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RESEARCH ARTICLE

IMPACT OF INORGANIC AND ORGANIC NUTRIENT SOURCES AND LEVELS ON YIELD, N UPTAKE AND ITS USE EFFICIENCY OF RICE UNDER SRI AND CONVENTIONAL SYSTEM OF CULTIVATION

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ABSTRACT

Field experiments were conducted during Kharif season for two consecutive years of 2008-09 and 2009-10 with rice at Experimental Farm, Annamalai University, Annamalai Nagar (Tamil Nadu), India on deep clay soil (*Typic Haplusterts*) to study the impact of inorganic and organic nutrient sources and levels on yield, N uptake and its use efficiency in rice under SRI and conventional system of cultivation (CSC). The experiments were conducted in split plot design with two methods of cultivation (SRI and conventional) as main plot treatments and twelve sub plot treatments viz., three inorganic alone applied treatments (100 % RDF, STCR based RDF, LCC based N (Recommended dose of fertilizer P&K without basal N), nine integrated nutrient management treatments (STCR based IPNS , based on 100 % RDF two levels of fertilizer nitrogen (75and 50 per cent) in combination with two levels of N (25 and 50 per cent) through different organic manures *viz.,* Farmyard manure (FYM), Green manure (GM), Pressmud (PM), Poultry manure (POM) as sub plot treatments. The results revealed that the highest grain yield (4661.1 kg ha^{-1}) and straw yield (6708.6 kg ha^{-1}), higher N uptake in grain (46.3 kg ha^{-1}) and lower N uptake in straw (42.5 kg ha^{-1}) in SRI as compared to CSC(4201.5,6367kg ha^{-1} and 39.2,46.1kg ha^{-1},respectively),and higher N use efficiency in SRI (ANUE-24.7 %, NER-134.7 kg kg^{-1}, NHI- 49.8 % and NP-1.00 kg $kg^{-1}day^{-1}$) over CSC(22.5 %,130.6 kg kg^{-1},43.9 and 0.97 kg $kg^{-1}day^{-1}$, respectively. Yield of grain (6507.4, 5774.1 kg ha^{-1}) and straw (8211.8, 7643.7 kg ha^{-1}), N uptake in grain (68.3,56.8 kg ha^{-1}) and straw (54.1,58.7 kg ha^{-1}), and N use efficiency(ANUE-45.2,40.1%,NHI- 55.1,48.5 %) were found be significantly higher and lower NER-120.3,116.2 kg kg^{-1}, NP-0.89,0.86 kg $kg^{-1}day^{-1}$ due to the application of STCR based IPNS (144:64:60 kg NPK ha^{-1} along with 12.5 t ha^{-1} FYM and bio-fertilizers *viz., Azospirillum* and *PSB)* treatment under SRI and conventional system of cultivation, respectively. N uptake showed highest significant positive relationship with grain and straw yields, and ANUE, NHI and negative relationship with NER and NP under both system of cultivation. Hence, the STCR based IPNS (144:64:60 kg NPK ha^{-1} along with 12.5 t ha^{-1} FYM and bio-fertilizers *viz., Azospirillum* and *PSB*) can be regarded as the best nutrient management practice under SRI and conventional system of cultivation for enhancing rice yield, N uptake and use efficiency in Cauvery deltaic zone of Tamilnadu.

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INTRODUCTION

Rice is the most important cereal crop grown throughout the world as a premier food crop over an area of 153 m ha with an average annual production of 600 mt. It is cultivated in more than 114 of the 193 countries in the world especially in Asian countries where more than 90 % of the world's rice is produced and consumed (FAO, 2008). In India, rice cultivated in an area of 44 m ha with an average production of 90 mt with the productivity of 2.0 t ha^{-1}. Demand for rice is increasing every year and it is estimated that in 2025 the requirement would be 140 mt. In Tamilnadu, the cultivated area of rice is around 2.08 m ha with a production of 7.4 mt and productivity of 3.5 t ha^{-1}. Ever increasing and nonstop growth of world population requires efficient, sustainable and eco-friendly sound input management practices to meet the demand of rice now and then. Although, the sustainability of

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rice production is challenged and threatened by declining water availability, soil fertility and productivity and hence, the security and livelihood of rice producers and consumers are in question. Therefore, researchers are looking for ways and means to decrease water and fertilizer use and increase the use efficiency of inputs.

Several factors influence the growth and yield of rice. One of the most important factors is N fertilization. It is one of the most yield limiting nutrients or key to achieve optimum grain yield in low land rice (Samonte *et al.,* 2006). Also it is required at much higher rate than other primary nutrients like phosphorus and potassium. Rice is the biggest user of N fertilizer consuming one third of the total N consumption in the world. Thus, nitrogen is the most critical input that limits rice production. In lowland rice nitrogen is subject to great losses through ammonia volatilization, denitrification, leaching and runoff which result to low N recovery efficiency in low land rice. The recovery of fertilizer N applied to rice seldom exceeds 30 – 40 per cent (Fageria and Baligar, 2001). Role of nitrogen in plants are innumerable such as dry matter production through enhancing photosynthetic activity which in turn determines the growth and tillering (which decides the number of potential panicles). It also plays a significant role in formation and death of tillers as well as differentiation and degeneration of spikelets, carbohydrate accumulation in culms and leaf sheaths, and grain filling. There are various sources and forms of N utilized by rice plants. The major sources are chemical fertilizers and soil N through organic matter mineralization.

The most vital problem in achieving high yields is question that how to improve the N absorption at different stages of crop growth and development. To use soil and applied N efficiently and avoid losses, it is essential to develop better ways to find the optimum level of N needed by rice to avoid potential yield loss (Prudente *et al*., 2008). Optimum level and timely N application are the pioneer technique of nitrogen management in rice for efficient utilization of applied N sources. Apart from these practices, N use efficiency can be enhanced by cultivation methods and selection of more appropriate sources thereby reducing losses and enhancing uptake efficiency of N which makes the rice production system sustainable and economically viable. Nitrogen use efficiency meant that N accumulated in the plant as uptake efficiency and N utilized for grain production as utilization efficiency (Mandana Tayafe *et al*., 2011). Use of fertilizers in conventional rice production methods had been reported to have poor nutrient use efficiency due to excessive use of water and readily available nature of nutrients in fertilizers, where the replacement of fertilizers by organic addition to reduce or avoid nutrient losses may not be advisable which duly affect the production capacity of soil and crop. The system of rice intensification (SRI) is an emerging technology, which could make rice production more efficient not only saving water and also other production sources (Rao *et al*., 2007). Buildup of soil organic matter and acceleration of microbial activity by keeping the rice field both in aerobic and anaerobic condition along with proactive interactions between the plant, soil, water and nutrient is possible under SRI (Tzudir and Ghosh, 2014). Thus, this study was conducted in Cauvery deltaic region, an intensively cultivated area where rice is the principal crop to evaluate the impact of varying levels and sources of N on the yield, relationship of N uptake with yield of rice and N use efficiency under SRI and conventional system of cultivation consecutively for two years.

MATERIALS AND METHODS

Field experiments were conducted in kharif season during 2008-09 and 2009-10 to study the effect of different levels of inorganic and organic nutrient sources on yield, N uptake and nitrogen use efficiency of rice under SRI and conventional methods of cultivation at Experimental Farm, Annamalai University, Annamalai Nagar (Tamilnadu), India. The experimental site is situated at 11°24' N latitude and 74°44' E longitude at an altitude of + 5.79 m above mean sea level in the southern part of India. Temperature and relative humidity during the experiment ranged from 28.5 to 38.5 ºC and 78.0 to 96.0 %, respectively. Soil of the experimental farm is classified as *Typic Haplusterts* (clay). The soil of the experimental fields are deep clay (43.6, 44.2 % clay), bulk density of 1.32, 1.33 Mg m^{-3}, with a water holding capacity of 36.5 per cent. The soil was neutral in reaction (pH 7.3, 7.5) and electrical conductivity was 0.35 and 0.37 dSm^{-1} respectively. The organic carbon content was 4.6 and 5.8 g kg^{-1}, CEC of 20.7 and 21.4 c mol (P^+) kg $^{-1}$ with low available N (227, 230 kg ha^{-1}), medium available P (19.9,21.3 kg ha^{-1}) and high available K (276,281 kg ha^{-1}). The experiments were conducted in split plot design with two methods of cultivation (SRI and conventional) as main plot treatments and twelve sub plot treatments [Three inorganic alone applied treatments viz.,T_1-100 % RDF(150:50:50 kg NPK ha^{-1}),T_2 - STCR Based RDF (144:64:60 kg NPK ha^{-1}), T_3-LCC Based N (Recommended Dose of Fertilizer P&K without basal N), Nine integrated nutrient management treatments viz.,T_4-STCR based integrated plant nutrient supply(144:64:60 kg NPK ha^{-1} along with 12.5 t ha^{-1} FYM and bio-fertilizers *viz*., *Azospirillum* and *PSB* as soil treatment), T_5 -75% fertilizer N +25% organic N (FYM), T_6 -75% fertilizer N +25% organic N (GM), T_7 - 75% fertilizer N + 25% organic N (PM), T_8 - 75% fertilizer N + 25% organic N (POM), T_9 - 50% fertilizer N + 50% organic N (FYM), T_{10} - 50% fertilizer N + 50% organic N (GM), T_{11} - 50% fertilizer N + 50% organic N (PM) and T_{12} - 50% fertilizer N + 50% organic N (POM)] and replicated thrice. The 100 % recommended N, P_2O_5 and K_2O for paddy was 150:50:50 kg ha^{-1} and the variety used was CO-43. The grain and straw yields were recorded from the net plot area and expressed in kg ha^{-1} at 14 per cent moisture level. The nutrient content in grain and straw were determined by the micro-Kjeldal di-acid digestion method. N uptake and equation for calculating N use efficiencies under various treatments are given in Table 1.

RESULTS AND DISCUSSION

Rice yield

The grain and straw yields of rice were significantly influenced by the application of N either through inorganics alone or in combination with organics in SRI and conventional system of cultivation as evidenced from pooled data (Table 2).

Yields of rice grain (4661.6, 4201.5 kg ha^{-1}) and straw (6708.6, 6367 kg ha^{-1}) were increased 10.95 % and 5.36 % in SRI over conventional method of cultivation. The benefits that are attributed higher towards grain and straw yields in SRI method of cultivation is due to planting single seedling, reducing competition between the multiple seedlings, overcoming the transplantation shock (Uphoff, 2003), square planting which is not only facilitate the cultivation practices but also favours better aeration, intermittent irrigation that creates favorable soil physical, physiochemical and biological properties making the plant to grow under non-hypoxic condition with deeper rooting depth (Barrison, 2002). However, in the present investigation such higher grain and straw yields might be due to fact that the SRI management practices led to more productive phenotypic characteristics with conducive soil conditions in getting full genetic potential for tillering, shoot growth, and grain filling. Thus, the grain and straw yields of rice were increased in SRI over conventional system of cultivation significantly in both the years.

Among nutrient levels and sources, the highest grain (6507 and 5774.1 kg ha^{-1}) and straw (8211.8 and 7643.9 kg ha^{-1})yields were registered in the treatment T_4- STCR based IPNS (144:64:60 kg NPK ha^{-1} along with 12.5 t ha^{-1} FYM and bio-fertilizers *viz*., *Azospirillum* and *PSB* as soil treatment) and it was on par with application of 75 % fertilizer N + 25 % N through FYM (T_5) registered 6204.6, 5505.9 kg ha^{-1} and 8076.7,7518.5 kg ha^{-1} of grain and straw yields respectively under SRI and conventional system of cultivation compared to the application of inorganic sources alone or other combination with organics nutrient levels and sources tried. This might be attributed due to balanced fertilization of nutrients based on STCR values and integration of inorganic and organic sources (FYM) combined with bio-fertilizers such as *Azosprillum*, which is heterotrophic and associative in nature able to fix 20 to 40 kg ha^{-1} of N and also produce growth promoting substances (Mishra *et al*., 2013). Thus, facilitated the nutrient availability throughout the crop development period and enhanced N uptake resulting more synthesis of photosynthates and a positive source to sink relationship.

Table 1. Methods used for calculating nutrient uptake and use efficiency

Nutrient uptake	(Nutrient content % X Dry matter production) /100
Agronomic N use efficiency (ANUE)	Grain yield kg ha^{-1} X Amount of nutrient applied kg ha^{-1} (Yoshida *et al*.,1981)
Nutrient Efficiency Ratio (NER)	Dry matter yield at harvest kg ha^{-1} / N accumulation at harvest kg ha^{-1} (Devasanapathy *et al.,* 2008)
Nutrient Harvest Index (NHI)	Nutrient uptake in economic yield kg ha^{-1}/ Nutrient uptake in biological yield kg ha^{-1} (Quanbao *et al.,* 2007)
Nutrient productivity (NP)	(Biological yield kg ha^{-1} / Total crop N uptake kg ha^{-1}) / Total duration of the crop in days (Devasanapathy *et al.,* 2008)

Table 2. Impact of inorganic and organic nutrient sources and levels on grain and straw yield of rice (Pooled mean of two years)

Parameters	Grain yields kg ha^{-1}			Straw yields kg ha^{-1}		
Treatments	SRI	CSC	Mean	SRI	CSC	Mean
T_1 -100% RDF	4607.2	4188.4	4397.8	6792.9	6478.1	6635.5
T_2 - STCR Based RDF	4693.2	4266.6	4479.9	6875.2	6556.6	6715.9
T_3 - LCC Based N (RDF P&K)	3178.8	2908.4	3043.6	5231.1	5246.9	5239.0
T_4 - STCR Based IPNS	6507.4	5774.1	6140.7	8211.8	7643.7	7927.7
T_5 -75% fertilizer N +25% organic N (FYM)	6204.6	5505.9	5855.2	8076.7	7518.5	7797.6
T_6 -75% fertilizer N +25% organic N (GM)	5654.2	5022.3	5338.3	7639.3	7118.3	7378.8
T_7 - 75% fertilizer N + 25% organic N (PM)	4859.4	4390.4	4624.9	7002.8	6637.3	6820.1
T_8 - 75% fertilizer N + 25% organic N (POM)	4966.6	4483.0	4724.8	6967.8	6597.5	6782.6
T_9 - 50% fertilizer N + 50% organic N (FYM)	4061.8	3692.6	3877.2	6310.0	6017.6	6163.8
T_{10} - 50% fertilizer N + 50% organic N (GM)	3841.7	3492.5	3667.1	6232.4	5943.7	6088.1
T_{11} - 50% fertilizer N + 50% organic N (PM)	3658.5	3325.9	3492.2	5573.1	5314.8	5444.0
T_{12} - 50% fertilizer N + 50% organic N (POM)	3705.4	3368.5	3537.0	5589.8	5330.7	5460.3
Mean	4661.6	4201.5	4431.6	6708.6	6367.0	6537.8
	M	S	M x S	M	S	M x S
SEd±	71.73	152.0	218.0	53.26	139.9	196.8
CD (P=0.05)	308.6	306.4	NS	229.2	282.0	NS

Table 3. Impact of inorganic and organic nutrient sources and levels on N uptake of rice (Pooled mean of two years)

Parameters	N uptake (Grain) kg ha^{-1}			N uptake (Straw) kg ha^{-1}		
Treatments	SRI	CSC	Mean	SRI	CSC	Mean
T_1 -100% RDF	46.1	39.3	42.7	44.0	47.5	45.7
T_2 - STCR Based RDF	46.9	40.0	43.5	44.6	48.1	46.3
T_3 - LCC Based N (RDF P&K)	28.5	24.5	26.5	28.0	31.5	29.8
T_4 - STCR Based IPNS	68.3	56.8	62.5	54.1	58.7	56.4
T_5 -75% fertilizer N +25% organic N (FYM)	64.5	53.7	59.1	53.2	57.7	55.4
T_6 -75% fertilizer N +25% organic N (GM)	57.7	48.1	52.9	50.1	54.3	52.2
T_7 - 75% fertilizer N + 25% organic N (PM)	48.6	41.2	44.9	45.6	49.3	47.5
T_8 - 75% fertilizer N + 25% organic N (POM)	50.7	42.9	46.8	45.5	49.2	47.3
T_9 - 50% fertilizer N + 50% organic N (FYM)	39.0	33.3	36.1	38.6	41.7	40.2
T_{10} - 50% fertilizer N + 50% organic N (GM)	36.9	31.5	34.2	38.1	41.2	39.7
T_{11} - 50% fertilizer N + 50% organic N (PM)	34.4	29.4	31.9	34.1	36.8	35.4
T_{12} - 50% fertilizer N + 50% organic N (POM)	34.9	29.8	32.3	34.2	36.9	35.5
Mean	46.3	39.2	42.8	42.5	46.1	44.3
	M	S	M x S	M	S	M x S
SEd±	0.539	1.554	2.376	0.533	1.402	1.192
CD (P=0.05)	2.324	3.135	NS	2.301	2.83	NS

Table 4. Impact of inorganic and organic nutrient sources and levels on N use efficiency of rice (Pooled mean of two years)

Parameters	Agronomic N use efficiency (%)		Nitrogen efficiency ratio (kg kg^{-1})		Nitrogen harvest index (%)		Nitrogen Productivity (kg kg^{-1} day^{-1})	
Treatments	SRI	CSC	SRI	CSC	SRI	CSC	SRI	CSC
T_1	30.7	27.9	126.6	123.0	50.4	44.6	0.94	0.91
T_2	32.6	29.7	126.4	122.9	50.6	44.7	0.94	0.91
T_3	26.5	24.3	152.1	143.4	47.0	43.5	1.13	1.07
T_4	45.2	40.1	120.3	116.2	55.1	48.5	0.89	0.86
T_5	41.4	36.7	121.4	117.0	54.1	47.5	0.90	0.87
T_6	37.7	33.5	123.5	118.6	52.8	46.2	0.91	0.88
T_7	32.4	29.3	125.9	121.9	50.9	44.8	0.93	0.90
T_8	33.1	29.9	124.2	120.4	52.0	45.9	0.92	0.89
T_9	27.1	24.6	133.7	129.5	49.6	43.7	0.99	0.96
T_{10}	25.6	23.3	134.4	129.9	49.4	43.3	1.00	0.96
T_{11}	24.4	22.2	134.9	130.7	49.6	43.7	1.00	0.97
T_{12}	24.7	22.5	134.7	130.6	49.8	43.9	1.00	0.97
Mean	31.8	28.7	129.8	125.3	50.9	45.0	0.96	0.93

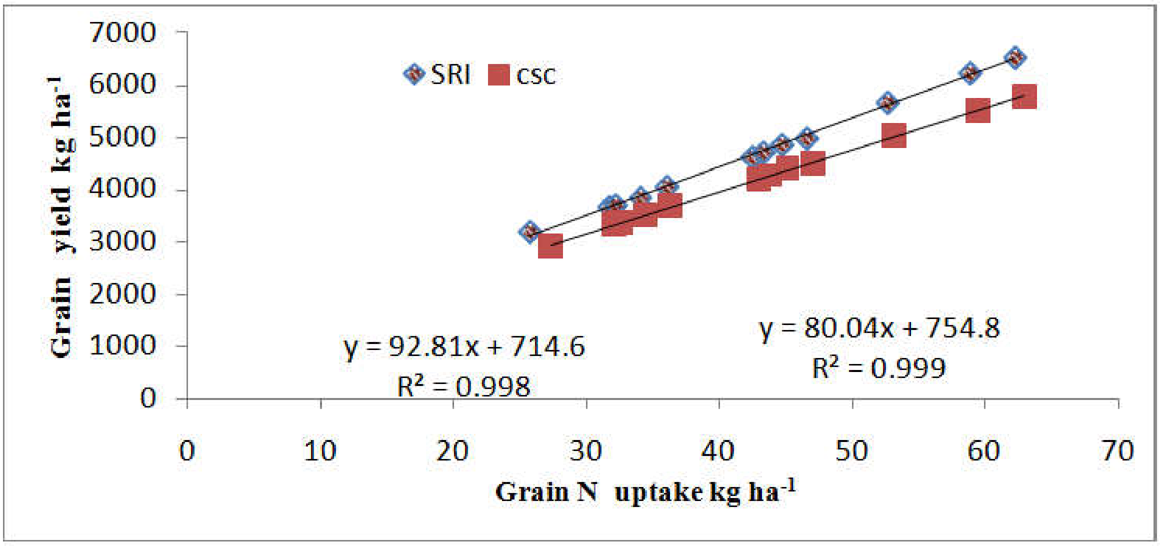

Fig. 1. Linear relationship between grain yields with N uptake

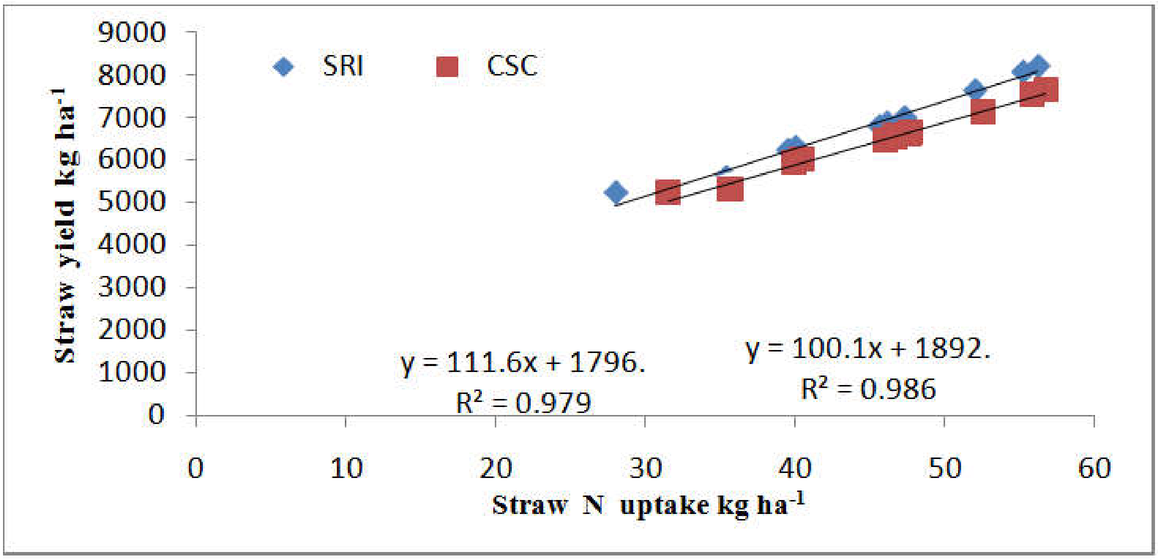

Fig. 2. Linear relationship between straw yields with N uptake

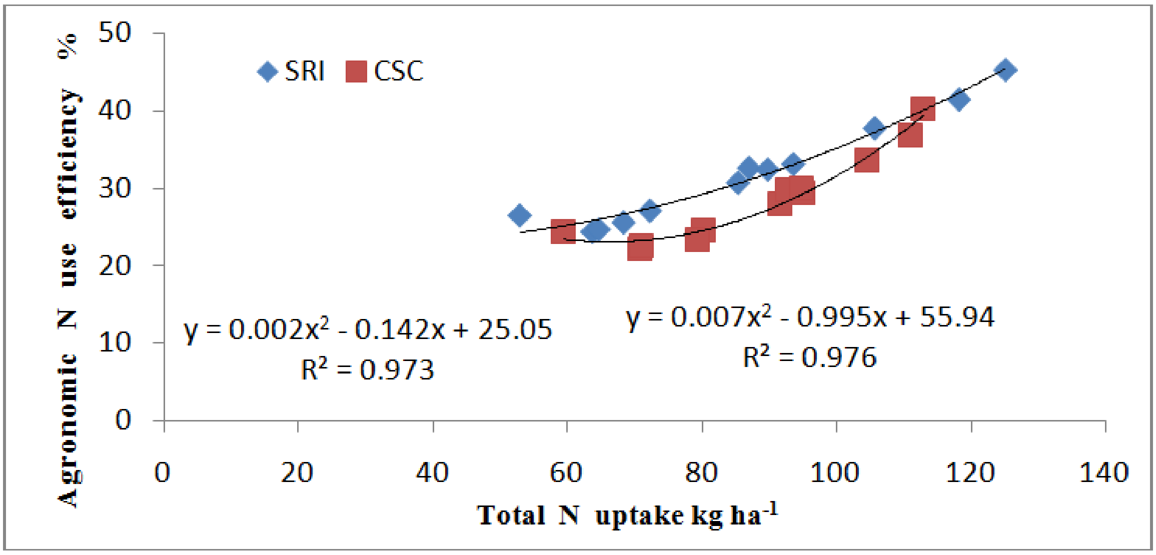

Fig.3. Relationship (Polynomial) between ANUE with N uptake

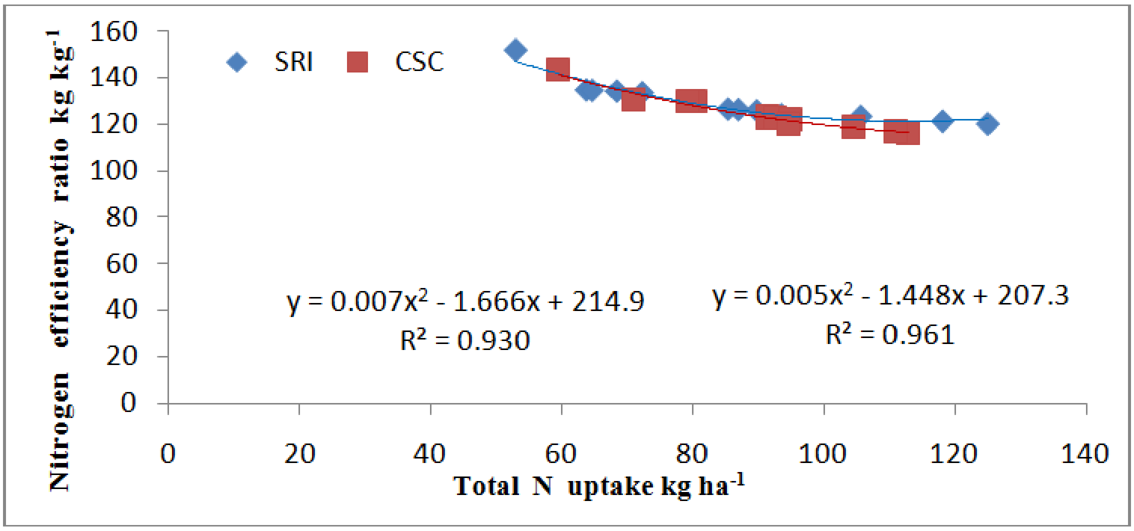

Fig.4. Relationship (Polynomial) between NER with N uptake

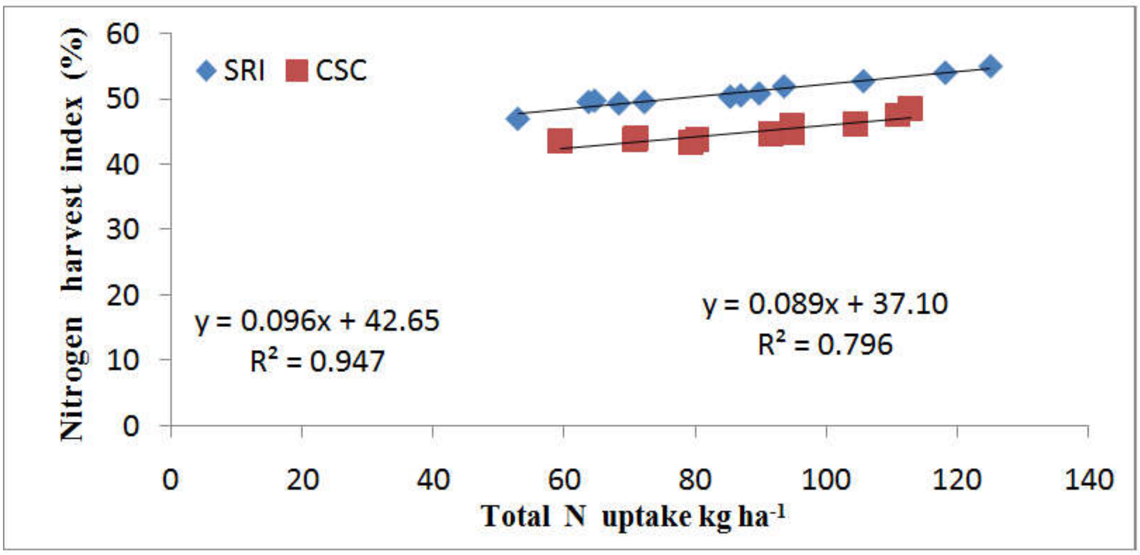

Fig. 5. Linear relationship between NHI with N uptake

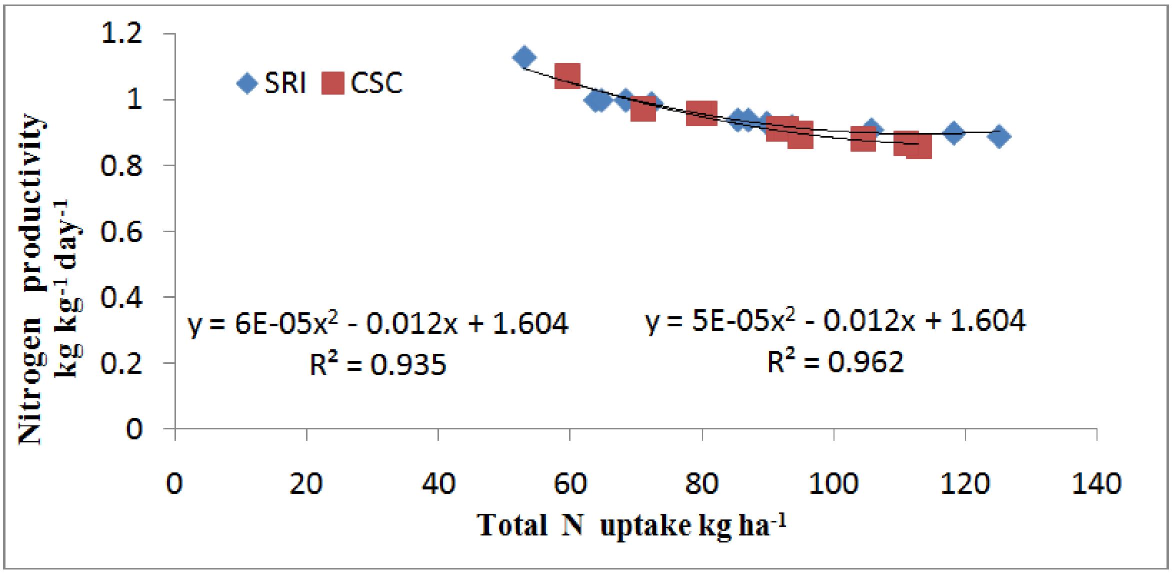

Fig. 6. Relationship (Polynomial) between NP with N uptake

The appliance of farm yard manure as one of the best components of integrated nutrient management might caused an important effect on release percentage of soil available nitrogen (Jagtap *et al*., 2005). Further, zinc and sulphur the yield limiting nutrients; significantly affect the yield of rice are provided by FYM substitution instead of supplying additional quantities of NPK to increase the yield (Anand Swarup, 2010).Whereas the lowest grain (3178.8, 2908.4 kg ha^{-1}) and straw (5231.1, 5246.9 kg ha^{-1}) yields were registered by the treatment received application of N through LCC based N without basal N and recommended dose of P and K (T_3). This might be due to less number of tillers produced, comparatively weaker root and shoot stimulatory effects which resulted in lower uptake of nutrients at different developing stages of crop growth irrespective of cultivation methods compared to higher levels inorganic fertilizer N combined with organic manure, and / or 100 % RDF and STCR based RDF of NPK in splits facilitated the initial growth and development of crop with added fertilizer nutrients which was lack in poorly performed treatment T_3. This findings of the present study was in conformity with Yoshida *et al*. (1977) who stated that N obtained at early growth stages resulted in the production of more straw yield, and with those of Kumari *et al.* (2000), and Pramanik and Bera (2015) reported that yield obtained by the application of inorganic sources alone was lower than with the combined application of chemical fertilizers and organic materials together. The treatments applied followed the order $T_4>T_5>T_6>T_8>T_7>T_2>T_1>T_9>T_{10}>T_{12}>T_{11}$ and T_3 in both methods of cultivation. The amount of N absorbed by grain and straw of rice had high correlations with N uptake (Fig 1 & 2) due to different nutrient management practices tested. And it can be described by the relationship given in Eq.1-2 (grain yield in SRI and CSC) and Eq.3-4 (straw yield in SRI and CSC) given below,

$Y=92.81x+714.6$; $R^2=0.998$ ………………………………...(1)

$Y=80.04x+754.8$; $R^2=0.999$ ………………………………...(2)

$Y=116.6x+1796$; $R^2= 0.979$ ………………………………...(3)

$Y=100.1x +1892$; $R^2=0.986$ ………………………………...(4)

Where Y= yield (grain / straw) kg ha^{-1}and x= N uptake (grain /straw) kg ha^{-1}.

The interaction effects of cultivation methods and nutrient management practices were found to be non significant on rice yield.

Nitrogen uptake

As evidenced from pooled data in table. 3, 18.11 % higher grain uptake was observed in SRI (46.3 kg ha^{-1}) over conventional method of cultivation (39.2 kg ha^{-1}) but 8.47 % higher straw N uptake was registered by conventional method of cultivation (46.1 kg ha^{-1}) as compared to SRI (42.5 kg ha^{-1}). The uptake of nutrients is a function of the nutrient supply from the soil, growth duration and cultural practices which in turn affects the concentration of N in different parts of plant and dry matter accumulation. These factors are mutually independent i.e. healthy crop depends on better nutrient supply and adequate nutrient availability produces higher dry matter production which facilitated the higher absorption and translocation of nutrient from soil to plant resulting in higher nutrient uptake in grain in SRI than conventional method of cultivation which recorded higher straw N uptake but lower grain uptake due to lack of N accumulation during grain filling stage. The present study results are in line with those of Jayadeva (2007) who reported that loss of nutrients under SRI is generally low and efficiency of the nutrient was high, which resulted in higher N uptake compared to conventional system which is under continuous submergence of water. Among the nutrient levels and sources, it is evidenced from the pooled data the N uptake (Table 3) was significantly higher in grain and straw in the application of STCR based IPNS (144:64:60 kg NPK ha^{-1} along with 12.5 t ha^{-1} FYM and bio-fertilizers *viz*., *Azospirillum* and *PSB* as soil treatment) treatment under

SRI and conventional methods of cultivation (68.3,56.8 and 54.1,58.7 kg ha^{-1}) compared to other INM combinations, and inorganic alone applied treatments (T_1,T_2 and T_3). Similar to the grain and straw yields, next to T_4, the N uptake was increased significantly with combined application of 75 % inorganic N and 25 % N through FYM (T_5) and or GM (T_6) with grain and straw N uptake of 64.5, 53.7 and 53.2, 57.7 kg ha^{-1}; 57.7, 48.1 and 50.1, 54.3 kg ha^{-1}, respectively and other treatments tested were followed the same order similar to that of grain and straw yields. The present investigation results are in consonance with those of Mamata Begum *et al*. (2007) and Singh *et al*. (2008). They reported that the increase in N uptake was probably due to the enhanced soil atmospheric conditions, which encouraged the better proliferation of root system and facilitated synchrony between requirement and provision, which in turn drew more nutrients from larger area and greater depth. Hence, in this study higher uptake of N might be attributed to the positive effect of substitution of organics 100 per cent with STCR based RDF along with bio-fertilizers or 25 per cent FYM with 75 per cent RDF with improved N content of the soil through greater microbial activity led to enhanced N mineralization and accumulation of higher amount of N in soil, further facilitated continuous availability to crop and enhanced the uptake significantly. The above said processes were lack or not realized under the application of least performed treatment T_3 (LCC based N application with RDF of P & K and without basal N) which recorded lowest N uptake in grain and straw 28.5,24.5 and 28.0,31.5 kg ha^{-1} under SRI and conventional system of cultivation, respectively.

N use efficiency

It is evidenced from the pooled data that the N use efficiency (Table 4) was significantly enhanced by SRI method and also registered 10.87,3.59,11.86 and 3.22 per cent higher values of use efficiency indices viz., agronomic nitrogen use efficiency (ANUE) of 31.8 % , nutrient efficiency ratio (NER) of 129.8 kg kg^{-1},nutrient harvest index (NHI) of 50.9 % and nutrient productivity (NP) of 0.96 kg kg^{-1}day^{-1} over conventional method of cultivation which recorded 28.7%,125.3 kg kg^{-1},45.5 % and 0.93 kg kg^{-1}day^{-1} of ANUE,NER,NHI and NP, respectively. Nutrient use efficiency has been comprehensively used as a measure of competence of a plant to acquire and utilize nutrients for economic and biological yield. The increase in biomass production, root structure and root distribution patterns have been found to be important adaptive mechanism for acquiring nutrients. Greater NUE at lower levels is common because of efficient utilization of nutrients (Fageria, 1992). Nitrogen use efficiency by flooded rice is less than 50% (Fageria and Baligar, 2001, 2005), it can be improved by adequate management practices (Use of N fertilizers in higher levels, form and methods of application). Further, the uptake efficiency and utilization efficiency were realized better in SRI this would have ascribed due to the benefits attributed by agronomic principles of SRI method of cultivation resulted in more dry matter production and N uptake over conventional method of cultivation which under prolonged submergence leads to loss of N through leaching, volatilization etc., which are inevitable. Similar loss of N under lowland conditions was reported by Salem *et al.* (2011), Fageria *et al*. (2014). Among nutrient management practices tried, application of STCR based IPNS registered the highest AUE and NHI (45.2, 40.1 and 55.1,48.5 %) and lowest NER and NP (120.3,116.2 kg kg^{-1} and 0.89,0.86 kg kg^{-1} day^{-1}) and it was followed by the combined application of 75% fertilizer N + 25 % organic N through FYM (T_5)by registering 41.4,36.7 and 54.1,47.5 % of ANUE and NHI and 121.4,117.0 kg kg^{-1} and 0.90,0.87 kg kg^{-1} day^{-1}, respectively (Table 4). These results might be attributed due to enhanced availability of applied nutrients from different sources and levels to the crop and its captivating power of converting the nutrients from source to sink helped in improving the efficiency by the crop. Results indicated that the capacity of yield increase per kilogram pure N declined with increasing N application in AUE and NHI (Fig. 3 & 5) in contrary to NER and NP where the capacity of yield increase per kilogram pure N increased in fact with decreasing N application (Fig. 4 & 6). Thereby, results proved scientifically that there was no use of more or less application of N and better to keep use balanced or STCR based nutrient levels.Further, the linear and polynomial trend analysis revealed that the grain and straw N uptake of rice is increasing with increase in N use efficiency in both methods of cultivation under INM practices. It can be described through the following equations,

Relationship (Polynomial) between ANUE with total N uptake (grain and straw kg ha^{-1})

$Y=0.002x^2 – 0.142 x + 25.05; R^2=0.973$ …………………...(5)

$Y=0.007x^2 – 0.995 x + 55.94; R^2=0.976$ …………………...(6)

Where Y= Agronomic N use efficiency (%) and x= Total N uptake (kg ha^{-1})

Relationship (Polynomial) between NER with N uptake (grain and straw kg ha^{-1})

$Y=0.007x^2 – 0.1666 x + 214.9; R^2=0.930$ ………………….(7)

$Y=0.005x^2 – 0.1448 x + 207.3; R^2=0.961$ ………………….(8)

Where Y= Nitrogen efficiency ratio (kg kg^{-1}) and x= Total N uptake (kg ha^{-1})

Linear relationship between NHI with N uptake (grain and straw kg ha^{-1})

$Y=0.096x +42.65; R^2=0.947$ ………………………………..(9)

$Y=0.089x + 37.10; R^2=0.796$ ……………………………...(10)

Where Y= Nitrogen harvest index (%) and x= Total N uptake (kg ha^{-1})

Relationship (Polynomial) between NP with N uptake (grain and straw kg ha^{-1})

$Y=6E - 05x^2 – 0.012x + 1.6041; R^2=0.935$ ………………..(11)

$Y=5E - 05x^2 – 0.012x + 1.604; R^2=0.962$ …………………(12)

Where Y= Nitrogen productivity (kg $kg^{-1}day^{-1}$) and x= Total N uptake (kg ha^{-1})

The present results are in line with the findings of Quanbao *et al.* (2007), Malik *et al.* (2009) and Tayefe *et al*. (2011). On contrary Artacho *et al*. (2009) reported that NHI was not affected markedly with N fertilization and Nayak *et al*. (2015) opined that the NHI was maximum when crop received no nitrogen fertilization.The lowest values of AUE, NHI and highest values of NER and NP were recorded under LCC based N applied plots in both the years. It might be ascribed due to low level of inorganic fertilizer applied with different timings and its susceptibility to different types of losses leads to delayed growth and development processes in early stages thus affected dry matter production and uptake. So, lesser nitrogen use efficiency is victim with lower level of N application through inorganic sources proved evidently. This finding in the present study is in confirmation with that of Pandey *et al*. (2007) and Salem *et al.* (2011).

Conclusion

Analysis of pooled data of two consecutive years of investigation of rice revealed that integrated use of STCR based RDF along with FYM and bio-fertilizers followed by combined application of 75 per cent RDF of inorganic N and 25 per cent of RDF N through FYM or GM registered higher grain and straw yields of rice, greater N uptake and potentially better N use efficiency (ANUE,NER,NHI and NP) under system of rice intensification and were also significantly superior than rest of nutrient management practices. Besides, being better option for increasing yield and uptake efficiency and utilization efficiency of rice, these INM practices helps to maintain the soil fertility and productivity sustainably.

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