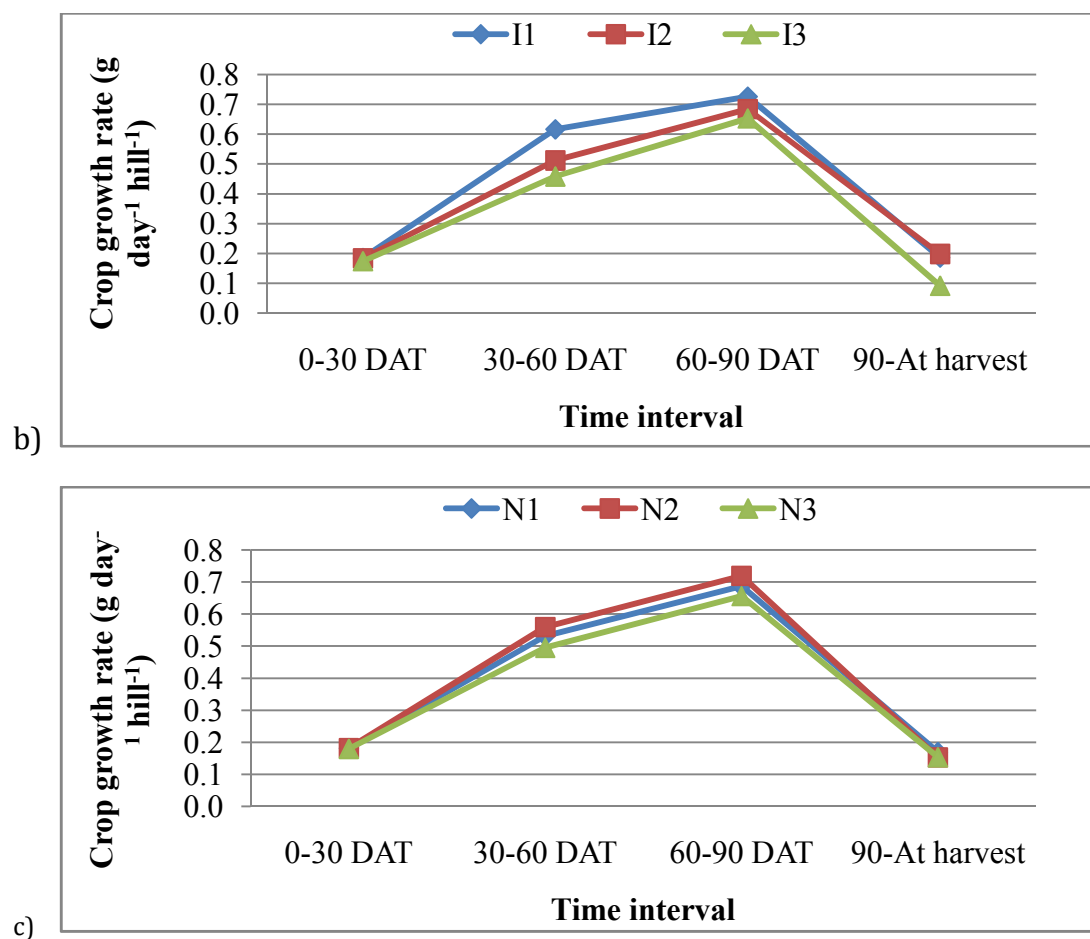


Figure 2: Crop growth rate of rice as influenced by (a) establishment methods, (b) irrigation regimes and (c) nutrient levels (*rabi* mean data)

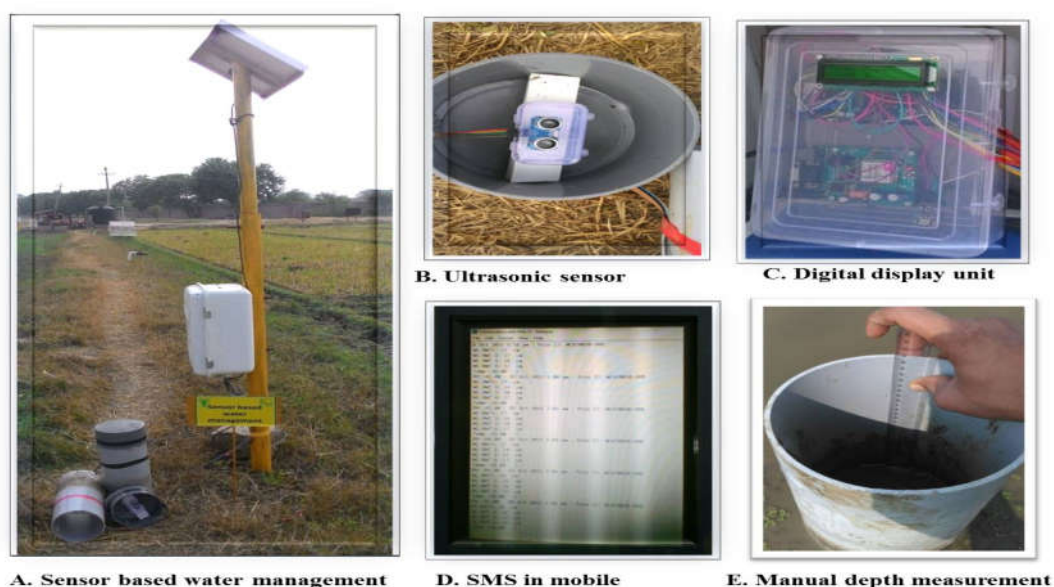


Plate 1: Ultrasonic water level measurement tools and devices

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CoA, IGKV, Raipur

Dear

1. It is in reference to your article entitled "**Influence of establishment methods, water and nutrient management on productivity of rice-rice cropping system under transplanted**" Authored by **Lekh Ram Sahu, R. Mahender Kumar and M.C. Bhambri** registered under reference JAI MS-892
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