Review Article

Changes in soil nitrogen availability as influenced by direct seeded rice and transplanted rice ecosystem, nutritional approaches and ~~slow release~~slow-release nitrogen sources

ABSTRACT

Anexperiment was conducted on nutrient management approaches under different rice ecosystem using slow release nitrogen sources at the Agricultural Research Station, Dhadesugur, University of Agricultural Sciences, Raichur.The initial and final soil N content was analyzed at active tillering, panicle initiation, milking stages and at harvest of direct seeded and transplanted rice.The ~~three way~~three-way interaction (M x N x S) ~~had~~ proved that a significantly higher value of available N content in soil was noticed in SSNM (6 t ha^{-1}) treated plot with neem coated urea in transplanted rice ($M_2N_3S_2$) at active tillering stage (245.96 kg ha^{-1}) and at harvest (213.46 kg ha^{-1}), respectively, while application of NCU through SSNM approach (7 t ha^{-1}) in direct seeded rice ($M_1N_4S_2$) obtained maximum available N content at panicle initiation stage (229.18 kg ha^{-1}) and application of NCU through STCR approach for the yield target of 7 t ha^{-1} in direct seeded rice ($M_1N_2S_2$) at milking stage (218.15 kg ha^{-1}).

Comment [TTS1]: This is part of introduction

Comment [TTS2]: Methodology, and Conclusion is missing. Kindly include it

Key words: Direct seeded rice, transplanted rice, SSNM, neem coated urea

Introduction

Nitrogen is a major nutrient for plant growth and is supplied to plants from different sources, but the ~~The nitrogen is major nutrient for plant growth and it is supplied to plants from different sources, but~~ main problem of low N availability is due to the losses of N in flooded and aerobic rice. The alternate moist-dry soil conditions may stimulate the nitrification-denitrification process, resulting in a loss of N through N_2 and N_2O. A method for reducing N fertilizer loss is the application of nitrification inhibitors to slow the conversion of NH_4^+-N in soil and to prolong the N availability for crop uptake (Irigoyen *et al*., 2003; Di, *et al.,* 2007).

The use of slow release N-fertilizers such as neem coated urea and urea supergranules in rice has been reported to be a better option than ordinary urea in almost all types of soils (Meelu *et al.*, 1983). The physical intromission of urea granules in an appropriate coating material is one such technique that produces ~~controlled release~~controlled-release coated urea. The development of ~~controlled release~~controlled-release coated urea is a green technology that reduces nitrogen loss caused by volatilization and leaching~~not only reduces nitrogen loss caused by volatilization and leaching, but also~~ alters the kinetics of N release, which, in turn, provides nutrients to plants at a pace that is more compatible with their metabolic needs. Nitrification inhibiting properties of neem and its role in increasing NUE in rice was first reported by Bains *et al.* (1971). Devakumar and Goswami (1992) reported that oil derived from neem seeds contain melicians of which epinimbin, deacetyl, salanin and azadirachtin showed dose dependent inhibition of nitrification. According to Singh and Singh (2003) oil forms a fine coating and protects the N due to denitrification losses and thereby ensuring regulated and continuous availability of N over a long period of time, as required by crops. The chemistry of N in direct seeded rice (DSR) and transplanted rice (TPR) soil is a subject of unusual scientific interest and great practical utility. The behaviour of N in flooded lowland soils differs remarkably from that in upland soils.

The SSNM, STCR and nutrient expert approaches along with different sources of nitrogen *viz.*, urea super granules and neem coated urea provide principle and tools for supplying crop nutrients as and when needed to achieve higher yield. These approaches not specifically aim to reduce or increase fertilizer use. Instead, they aim to apply nutrients at optimal rates and time to achieve higher yield and efficiency of nutrient use by the crop, leading to more net returns per unit of fertilizer invested. The appropriate timing and rate of fertilizer application ~~helps~~ helpto increase higher yield and fertilizer use efficiency under TPR and DSR. In the view above, the present investigation is carried out to enhance the soil N availability with varying nutrient management approaches and reduce the loss of N by using~~of above, the present investigation is carried out to enhance the soil N availability with varying nutrient management approaches and reduce the loss of N by the use ofslow release~~slow-release N sources.

Materials and Methods

Selection of field's soil samples for pot culture experiment

To investigate the effect of nutrient management using different techniques and N sources in transplanted and direct seeded rice, a field experiment was carried out during the *kharif* seasons of 2018-19 and 2019-20 at Agriculture Research Station, Dhadesugur, Raichur. The rice variety Gangavathi sona (GGV 05 01) released fromthe University of Agricultural Sciences, Raichur, Karnataka was used a ~~as~~ test crop.The experiment was laid out using Split-Split Plot Design.

Main plot : Ecosystem (M)

M_1 : Direct Seeded Rice (DSR), M_2: Transplanted rice (TPR)

Sub plot :Nutritional approaches (N)

N_0 : RDF
N_1 : Fertilizer based on STCR for yield target of 6 t ha^{-1}
N_2 : Fertilizer based on STCR for yield target of 7 t ha^{-1}
N_3 : Fertilizer based on SSNM for yield target of 6 t ha^{-1}
N_4 : Fertilizer based on SSNM for yield target of 7 t ha^{-1}
N_5 : Fertilizer based on NE for yield target of 6 t ha^{-1}
N_6 : Fertilizer based on NE for yield target of 7 t ha^{-1}

Sub-sub plot :Nitrogen sources (S)

S_1 : Urea super granules, S_2 : Neem coated urea

The absolute control for DSR and TPR was maintained outside the treatment plot. Application of FYM @ 7 t ha^{-1} and $ZnSO_4$ @ 25 kg ha^{-1} + foliar spray of $FeSO_4$ @ 0.5 per cent are common to all treatments except absolute control in rice. The fertilizers are applied to rice based on the RDF, STCR, SSNM and NE approach for different yield targets.The recommended dose of fertilizer for DSR and TPR in the North Eastern Dry Zone (Zone-2) is 100: 50: 50 and 150: 75: 75 kg N: P_2O_5: K_2O ha^{-1}, respectively (Package of practice, UAS, Raichur, 2016). As per RDF, 50 per cent N and full dose of P and K were applied as basal and remaining 50 per cent N in two equal splits were applied at 30 DAT or 60 DAS (Tillering stage) and 60 DAT or 90 DAS (Panicle initiation stage) for TPR and DSR.

The calculated fertilizer dose for direct seeded rice and transplanted rice for the yield target of 6.0 t ha^{-1} based on STCR approach was (168.02: 12.50: 75.88:: N, P_2O_5, K_2O kg ha^{-1}) and 7 t ha^{-1} was (202.52: 12.50: 95.88:: N, P_2O_5, K_2O kg ha^{-1}).

As per SSNM, calculated fertilizer dose recommended for direct seeded rice for 6.0 t ha^{-1} is: 133.13: 29.05: 70.34: N, P_2O_5, K_2O kg ha^{-1} and for 7.0 t ha^{-1} is 155.32: 33.89: 82.07: N, P_2O_5, K_2O kg ha^{-1}. The calculated fertilizer dose for transplanted rice for 6.0 t ha^{-1} is: 169.87: 25.57: 108.32: N, P_2O_5, K_2O kg ha^{-1} and for 7.0 t ha^{-1} is 198.19: 29.83: 126.37: N, P_2O_5, K_2O kg ha^{-1}.

As per NE software fertilizer recommendation for the experimental site was as follows.

- For the yield target of 6 t ha^{-1} the N: P: K dose for DSR were 118: 28: 38 kg ha^{-1}.
- For the yield target of 7 t ha^{-1} the N: P: K dose for DSR were 125: 35: 41 kg ha^{-1}.
- For the yield target of 6 t ha^{-1} the N: P: K dose for TPR were 141: 34: 55 kg ha^{-1}.
- For the yield target of 7 t ha^{-1} the N: P: K dose for TPR were 150: 38: 61 kg ha^{-1}.

The initial available N was low (134.40 kg ha^{-1}) in soil.The soil analytical data obtained in the study were subjected to statistical scrutiny, by following the procedures outlined by Gomez and Gomez (1976), to derive a valid conclusion. The level of significance used in ‘F’ and ‘t’ tests was $p = 0.05$. Critical difference values were calculated, wherever ‘F’ test was found significant.Results have been interpreted and discussed based on the pooled data of two years (2018 and 2019).

Results and Discussion

Available nitrogen

The available nitrogen content in the soil had been monitored at important physiological stages and is presented in Table 1. It was seen that the available N content decreased with the advancement of crop growth.

A perusal of the data indicated that soils of DSR contained higher amount of available N. Significantly higher available N content in the soil (208.98, 197.49 and

Table 1. Effect of ecosystem, nutritional approaches and nitrogen sources on available nitrogen (kg ha^{-1}) at various stages of rice during *kharif* season of 2018-19 and 2019-20 (pooled data)

	AT	*PI*	*MS*	*H*
Ecosystem (M)				
M_1	194.85^{b}	208.98^{a}	197.49^{a}	190.51^{a}
M_2	209.56^{a}	197.76^{b}	185.37^{b}	176.17^{b}
S.Em±	2.171	1.803	1.703	1.620
C.D (0.05)	13.211	10.970	10.364	9.857
Nutritional approaches (N)				
N_0	192.07^{d}	186.25^{d}	175.96^{e}	174.09
N_1	202.51^{a-c}	202.45^{bc}	189.90^{cd}	182.27
N_2	206.51^{ab}	208.78^{a}	196.22^{a-c}	185.98
N_3	211.21^{a}	212.74^{a}	201.76^{a}	195.17
N_4	206.68^{ab}	212.90^{a}	197.08^{ab}	186.64
N_5	195.36^{cd}	197.26^{c}	185.51^{d}	176.67
N_6	201.12^{bc}	203.21^{b}	193.59^{bc}	182.57
S.Em±	2.984	1.779	2.401	2.295
C.D (0.05)	8.709	5.194	7.009	NS
Nitrogen sources (S)				
S_1	185.57^{b}	193.05^{b}	183.34^{b}	176.71^{b}
S_2	218.84^{a}	213.69^{a}	199.53^{a}	189.97^{a}
S.Em±	1.294	1.414	1.173	1.222
C.D (0.05)	3.749	4.096	3.397	3.540

		Active tillering (AT)			*Panicle initiation (PI)*			*Milking stage (MS)*			*Harvest (H)*		
		Ecosystem x Nutritional approaches (M x N)											
	M x N	**M_1**	**M_2**	**N mean**	**M_1**	**M_2**	**N mean**	**M_1**	**M_2**	**N mean**	**M_1**	**M_2**	**N mean**
N	**N_0**	179.28^{ef}	204.86^{b-d}	**192.07^{d}**	187.17^{gh}	185.33^{h}	**186.25^{d}**	182.64^{c}	169.28^{d}	**175.96^{e}**	185.57^{a-c}	162.62^{e}	**174.09**
	N_1	200.88^{b-d}	204.14^{b-d}	**202.51^{a-c}**	209.04^{a-d}	195.87^{e-h}	**202.45^{bc}**	191.81^{bc}	187.99^{c}	**189.90^{cd}**	188.31^{a-c}	176.23^{cd}	**182.27**
	N_2	207.07^{a-d}	205.94^{a-d}	**206.51^{ab}**	217.79^{ab}	199.77^{c-f}	**208.78^{a}**	206.41^{a}	186.04^{c}	**196.22^{a-c}**	194.28^{a}	177.68^{cd}	**185.98**
	N_3	201.16^{b-e}	221.27^{a}	**211.21^{a}**	215.49^{ab}	209.99^{a-c}	**212.74^{a}**	202.27^{ab}	201.26^{ab}	**201.76^{a}**	195.63^{a}	194.70^{a}	**195.17**
	N_4	198.04^{c-e}	215.32^{ab}	**206.68^{ab}**	218.48^{a}	207.31^{a-e}	**212.90^{a}**	207.57^{a}	186.59^{c}	**197.08^{ab}**	195.59^{a}	177.68^{cd}	**186.64**
	N_5	185.67^{ef}	205.06^{a-d}	**195.36^{cd}**	206.18^{b-e}	188.35^{f-h}	**197.26^{c}**	190.08^{bc}	180.94^{cd}	**185.51^{d}**	181.69^{b-d}	171.65^{de}	**176.67**
	N_6	191.88^{d-f}	210.36^{a-c}	**201.12^{bc}**	208.74^{a-d}	197.67^{d-g}	**203.21^{b}**	201.68^{ab}	185.50^{c}	**193.59^{bc}**	192.50^{ab}	172.64^{de}	**182.57**
	M mean	**194.85^{b}**	**209.56^{a}**		**208.98^{a}**	**197.76^{b}**		**197.49^{a}**	**185.37^{b}**		**190.51^{a}**	**176.17^{b}**	
		S.Em±	**C.D (0.05)**		**S.Em±**	**C.D (0.05)**		**S.Em±**	**C.D (0.05)**		**S.Em±**	**C.D (0.05)**	
		1.398	4.049		1.527	4.424		1.267	3.669		1.320	3.824	
	N x S	**Nutritional approaches x Nitrogen sources (N x S)**											
N		**S_1**	**S_2**	**N mean**	**S_1**	**S_2**	**N mean**	**S_1**	**S_2**	**N mean**	**S_1**	**S_2**	**N mean**
	N_0	171.33	212.81	**192.07^{d}**	167.74^{h}	204.75^{c-e}	**186.25^{d}**	160.83^{ef}	191.09^{d}	**175.96^{e}**	165.74^{f}	182.45^{c-e}	**174.09**
	N_1	188.52	216.50	**202.51^{a-c}**	196.98^{c-g}	207.93^{d}	**202.45^{bc}**	187.22^{d}	192.59^{cd}	**189.90^{cd}**	179.60^{de}	184.94^{b-d}	**182.27**
	N_2	189.90	223.11	**206.51^{ab}**	199.20^{d-f}	218.36^{ab}	**208.78^{a}**	187.41^{de}	205.04^{ab}	**196.22^{a-c}**	180.73^{de}	191.23^{bc}	**185.98**
	N_3	191.85	230.58	**211.21^{a}**	203.24^{c-f}	222.25^{a}	**212.74^{a}**	191.78^{d}	211.74^{ab}	**201.76^{a}**	181.84^{c-e}	208.49^{a}	**195.17**
	N_4	191.57	221.80	**206.68^{ab}**	200.47^{d-f}	225.32^{a}	**212.90^{a}**	190.24^{d}	203.92^{a}	**197.08^{ab}**	180.87^{de}	192.41^{b}	**186.64**
	N_5	179.28	211.45	**195.36^{cd}**	188.79^{g}	205.74^{c-e}	**197.26^{c}**	180.03^{e}	191.00^{d}	**185.51^{d}**	173.48^{ef}	179.86^{de}	**176.67**
	N_6	186.58	215.65	**201.12^{bc}**	194.97^{fg}	211.44^{bc}	**203.21^{b}**	185.87^{de}	201.30^{bc}	**193.59^{bc}**	174.70^{ef}	190.43^{bc}	**182.57**
	S mean	**185.57^{b}**	**218.84^{a}**		**193.05^{b}**	**213.69^{a}**		**183.34^{b} `**	**199.53^{a}**		**176.71^{b}**	**189.97^{a}**	
		S.Em±	**C.D (0.05)**		**S.Em±**	**C.D (0.05)**		**S.Em±**	**C.D (0.05)**		**S.Em±**	**C.D (0.05)**	
		1.398	NS		1.527	4.424		1.267	3.669		1.320	3.824	
	M x S	**Ecosystem x Nitrogen sources (M x S)**											
		M_1	**M_2**	**S mean**	**M_1**	**M_2**	**S mean**	**M_1**	**M_2**	**S mean**	**M_1**	**M_2**	**S mean**
S	**S_1**	176.31^{c}	194.84^{b}	**185.57^{b}**	199.49	186.62	**193.05^{b}**	191.14^{b}	175.53^{c}	**183.34^{b}**	186.19^{a}	167.23^{b}	**176.71^{b}**
	S_2	213.40^{a}	224.29^{a}	**218.84^{a}**	218.48	208.89	**213.69^{a}**	203.84^{a}	195.21^{ab}	**199.53^{a}**	194.83^{a}	185.12^{a}	**189.97^{a}**
	M mean	**194.85^{b}**	**209.56^{a}**		**208.98^{a}**	**197.76^{b}**		**197.49^{a}**	**185.37^{b}**		**190.51^{a}**	**176.17^{b}**	
		S.Em±	**C.D (0.05)**		**S.Em±**	**C.D (0.05)**		**S.Em±**	**C.D (0.05)**		**S.Em±**	**C.D (0.05)**	
		0.399	1.157		0.436	NS		0.362	1.048		0.377	1.093	

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Table 1. Contd…

M x N x S		**Ecosystem x Nutritional approaches x Nitrogen sources (M x N x S)**											
		Active tillering (AT)			***Panicle initiation (PI)***			***Milking stage (MS)***			***Harvest (H)***		
		M_1	**M_2**	**N x S**	**M_1**	**M_2**	**N x S**	**M_1**	**M_2**	**N x S**	**M_1**	**M_2**	**N x S**
N_0	**S_1**	156.39^{e-g}	186.28^{j}	**171.33**	162.43^{m}	173.05^{lm}	**167.74**	169.48^{hi}	152.19^{j}	**160.83**	183.29^{e-h}	148.18^{k}	**165.74**
	S_2	202.18^{d-f}	223.45^{fg}	**212.81**	211.91^{b-g}	197.60^{h-j}	**204.75**	195.81^{d}	186.37^{d-g}	**191.09**	187.84^{d-f}	177.06^{f-h}	**182.45**
N_1	**S_1**	184.20^{e-g}	192.83^{g-j}	**188.52**	203.71^{d-i}	190.24^{jk}	**196.98**	194.43^{de}	180.00^{f-i}	**187.22**	186.03^{e-g}	173.17^{h-j}	**179.60**
	S_2	217.56^{c-e}	215.45^{e-g}	**216.50**	214.37^{b-d}	201.50^{e-j}	**207.93**	189.19^{d-g}	195.99^{cd}	**192.59**	190.59^{c-e}	179.29^{e-h}	**184.94**
N_2	**S_1**	184.35^{d-f}	195.46^{g-j}	**189.90**	208.02^{c-h}	190.39^{jk}	**199.20**	194.67^{de}	180.15^{f-i}	**187.41**	187.44^{d-f}	174.02^{g-j}	**180.73**
	S_2	229.80^{a-c}	216.43^{e-g}	**223.11**	227.56^{a}	209.16^{b-h}	**218.36**	218.15^{a}	191.93^{d-g}	**205.04**	201.11^{b-d}	181.35^{e-h}	**191.23**
N_3	**S_1**	187.11^{d-f}	196.58^{f-h}	**191.85**	214.16^{b-e}	192.32^{ij}	**203.24**	195.81^{d}	187.75^{d-g}	**191.78**	187.74^{d-f}	175.95^{f-i}	**181.84**
	S_2	215.20^{ab}	245.96^{a}	**230.58**	216.83^{a-c}	227.66^{a}	**222.25**	208.72^{a-c}	214.76^{a}	**211.74**	203.52^{ab}	213.46^{a}	**208.49**
N_4	**S_1**	183.35^{d-f}	199.79^{g-i}	**191.57**	207.78^{c-h}	193.16^{ij}	**200.47**	198.56^{b-d}	181.92^{e-h}	**190.24**	187.57^{d-f}	174.17^{g-j}	**180.87**
	S_2	212.74^{ab}	230.86^{e-g}	**221.80**	229.18^{a}	221.47^{ab}	**225.32**	216.59^{a}	191.25^{d-g}	**203.92**	203.62^{a-c}	181.19^{e-h}	**192.41**
N_5	**S_1**	167.01^{e-g}	191.56^{i}	**179.28**	199.76^{g-j}	177.82^{kl}	**188.79**	192.48^{d-f}	167.58^{i}	**180.03**	185.36^{e-h}	161.60^{j}	**173.48**
	S_2	204.33^{e-g}	218.56^{e-g}	**211.45**	212.60^{b-f}	198.88^{h-j}	**205.74**	187.69^{d-g}	194.31^{de}	**191.00**	178.02^{e-h}	181.71^{e-h}	**179.86**
N_6	**S_1**	171.78^{e-g}	201.38^{h-j}	**186.58**	200.55^{f-j}	189.39^{jk}	**194.97**	192.60^{d-f}	179.15^{g-i}	**185.87**	185.91^{e-h}	163.50^{ij}	**174.70**
	S_2	211.98^{b-d}	219.33^{e-g}	**215.65**	216.93^{a-c}	205.95^{c-h}	**211.44**	210.75^{ab}	191.86^{d-g}	**201.30**	199.09^{b-d}	181.78^{e-h}	**190.43**
	M mean	**194.85^{b}**	**209.56^{a}**		**208.98^{a}**	**197.76^{b}**		**197.49^{a}**	**185.37^{b}**		**190.51^{a}**	**176.17^{b}**	
	Control	**154.01**	**154.39**		**153.93**	**153.55**		**139.98**	**143.69**		**133.01**	**130.37**	
		S.Em±	**C.D (0.05)**		**S.Em±**	**C.D (0.05)**		**S.Em±**	**C.D (0.05)**		**S.Em±**	**C.D (0.05)**	
	M x N x S	2.796	8.098		3.054	8.848		2.533	7.338		2.640	7.648	
Control Vs Rest	**M_1**	5.425	15.715		3.437	9.957		5.624	16.293		3.804	11.018	
	M_2	4.993	14.464		5.265	15.251		2.944	8.529		5.017	14.534	

Note :														
NS : Non significant														
Main plot	**:**	**Ecosystem (M)**	**M_1**	**:**	Direct seeded rice	**M_2**	**:**	Transplanted rice						
Sub plot	**:**	**Nutritional approaches (N)**	**N_0**	**:**	RDF	**N_1**	**:**	STCR of 6 t ha^{-1}	**N_2**	**:**	STCR of 7 t ha^{-1}	**N_3**	**:**	SSNM of 6 t ha^{-1}
			N_4	**:**	SSNM of 7 t ha^{-1}	**N_5**	**:**	NE of 6 t ha^{-1}	**N_6**	**:**	NE of 7 t ha^{-1}			
Sub-sub plot	**:**	**Nitrogen sources (S)**	**S_1**	**:**	Urea super granules	**S_2**	**:**	Neem coated urea						

190.51 kg ha^{-1} at PI, MS and at harvest, respectively) was noticed in DSR soils (M_1) except at active tillering stage, while minimum (197.76, 185.37 and 176.17 kg ha^{-1} at active tillering, PI and MS, respectively) was in TPR (M_2). At active tillering stage, maximum available N content was observed in TPR soils (209.56 kg ha^{-1}) and lowest in DSR plot (194.85 kg ha^{-1}).

The soil remains unaltered due to nutritional approach (N) at harvest among the different nutritional approaches (N). Available N content in the soil of 211.21 and 201.76 kg ha^{-1} was recorded with the fertilizer application based on SSNM for yield target of 6 t ha^{-1} (N_3) at active tillering stage and milking stage, while at PI stage (212.90 kg ha^{-1}), it was comparable and significantly higher in nutritional approach based on SSNM for the yield target of 7 t ha^{-1} (N_4). Application of fertilizer based on STCR for the yield target of 7 t ha^{-1} (N_2) had shown similar trend. The minimum available N content was recorded in the RDF (N_0) applied plots (192.07, 186.25 and 175.96 kg ha^{-1} at PI, MS and at harvest, respectively).

Among the N sources, highest soil available N content (218.84, 213.69, 199.53 and 189.97 kg ha^{-1} at active tillering, PI, MS and at harvest, respectively) recorded with the application of NCU (S_2), followed by USG treated plots (S_1) with 185.57, 193.05, 183.34 and 176.71 kg ha^{-1} at active tillering, PI, MS and at harvest, respectively. However, marginal difference was noticed in the soil available N content with the application of NCU and USG at different stages of crop growth.

The interaction of ecosystem with nutritional approaches (M x N) was significantly differ at all stages of crop growth. The maximum available N in soil was recorded with the fertilizer application based on SSNM for the yield target of 6 t ha^{-1} in TPR soils (M_2N_3) at active tillering stage (221.27 kg ha^{-1}), through SSNM for the yield target of 7 t ha^{-1} in DSR (M_1N_4) at PI stage (218.48 kg ha^{-1}) and milking stage (207.57 kg ha^{-1}), while at harvest, fertilizer application based on SSNM for the yield target of 6 t ha^{-1} in DSR (M_1N_3) obtained higher available N (195.63 kg ha^{-1}) in soil, respectively. Though, minimum available N (179.28 kg ha^{-1}) was noticed in DSR plot which received nutrients based on RDF approach (M_1N_0) at active tillering stage, while at the PI stage (185.33 kg ha^{-1}), milking stage (169.28 kg ha^{-1}) and at harvest (162.62 kg ha^{-1}), it was in TPR plot which received nutrients based on RDF (M_2N_0).

The interaction of nutritional approaches with sources of urea (N x S) had revealed significant variations except at active tillering stage. The soils which contained NCU applied based on SSNM approach for the yield target of 7 t ha^{-1} (N_4S_2) resulted in significantly higher available N of 225.32 kg ha^{-1} at PI stage and 203.92 kg ha^{-1} at milking stage, respectively, whereas at harvest (208.49 kg ha^{-1}), application of NCU through SSNM approach for the yield target of 6 t ha^{-1} (N_3S_2) recorded higher available N content. The plot applied with USG through RDF (N_0S_1) had resulted in minimum available N content in soil (167.74, 160.83 and 165.74 kg ha^{-1} at PI, MS and at harvest, respectively).

The available N content remains unaltered due to the interaction of ecosystem with N sources (M x S) at PI stage. The results had further revealed that application of N as NCU in TPR (M_2S_2) registered significantly higher value of available N (224.29 kg ha^{-1}) at active tillering stage and in DSR (M_1S_2) at milking stage (203.84 kg ha^{-1}) and at harvest (194.83 kg ha^{-1}). However, in the DSR, USG treated plots (M_1S_1) had resulted in minimum available N (176.31 kg ha^{-1}) at active tillering stage and in TPR (M_2S_1) at milking stage (175.53 kg ha^{-1}) and at harvest (167.23 kg ha^{-1}), respectively.

The three way interaction (M x N x S) had proved that significantly higher value of available N content in soil was noticed in SSNM (6 t ha^{-1}) treated plot with NCU in TPR ($M_2N_3S_2$) at active tillering stage (245.96 kg ha^{-1}) and at harvest (213.46 kg ha^{-1}), respectively, while application of NCU through SSNM approach (7 t ha^{-1}) in DSR ($M_1N_4S_2$) obtained maximum available N content at PI stage (229.18 kg ha^{-1}) and application of NCU through STCR approach for the yield target of 7 t ha^{-1} in DSR ($M_1N_2S_2$) at milking stage (218.15 kg ha^{-1}). Furthermore, the minimum soil available N content was observed in DSR plot applied with USG based on RDF ($M_1N_0S_1$) at active tillering stage (156.39 kg ha^{-1}) and PI stage (162.43 kg ha^{-1}), whereas in TPR ($M_2N_0S_1$) at milking stage (152.19 kg ha^{-1}) and at harvest (148.18 kg ha^{-1}), respectively. However, marginal difference was noticed between DSR and TPR soils.

Among all treatment combinations with nutritional approaches for different yield targets applied with slow release N sources, the available N content in soil were found superior than control plots of DSR (154.01, 153.93, 139.48 and 133.01 kg ha^{-1} respectively) and TPR (154.39, 153.55, 143.69 and 130.37 kg ha^{-1}, respectively) during different stages of crop growth.

Soil N availability and N transformations are greatly affected by soil saturation. Water management in DSR differed from TPR, particularly within 2 weeks after sowing (or transplanting), thus the changes in soil saturation associated with the anaerobic or aerobic system may result in altered plant N uptake patterns and soil N transformation, along with influence on migration and transformation of N fertilizer in soil (Li *et al.*, 2003).

Anaerobic conditions in wet soils result in the accumulation of ammonium, and instability of nitrate in soil. Mineralization of N can occur in either aerobic or anaerobic conditions. But this process is slower under anaerobic conditions due to less efficient and incomplete decomposition which lowers the availability of N during the initial stages of crop growth (Sahrawat, 2004). Because of the lack of oxygen, the oxidation of organic matter and the release of NH_4^+ from organic N in submerged paddy soils and sediments depend on the availability of other electron acceptors such as ferric iron and sulphate (Sahrawat and Narteh, 2001).

When soil is subjected to aerobic-anaerobic cycles, nitrate concentrations tend to increase during aerobic periods but then rapidly decrease when fields are flooded, with soil nitrate presumably lost due to denitrification and decrease the N availability in soil (Becker *et al.*, 2007; Linquist *et al.*, 2011). In upland DSR cultivation, the soil is subjected to alternate flooding and drainage; nitrates formed during conditions of oxidation are lost, whereas on submergence because of denitrification (Prasad and Rajale, 1972). Thus the response of DSR to N was less than that of TPR because of higher losses of applied N from DSR fields (Vacharotayan and Takai, 1983). The higher available N than initial values in transplanting method of rice field was due to the restricted water movement to lower depth of profile which helped in minimizing the leaching losses and an indirect increase in the availability of nutrients by puddling is due to a reduction in cation leaching. Similar results were reported by Saharawat *et al.* (2005).

Comment [TTS6]: Inconsistence in referencing

Flooding and drying treatments seem to retard nitrification of soil N but conserve that of fertilizer NH_4^+ applied which increase the availability of N in DSR fields (M_1). It is also known that wetting and drying of soils stimulate decomposition of organic matter due to what is called the 'Birch effect' and this results in flush of inorganic N after each cycle of drying and wetting (Birch, 1960). The repeated wetting and drying of the soil breaks down water soluble aggregates and exposes new sections of substrate and soil to microbial attack. Drying partially sterilizes the soil, releasing N compounds from the dead biomass. Drying also converts organic N compounds to more soluble forms that are readily utilized by the remaining soil microbes. The net release of inorganic N to the solution phase was highest in anaerobic (TPR) and least in aerobic systems (DSR) which reduces available N content under DSR.

Reddy and Patrick (1975) reported that more frequency of alternate wetting and drying (2 days interval) of soil causes higher N loss (24.3 %) as compared to less frequency of alternated wetting and drying (64 days interval, 12.9 % loss) due to nitrification-denitrification which is the main feature of DSR. There was comparatively lesser leaching of NO_3^--N under continuous flooding, when compared to intermittent flooding, which facilitates the oxidation of NH_4^+ into NO_3^-, thus reduces the availability of N under DSR applied with USG based on RDF ($M_1N_0S_1$) at active tillering and panicle initiation stage indicated in this study. Alternate wetting and drying can lead to high N losses due to alternate nitrification (under dry conditions). Many studies indicated that DSR requires very little or no supply of N fertilizer during first 3 to 4 weeks. Much of the N fertilizer applied as basal dose is not utilized by the crop and lost from the root zone. This is reason because the DSR indicated low available N content at active tillering stage. Therefore, to obtain high efficiency of N fertilizer, the major part of total N needs to be applied at the stage of 3 to 4 weeks after germination and rest at PI stage (Krishnaiah, 1998). Mahajan and Chauhan (2011) mentioned that N requirement of DSR at different growth stages can be met by increasing the number of splits and doses of N.

Available N in the soil increased up to panicle initiation stage and then started declining as the growth advanced. This might be due to increase in the uptake of N by the rice crop. Application of N in three equal splits recorded higher amount of available N at all the stages of crop growth. This is because of fractional application and associated reduced leaching, volatilization and denitrification. The application of fertilizer N immediately before permanent flooding reduces NH_3 loss during production of dry-seeded rice on non-puddled soils and increases availability of N (Griggs *et al*., 2007).

General recommendations for NPK fertilizers (N_0) in puddled rice are similar to those in DSR, except that soil test based N application is applicable in DSR to compensate for the higher losses and lower availability of N from soil mineralization at the early stage as well as the longer duration of the crop in the main field of DSR. There was overall decreased in available N status of soil than initial but it was marginally increased in treatments which received NPK as per soil test. During *kharif* season, the soil available N recorded higher in SSNM method for the yield target of 6 and 7 t ha^{-1} (N_{3-4}) than the STCR approach for the yield target of 6 and 7 t ha^{-1} (N_{1-2}), NE approach for the yield target of 6 and 7 t ha^{-1} (N_{5-6}), RDF (N_0) and absolute control. This could be due to high dose of N applied to soil and lower amount was taken up by paddy. The findings are in line with Singh *et al.* (2015), Paradkar *et al.* (2016) and Raghavendra (2017). Application of potassic fertilizers based on soil test had significant effect on N availability in soil. This suggests that appropriate K supply not only increases NO_3 absorption in roots, but also promotes the transport from roots to shoots.

Neem coated urea (S_2) could be attributed to the slow nitrification of applied urea and reduction in N losses caused by hydrolysis and denitrification resulting in gradual release of available N and also its greater availability to the crop. The results observed in this investigation are in consonance with the findings of Mani and Palaniappan (1979). Neem coated urea maintained high available N in soil at all the stages. Neem coated urea deactivate the ammonia mono oxygenize enzyme responsible for the oxidation of NH_4^+-N to nitrite form. Neem coated urea help to retain soil N in the ammoniacal form for a longer time and therefore provide more availability of N for its uptake by rice plants. Moreover, due to the remarkable degree of nitrification inhibition by the alkaloid nimbidin present in the NCU reduced the N losses associated with the rice soil ecology and resulted in the absorption of N by rice for a longer period (Bhalla and Prasad, 2008). Neem cake has an adequate quantity of NPK in organic form for plant growth. Being a totally botanical product it contains essential macro and micro nutrients as N (2-5%), P (0.5-1.0%), K (1-2%), Ca (0.5-3.0%), Mg (0.3-1.0%), S (0.2-3.0%), Zn (15-60 ppm), Cu (4-20 ppm), Fe (500-1200 ppm), Mn (20-60 ppm). It is rich in both sulphur compounds and bitter limonoids.

Initially NCU released N slowly up to a week thereafter rapid release was noticed, whereas in case of USG most of N was release within 20 days after application. In case of urea in soil, solubilise within 7 to 10 days after its application. These finding are in close conformity with those of Gandeza *et al.*(1991) and Zvomuya *et al.*(2003). Dissolution of nutrient in coating depends on coating thickness, size of urea particles and permeability of water into the coating (Shaviv *et al.*, 2005). Similarly, USG have been reported to be more efficient than prilled urea for TPR. Neem coated urea contains melicians (generally known as neem bitters) of which epinimbin, diacetyl and azadirachtin are the main fractions, which are responsible for nitrification inhibition action, thereby increases the N availability.

No conclusion in this manuscript

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