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Evaluation of various sources of organic manures on nitrogen use efficiency in rice-rice cropping system

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Investigations were carried out to study the effect of organic farming with various sources of organic manures and their combinations on nitrogen use efficiency parameters of ADT 36 rice (*Oryza sativa* L.). The experiments were laid out in randomized block design (RBD) with fourteen treatments, comprising twelve treatment combinations of organic manures, one treatment with recommended dose of chemical fertilizer and the other was absolute control which were replicated three times. The recommended dose of NPK fertilizer was 90: 40: 40 kg ha^{-1} for *Kharif* and *Rabi* rice. The recommended dose of 90 kg N ha^{-1} was substituted through organics viz., farm yard manure (FYM), *Sesbaniarostrata*, composted coirpith alone and in combination with neem cake and Azolla. The nitrogen use efficiency parameters such as partial factor productivity (PFP_N), agronomic efficiency (AE_N), recovery efficiency of applied nitrogen (RE_N), physiological efficiency of applied nitrogen (PE_N) and internal efficiency of applied nitrogen(IE_N) values were high in the treatment receiving FYM + neem cake applied at 90 kg N ha^{-1} level.

Key words: Partial factor productivity, agronomic efficiency, recovery efficiency of applied nitrogen, physiological efficiency of applied nitrogenand internal efficiency of applied nitrogen.

INTRODUCTION

Indiscriminate use of chemical fertilizers over years for crop production resulted in deterioration of soil quality and decline in crop yield. Out of total geographical area of 328.7 m ha in India, nearly 174 m ha of land is subjected to environmental hazards due to improper soil management. Therefore, the per capita availability of cultivable land is likely to be reduced from 0.48 ha in 1951 to 0.15 ha in 2010 due to degradation of soil resource coupled with increase in population. Intensive cultivation and growing of exhaustive crops have also made the soil deficient in macro as well as in micronutrients. Use of only nitrogenous and phosphatic fertilizers, as practiced by farmers also create nutrient imbalance in soil besides deficiency in micronutrients. Application of higher dose nitrogen and phosphorus in aquatic ecosystem has led to extensive eutrophication and degradation of freshwater and marine ecosystem in many areas where agriculture is concentrated. Synthetically compounded nitrogenous fertilizer creates multiple risks to both wildlife populations and health. Dissolved nitrate levels of 2 ppm or greater (10 ppm) are known to interfere with normal development of amphibians (Environment Canada, 2002; Bugg et al., 2003). Organic manures not only supply the plant nutrients but also improve soil health. Moreover, the amount of micronutrients present in organic manures

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Abbreviations: PFPN, Partial factor productivity; **PEN,** physiological efficiency of applied nitrogen; **AEN,** agronomic efficiency; **REN,** recoveryefficiency of applied nitrogen; **IEN,** internal efficiency.

Table 1. Anaiyur series (Anr).

Horizon	Description
Ap	0-15 cm; dark yellowish brown (10 YR 4/4D, 10 YR 3/4D M); sandy clay loam; massive breaking to medium subangular blocky; slightly hard (dry), friable (moist), slightly sticky and slightly plastic (wet); few fine yelowish brown faint mottlings (10 YR 5/8); few fine lime and iron concretions; few fine, many very fine roots; many fine pores; strong efferescence; cracks present; moderately repid permeability; clear smooth boundary' pH 8.3.
Ass_1	15-34 cm; dark yellowish brown (10 YR 3/4D), dark brown (10 Y3/3m); sandy clay loam; massive breaking to weak medium subangular blocky; slightly hard (dry), friable (moist), slightly sticky and slightly plastic (wet); many fine faint yellowish brown (10 YR 5/8) mottlings; few fine lime and iron concentration; few fine and very fine and very fine roots; many fine pores; intersecting slickensides; strong effervescence; cracks present; moderate permeability; clear smooth boundary; pH 8.6.
Ass_2	34-79 cm; grayish brown (10 YR 5/3 M); sandy clay; moderate medium subangular blocky; firm (moist), sticky an plastic (wet); many fine faint grayish brown (2.5 Y 5/2) mottlings; few very fine and fine lime concretions; very few fine roots; few fine and very fine pores; slicken sides and sand pockets present; strong effevescences; moderate permeability; clearwavy boundary; pH 8.6.
Ass_3	79-129 cm; yellowish brown (10 YR 5/6 M) rubbed;msanbdy clay; moderate medium subangular block to angular blocky; firm (moist)., sticky andplastic (wet); many fine distinct light brownish gray (2.5 Y 6/2) mottlings; common fine lime and iron concretions; very few very fine pores; intersecting slickensides; violent effervescence; slow permeability pH 8.7.
Ass_4	129-157 cm; brown (10 YR 5/3 M) rubbed; sandy clay; moderate medium subangular to angular blocky; very firm (moist), sticky and plastic (wet); many fine prominet light brownish gray (2.5 Y 6/2) mottlings; common fine lime and iron concretions; very few very fine pores; intersecting slickensides; violent effervesecence; slow permeability; pH 8.7.

may be sufficient to meet the requirement of crop production (Duhan and Mahendra, 2002). Use of organic manures in one form or the other has advantages like nutrient conservation, slow release, improvement of soil physical conditions and enhanced biological activities resulting in higher crop yields.

Nutrient use efficiency can be expressed several ways. Mosier et al. (2004) described 4 agronomic indices commonly used to describe nutrient use efficiency: partial factor productivity (PFP, kg crop yield per kg nutrient applied); agronomic efficiency (AE, kg crop yield increase per kg nutrient applied); apparent recovery efficiency (RE, kg nutrient taken up per kg nutrient applied); and physiological efficiency (PE, kg yield increase per kg nutrient taken up). Fixen (2005) provides a good overview of these different terms with examples of how they might be applied.

Enhanced nitrogen use efficiency, mainly for nitrogen (N), is an important objective in cropping system development. Determination of N use efficiency in cereal based agro-ecosystems enabled broad assessment of agronomic management and environmental factors related to N use, Grain yield and N accumulation, N in aboveground, N harvest index, and grain N accumulation are the key indicators of N use efficiency (Huggins and Pan, 2003). The highest nutrient use efficiency always occurs at the lower parts of the yield response curve, where fertilizer inputs are lowest, but effectiveness of fertilizers in increasing crop yields and optimizing farmer profitability should not be sacrificed for the sake of efficiency alone. There must be a balance between optimal nutrient use efficiency and optimal crop productivity (Roberts, 2008).

Keeping the above in view and the known possible reasons of low productivity of rice, the present study was taken up to evaluate the nutrient use efficiency (NUE) of various sources of organic manures in combination with biofertilizer aiming to develop a sustainable rice-rice production system management with eco-friendly techniques at profitable levels.

MATERIALS AND METHODS

The experimental field soil comes under Anaiyur soil series (EnticHaplustert) in soil taxonomy and the details of profile description are given in Table 1 and Figure 1. The initial soil physico - chemical properties are furnished in Table 2. Rice variety ADT 36 was raised during *Kharif* season (June – September) and was followed by the same variety during *Rabi* season (October – January) in the wetlands of Vadipatti, Madurai district, Tamil Nadu, India representing PeriyarVaigai Command Area.

The field experiment was conducted in randomized block design with 14 treatment combinations replicated thrice and treatment details are as follows: T_1, Control; T_2,recommended dose of NPK (90: 40: 40 kg N: P_2O_5: K_2O ha^{-1}); T_3, 100% N as farmyard manure (FYM); T_4, 100% N as *Sesbaniarostrata* (SR); T_5, 100% N as composted coirpith(CCP); T_6, 50% N as FYM + 50% N as neem cake (NC); T_7, 50% N as FYM + 25% N as NC + 25% N as Azolla; T_8, 50% N as SR + 50% N as NC; T_9, 50% N as SR + 25% N as NC + 25% N as azolla; T_{10},50% N as CCP + 50% N as NC; T_{11}, 50% N as CCP + 25% N as NC + 25% N as azolla; T_{12}, 50% N as FYM + 50% N as azolla; T_{13}, 50% N as SR + 50% N as azolla; T_{14}, 50% N as CCP + 50% N as azolla.

Layout of the field experiment

The field was divided into 42 plots of 12 m^2 (3 x 4m) size with

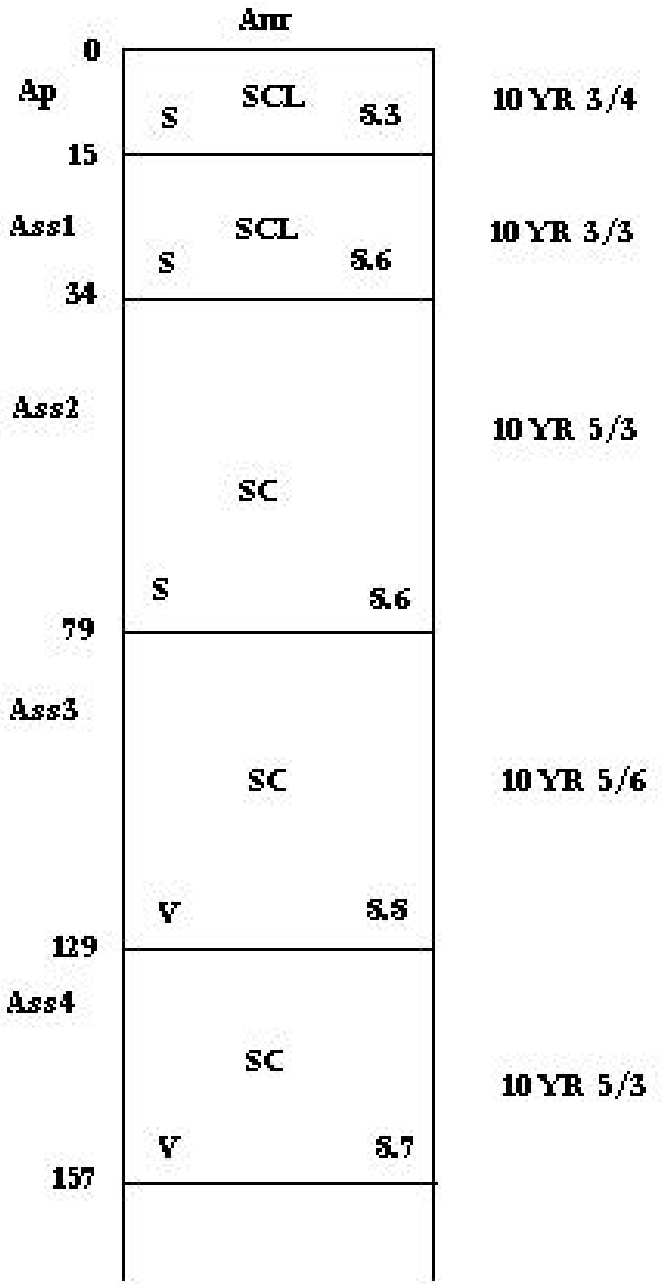

Figure 1. Profile of Anaiyur (Anr) series of soil. Soil taxonomy: Fine montmorillonitic isohyperthermic entichaphistert.

adequate irrigation and drainage channels with clear demarcation of boundary for the three replications. The treatments were allotted to plots using Fisher's random numbers in each replication.

First crop of rice

During *Kharif* 04, twenty five days old seedlings were transplanted at 2 seedlings per hill with a spacing of 15 x 10 cm. A depth of 5 cm water was maintained in the field from establishment till 7 days before harvest. The routine cultural operations were followed to maintain a good crop growth and the crop was harvested by leaving border rows on all the four sides of the plot at maturity stage. Grain and straw yields were recorded separately.

Second crop of rice

After harvesting the rice crop, the field was prepared to fine tilth with spade, without disturbing the individual plots. The same number of 42 plots of equal size (3 x 4 = 12 m^2) were used to test the second crop by retaining the layout intact. Rice var. ADT 36 was transplanted and all routine cultural operations were adopted till the maturity and the crop was harvested by leaving border rows on all four sides of the plot. Grain and straw yields were recorded separately.

Application of organic manures and fertilizers

There are twelve treatments involving various sources of organic manures such as farmyard manure, green leaf manure (*Sesbaniarostrata*), composted coirpith, azolla and neem cake applied on stipulated N basis. These manures were analyzed for N, P and K contents and the quantity of organic manures used to supply the required quantity of N as per treatment schedule (Tables 4 to 7) were calculated and applied at ten days prior to transplanting. The treatment that received fertilizer N at 90 kg ha^{-1} and P_2O_5 and K_2O each at 40 kg ha^{-1} received the nutrients in the form of urea, super phosphate and muriate of potash. Half the dose of N and K_2O and full dose of P_2O_5 were applied basally and the remaining half of the N and K_2O were applied in 2 equal splits at tillering and panicle initiation stages. The absolute control treatment received no manures or fertilizers.

Nutrient use efficiency

Partial factor productivity (PFP_N)

Cassman et al. (1996) introduced the term Partial Factor Productivity. The effectiveness of applied nutrients is to establish by this factor. The most important advantage of this index is that it quantifies total economic output from any particular factor/nutrient, relative to its utilization from all resources in the system, including native soil nutrients and nutrients from applied inputs (Dobermann and Fairhurst, 2000). Thus, the changes in PFP for N over the years can be used to indicate the sustainability of the potato production system.PFP_N = kg grain per kg N applied:

$$PFP_N = GY_{+N} / FN$$

Where, $GY_{+N}$is the grain yield in kg ha^{-1} and FN is the amount of fertilizer N applied in kg ha^{-1}.

Agronomic efficiency (AE_N)

AE_N = kg grain yield increase per kg N applied (often used synonym: N use efficiency:

$$AE_N = \Delta\ GY_{+N} / FN$$

Where, $GY_{+N}$is the grain yield in a treatment with N application kg ha^{-1}. GY_{0N} is the grain yield in a treatment without N application, and FN is the amount of fertilizer N applied, all in the kg ha^{-1}.

Recovery efficiency of applied nitrogen (RE_N)

RE_N = kg N taken up per kg N applied:

Table 2. Initial soil physico chemical characteristics of the experimental field.

S/N	Particulars	Value
A. Mechanical analysis		
1	Clay (%)	21.15
2	Silt (%)	10.50
3	Fine sand (%)	40.70
4	Coarse sand (%)	27.25
	Texture	Sandy clay loam
B. Physical properties		
1	Bulk density (Mg m^{-3})	1.24
2	Particle density (Mg m^{-3})	2.48
3	Hydraulic conductivity (cm h^{-1})	4.4
4	Water holding capacity (%)	38.4
5	Pore space (%)	52.7
C. Physico chemical properties		
1	pH	7.9
2	EC (dS m^{-1})	0.4
3	CEC (cmol (p^+) kg^{-1})	20.1
D. Chemical properties		
1	Total N (%)	0.32
2	Total P (%)	0.05
3	Total K (%)	0.18
4	Total Ca (%)	0.75
5	Total Mg (%)	0.21
6	Available N (kg ha^{-1})	285
7	Available P (kg ha^{-1})	15.0
8	Available K (kg ha^{-1})	380
9	Exchangeable Ca (cmol (P^+) kg^{-1})	4.3
10	Exchangeable Mg (cmol (P^+) kg^{-1})	2.4
11	Available Zn (ppm)	1.46
12	Available Cu (ppm)	1.25
13	Available Fe (ppm)	10.5
14	Available Mn (ppm)	19.5
15	Organic carbon (%)	0.59

$RE_N = UN_{+N} – UN_{0N}$

Where, UN_{+N} is the total N uptake measured in above ground biomass at physiological maturity (kg ha^{-1}) in plots that received applied N at the rate of FN (kg ha^{-1}). UN_{0N} is the total N uptake without N addition.

Physiological efficiency of applied nitrogen (PE_N)

PE_N = kg grain yield increase per kg fertilizer N taken up:

$PE_N = (GY_{+N} – GY_{0N}) / (UN_{+N} – UN_{0N})$

Where, GY_{+N} is the grain yield in a treatment with N application kg ha^{-1}. GY_{0N} is the grain yield in a treatment without N application. UN_{+N} are the total N uptake in a treatment with N application kg ha^{-1}. UN_{0N} is the total N uptake in a treatment without N application.

Internal efficiency of applied nitrogen (IE_N)

IE_N = kg grain per kg N taken up:

$IE_N = GY / UN$

Where, GY is the grain yield (kg ha^{-1}) and UN is the total N uptake (kg ha^{-1}).

RESULTS AND DISCUSSION

Ammonical nitrogen

Ammonical N - Kharif'04

Among various treatments, FYM + NC (T_6) showed significantly more soil ammonical N (48.8 ppm) as compared to absolute control (22.0 ppm). The per cent increase over control was 122%. But T_6 treatment was on par with recommended NPK fertilizer (47.9 ppm), SR + NC (45.6 ppm), CCP + NC (43.1 ppm) and FYM + NC + azolla (42.0 ppm) treatments (Table 3).

Table 3. Ammonical nitrogen (ppm) content of soil - *Kharif'*04.

	Treatment (T)	Active tillering (S_1)	Panicle initiation (S_2)	Post harvest (S_3)	Mean
T_1	Control	17.5	25.3	23.2	22.0
T_2	Rec. NPK fertilizer	43.0	51.2	49.4	47.9
T_3	FYM	36.5	41.2	39.1	38.9
T_4	SR	36.0	41.2	38.5	38.6
T_5	CCP	30.2	38.1	35.3	34.5
T_6	FYM + NC	43.8	53.0	49.5	48.8
T_7	FYM + NC + Azolla	37.2	46.3	42.5	42.0
T_8	SR + NC	40.7	49.5	46.7	45.6
T_9	SR + NC + Azolla	34.9	42.0	40.1	39.0
T_{10}	CCP + NC	38.7	47.5	43.2	43.1
T_{11}	CCP + NC + Azolla	33.4	41.7	39.5	38.2
T_{12}	FYM + Azolla	34.9	41.1	40.1	38.7
T_{13}	SR + Azolla	37.2	43.2	41.7	40.7
T_{14}	CCP + Azolla	28.5	38.2	34.2	33.6
	Mean	35.8	42.8	40.2	-
		SEd		*CD (p = 0.05)*	
	T	3.4		6.7	
	S	1.6		1.3	
	T × S	5.8		NS	

FYM, Farmyard manure; SR, *Sesbaniarostrata*; CCP, composted coirpith; NC, neem cake.

Among FYM treatments, FYM + NC (T_6) showed higher soil ammonical N (48.8 ppm) followed by FYM + NC + azolla (42 ppm), FYM (38.9 ppm) and FYM + azolla (38.7 ppm) treatments. The treatment T_6 was significantly higher to T_{12} and T_3 treatments were on par with each other. The availability of nitrogen in soil as influenced by various FYM treatments in the order of FYM + NC > FYM + NC + azolla> FYM + azolla> FYM. Among SR treatments SR + NC (45.6 ppm) showed higher value than SR + azolla (40.7 ppm), SR + NC + azolla (39 ppm) and SR (38.6 ppm) treatments. But all the SR treatments were on par with each other. The availability of nitrogen in soil as influenced by various *S. rostrata* treatments in the order of SR + NC > SR + NC + azolla> SR + azolla> SR. Among all the CCP treatments CCP + NC (T_{10}) registered higher ammonical N (43.1 ppm) followed by CCP + NC + azolla (38.2 ppm). These treatments were significantly higher to CCP + azolla treatment (33.6 ppm). T_5 was on par with T_{11} and T_{10} treatment was on par with T_{11}. The availability of nitrogen in soil as influenced by various CCP treatments in the order of CCP + NC > CCP + NC + azolla> CCP > CCP + azolla. Among BF treatments, FYM + NC + azolla (T_7) showed higher ammonical N (42.0 ppm). This was followed by SR + azolla (40.7 ppm), SR + NC + azolla (39.0 ppm), FYM + azolla (38.7 ppm), CCP + NC + azolla (38.2 ppm)and CCP + azolla (33.6 ppm) treatments. But T_7 treatment was significantly higher to T_{14} treatment. T_{13} showed significantly higher value than T_{14} treatment. T_{11} and T_{14} treatments were on par with each other. Among different plant growth stages, the panicle initiation stage (S_2) registered higher ammonical N (42.8 ppm) than the post harvest stage (40.2 ppm). But both were on par with each other. S_2 and S_3 were significantly higher than active tillering stage (35.8 ppm).

Ammonical N - Rabi'04

Among various organic treatments, FYM + NC (T_6) registered significantly higher ammonical N (50.1 ppm) than absolute control treatment (23.1 ppm). The per cent increase over control was 117. But T_6 treatment was on par with recommended NPK fertilizer (49.0 ppm), SR + NC (46.9 ppm), CCP + NC (44. 4 ppm) and FYM + NC + azolla (43.2 ppm) treatments (Table 4).

Among FYM treatments, FYM + NC (T_6) showed higher soil ammonical N (48.8 ppm) followed by FYM + NC + Azolla (43.2 ppm). But both were on par with each other. Treatment T_6 was significantly higher to FYM (40.1 ppm) and FYM + azolla (40.0 ppm). But T_7, T_3 and T_2 on par with each other. The availability of nitrogen in soil as influenced by various FYM treatments in the order of FYM + NC > FYM + NC + Azolla> FYM + azolla> FYM. Among SR treatments, SR + NC showed higher value (46.9) than SR + azolla (41.9 ppm) treatment. SR + NC + azolla (40.2 ppm) and SR (39.9 ppm). But all SR treatments were on par with each other. The availability

Table 4. Ammonical nitrogen (ppm) content of soil - *Rabi*'04.

Treatment (T)		Active tillering (S_1)	Panicle initiation (S_2)	Post harvest (S_3)	Mean
T_1	Control	18.7	26.4	24.3	23.1
T_2	Rec. NPK fertilizer	44.2	52.3	50.5	49.0
T_3	FYM	37.8	42.3	40.3	40.1
T_4	SR	37.4	42.4	39.7	39.9
T_5	CCP	31.6	39.3	36.4	35.8
T_6	FYM + NC	45.2	54.3	50.8	50.1
T_7	FYM + NC + Azolla	38.5	47.5	43.7	43.2
T_8	SR + NC	42.0	50.8	47.9	46.9
T_9	SR + NC + Azolla	36.2	43.2	41.3	40.2
T_{10}	CCP + NC	40.1	48.7	44.4	44.4
T_{11}	CCP + NC + Azolla	34.7	42.9	40.7	39.4
T_{12}	FYM + Azolla	36.2	42.4	41.3	40.0
T_{13}	SR + Azolla	38.5	44.4	42.9	41.9
T_{14}	CCP + Azolla	29.8	39.4	35.4	34.9
	Mean	37.4	43.8	40.8	-
		SEd		*CD (p = 0.05)*	
T		4.0		8.0	
S		1.9		3.7	
T × S		6.9		NS	

FYM, Farmyard manure; SR,*Sesbaniarostrata*; CCP, composted coirpith; NC, neem cake.

of nitrogen in soil as influenced by various *S. rostrata* treatments in the order of SR + NC > SR + azolla> SR + NC + azolla> SR. Among CCP treatments CCP + NC (T_{10}) registered significantly higher ammonical N (44.4 ppm) than CCP + NC + Azolla (39.4 ppm), CCP (35.8 ppm), CCP + azolla (34.9 ppm) T_{10} was significantly higher than T_5 and all other treatment on par with each other. The availability of nitrogen in soil as influenced by various CCP treatments in the order of CCP + NC > CCP + NC + Azolla> CCP > CCP + azolla.

Among BF treatments FYM + NC + azolla showed higher ammonical N (48.8 ppm) than SR + NC + azolla (40.2 ppm), SR + azolla (41.9 ppm), FYM + azolla (40.0 ppm) CCP + NC + azolla (39.4 ppm) and CCP + azolla (34.9 ppm). T_7 was significantly higher to T_{14} treatment. T_9, T_{11}, T_{12}, T_{13} and T_{14} treatments were on par with each other. Among different plant growth stages, S_2 registered significantly higher ammonical N value (43.8 ppm) than active tillering stage (37.4 ppm). But S_1 was on par with post harvest stage ammonical N (40.8 ppm).

Nitrate nitrogen

Nitrate N - Kharif'04

Among various treatments FYM + NC (T_6) registered significantly higher soil nitrate N (14.0 ppm) compared to absolute control (2.1 ppm) treatment (Table 5). But T_6 treatment was on par with recommended NPK fertilizer (13.2 ppm) and SR + NC (12.9 ppm).

Among FYM treatments, FYM + NC (T_6) showed significantly higher soil nitrate N (14.0 ppm) than FYM + NC + azolla (11.1 ppm), FYM (10.2 ppm) and FYM + azolla (9.3 ppm) treatments. T_3, T_7 and T_{12} treatments were on par with each other. The availability of nitrogen in soil as influenced by various FYM treatments in the order of FYM + NC > FYM + NC + Azolla> FYM > FYM + azolla. Among SR treatments, SR + NC (T_8) showed significantly higher nitrate N (12.9 ppm) than SR (10.2 ppm), SR + NC + azolla (10.0 ppm) and SR + azolla (9.2 ppm) treatments. T_4, T_9 and T_{13} treatments were on par with each other. The availability of nitrogen in soil as influenced by various *S. rostrata* treatments in the order of SR + NC > SR + NC + azolla> SR > SR + azolla. Among CCP treatments, CCP + NC (T_{10}) gave significantly higher nitrate N (11.9 ppm) followed by CCP (9.2 ppm) CCP + NC + azolla (9.1 ppm) and CCP + azolla (8.0 ppm) treatments. T_5, T_{11}, and T_{14} treatments were on par with each other. The availability of nitrogen in soil as influenced by various CCP treatments in the order of CCP + NC > CCP + NC + azolla> CCP > CCP + azolla.

Among BF treatments, FYM + NC + azolla (T_7) showed higher nitrate N (11.1 ppm) followed by SR + NC + azolla (10.0 ppm). The treatments T_7 and T_9 was significantly higher to CCP + azolla (8.0 ppm) T_9 on par with FYM + azolla (9.3 ppm) were SR + azolla (9.2 ppm) CCP + NC +

Table 5. Nitrate nitrogen (ppm) content of soil - *Kharif'* 04.

Treatment (T)		Active tillering (S_1)	Panicle initiation (S_2)	Post harvest (S_3)	Mean
T_1	Control	2.6	2.2	1.6	2.1
T_2	Rec. NPK fertilizer	11.1	14.8	13.7	13.2
T_3	FYM	5.9	13.5	11.1	10.2
T_4	SR	5.7	13.3	11.5	10.2
T_5	CCP	4.6	12.5	10.6	9.2
T_6	FYM + NC	11.5	16.2	14.4	14.0
T_7	FYM + NC + Azolla	8.4	13.3	11.6	11.1
T_8	SR + NC	10.5	14.8	13.3	12.9
T_9	SR + NC + Azolla	7.8	11.8	10.5	10.0
T_{10}	CCP + NC	10.3	13.6	11.8	11.9
T_{11}	CCP + NC + Azolla	6.2	10.8	10.2	9.1
T_{12}	FYM + Azolla	8.3	10.4	9.2	9.3
T_{13}	SR + Azolla	8.4	10.3	8.9	9.2
T_{14}	CCP + Azolla	5.3	10.3	8.4	8.0
	Mean	7.6	12.0	10.5	-
		SEd		*CD (p = 0.05)*	
	T	1.0		2.0	
	S	0.5		0.9	
	T × S	1.7		NS	

FYM, Farmyard manure; SR, *Sesbaniarostrata*; CCP, composted coirpith;NC, neem cake.

azolla (9.1 ppm) treatments. Among different plant growth stages the PI stage (S_2) showed significantly higher higher nitrate N (12.0 ppm) than post harvest stage (10.5 ppm) and active tillering stage (7.6 ppm). But S_3 was significantly higher to S_1.

Nitrate N - Rabi'04

During *Rabi*'04 among various treatments FYM + NC (T_6) registered significantly higher soil NO_3-N (13.5 ppm) compared to absolute control (3.0 ppm) treatment (Table 6). But T_6 treatment was on par with recommended NPK fertilizer (12.6 ppm) and SR + NC (12.3 ppm). Among FYM treatments, FYM + NC (T_6) showed significantly higher soil NO_3 N (13.5 ppm) than FYM + NC + azolla (10.6 ppm), FYM (9.7 ppm) and FYM + azolla (8.6 ppm) treatments. The treatments T_3, T_7 and T_{12} were on par with each other. The availability of nitrogen in soil as influenced by various FYM treatments in the order of FYM + NC > FYM + NC + Azolla> FYM > FYM + azolla. Among SR treatments, SR + NC (T_8) showed significantly higher NO_3- N (12.3 ppm) than SR (9.6 ppm), SR + NC + azolla (9.6 ppm) and SR + azolla (8.7 ppm). T_4, T_9 and T_{13} treatments were on par with each other. The availability of nitrogen in soil as influenced by various *S. rostrata* treatments in the order of SR + NC > SR + NC + azolla> SR > SR + azolla. Among CCP treatments CCP + NC (T_{10}) gave significantly higher NO_3-N (11.3 ppm) than CCP (8.7 ppm), CCP + NC + azolla (8.7 ppm) CCP + azolla (7.5 ppm). T_5, T_{11} and T_{14} treatments were on par with each other. The availability of nitrogen in soil as influenced by various CCP treatments in the order of CCP + NC > CCP + NC + azolla> CCP > CCP + azolla.

Among BF treatments, FYM + NC + azolla (T_7) showed higher NO_3-N (10.6 ppm) than SR + NC + azolla (9.6 ppm). T_9 and T_9 was significantly higher to CCP + azolla (7.5 ppm). T_9 on par with SR + azolla (8.7 ppm) and CCP + NC + azolla (8.7 ppm) FYM + azolla (8.6 ppm) treatments. Among different plant growth stages the PI stage (S_2) registered significantly higher nitrate N (11.6 ppm) than post harvest stage (10.1 ppm) and active tillering stage (7.1 ppm). But S_3 was significantly higher to S_1 stage.

Available N - *Kharif'* 04

Among various organic manure treatments FYM + NC (T_6) registered significantly higher soil available N (321kg ha^{-1}) compared to absolute control (238 kg ha^{-1}) treatment. The per cent increase over control was 35. But T_6 treatment was on par with T_7 (312 kg ha^{-1}), T_8 (310 kg ha^{-1}) and T_9 (310 kg ha^{-1}) treatments (Table 7).

Among FYM treatments, FYM + NC (T_6) recorded higher available N (321 kg ha^{-1}) followed by FYM + NC + azolla treatment (312 kg ha^{-1}). But these treatments were on par with each other. The per cent increase in FYM + NC

Table 6. Nitrate nitrogen (ppm) content of soil - *Rabi*'04.

Treatment (T)		Active tillering (S_1)	Panicle initiation (S_2)	Post harvest (S_3)	Mean
T_1	Control	3.5	3.0	2.6	3.0
T_2	Rec. NPK fertilizer	10.3	14.2	13.2	12.6
T_3	FYM	5.3	13.1	10.6	9.7
T_4	SR	5.1	12.8	11.0	9.6
T_5	CCP	4.1	12.0	10.1	8.7
T_6	FYM + NC	10.9	15.6	13.9	13.5
T_7	FYM + NC + Azolla	7.9	12.8	11.1	10.6
T_8	SR + NC	10.0	14.3	12.7	12.3
T_9	SR + NC + Azolla	7.3	11.5	10.0	9.6
T_{10}	CCP + NC	9.5	13.1	11.3	11.3
T_{11}	CCP + NC + Azolla	5.7	10.6	9.7	8.7
T_{12}	FYM + Azolla	7.3	9.9	8.7	8.6
T_{13}	SR + Azolla	7.9	9.8	8.3	8.7
T_{14}	CCP + Azolla	4.8	9.8	7.9	7.5
	Mean	7.1	11.6	10.1	-
		SEd		*CD (p = 0.05)*	
	T	1.0		1.9	
	S	0.4		0.9	
	T × S	1.7		NS	

FYM, Farmyard manure; SR, *Sesbaniarostrata*; CCP, composted coirpith; NC, neem cake.

Table 7. Available nitrogen content (kg ha^{-1}) of soil - *Kharif*'04.

Treatment (T)		Active tillering (S_1)	Panicle initiation (S_2)	Post harvest (S_3)	Mean
T_1	Control	252	246	217	238
T_2	Rec. NPK fertilizer	322	319	272	304
T_3	FYM	328	322	252	301
T_4	SR	322	312	257	297
T_5	CCP	322	307	242	290
T_6	FYM + NC	342	332	289	321
T_7	FYM + NC + Azolla	332	331	272	312
T_8	SR + NC	330	325	274	310
T_9	SR + NC + Azolla	327	324	280	310
T_{10}	CCP + NC	325	321	260	302
T_{11}	CCP + NC + Azolla	323	318	272	304
T_{12}	FYM + Azolla	329	327	262	306
T_{13}	SR + Azolla	325	317	262	301
T_{14}	CCP + Azolla	321	313	252	295
	Mean	321	315	262	-
		SEd		*CD (p = 0.05)*	
	T	8		16	
	S	4		7	
	T × S	14		NS	

FYM, Farmyard manure; SR, *Sesbaniarostrata*; CCP, Composted coirpith; NC, Neem cake.

over FYM + NC + Azolla, FYM + Azolla and FYM was 2.8, 4.7 and 6.2 respectively. Among SR treatments SR + NC and SR + NC + azolla registered available N of 310 kg ha^{-1}. The per cent increase in SR + NC and SR + NC + azolla

Table 8. Available nitrogen content (kg ha^{-1}) of soil - *Rabi*'04.

Treatment (T)		Active tillering (S_1)	Panicle initiation (S_2)	Post harvest (S_3)	Mean
T_1	Control	212	200	187	200
T_2	Rec. NPK fertilizer	328	322	277	309
T_3	FYM	332	328	258	306
T_4	SR	326	317	261	301
T_5	CCP	318	313	246	292
T_6	FYM + NC	350	340	297	329
T_7	FYM + NC + Azolla	337	337	278	317
T_8	SR + NC	336	331	280	316
T_9	SR + NC + Azolla	333	327	284	315
T_{10}	CCP + NC	330	324	267	307
T_{11}	CCP + NC + Azolla	329	323	276	309
T_{12}	FYM + Azolla	333	333	264	310
T_{13}	SR + Azolla	330	322	267	306
T_{14}	CCP + Azolla	326	318	258	301
	Mean	323	317	264	-
		SEd		*CD (p = 0.05)*	
	T	8		16	
	S	4		7	
	T × S	14		NS	

FYM, Farmyard manure; SR, *Sesbaniarostrata*; CCP, composted coirpith; NC, neem cake.

over SR + azolla and SR was 2.9 and 4.1, respectively. Among CCP treatments CCP + NC + azolla showed higher available N (304 kg ha^{-1}). But it was on par with T_{10} (302 kg ha^{-1}) and T_{14} (295 kg ha^{-1}) treatments (Table 7).

Among the BF treatments, FYM + NC + BF gave higher available N (312 kg ha^{-1}) followed by SR + NC + azolla (310 kg ha^{-1}), but both were on par with each other. The CCP + NC + azolla registered higher available N (304 kg ha^{-1}) followed by FYM + azolla (306 kg ha^{-1}), SR + azolla (301 kg ha^{-1}), CCP + azolla (295 kg ha^{-1}). But all the treatments were on par with each other.

The recommended NPK fertilizer treatment showed significantly low available N (304 kg ha^{-1}) compared to FYM + NC treatment (321 kg ha^{-1}). But T_2 was significantly higher available N than the absolute control treatment (238 kg ha^{-1}). Among different plant growth stages, active tillering stage showed significantly higher available N (321 kg ha^{-1}) than panicle Initiation (PI) and post harvest stages. The panicle initiation stage showed significantly higher available N (315 kg ha^{-1}) than the post harvest stage (262 kg ha^{-1}). The soil available N content was found to be decreasing from tillering stage (321 kg ha^{-1}) to post harvest stage (261 kg ha^{-1}).

Available N - Rabi'04

Among various organic manures treatments tried, FYM + NC (T_6) showed significantly higher soil available N (329 kg ha^{-1}) compared to absolute control (200 kg ha^{-1}). The per cent increase over control was 65 (Table 8).

Among FYM treatments, FYM + NC gave higher available N (329 kg ha^{-1}) followed by FYM + NC + azolla treatment (317 kg ha^{-1}). But both were on par with each other. The availability of nitrogen in soil as influenced by various FYM treatments in the order of FYM + NC > FYM + NC + Azolla> FYM + azolla> FYM. The SR + NC registered higher available N (316 kg ha^{-1}) followed by SR + NC + azolla treatment (315 kg ha^{-1}). But both were on par with each other. The availability of nitrogen in soil as influenced by various *S. rostrata* treatments in the order of SR + NC > SR + NC + azolla> SR + azolla> SR. Among CCP treatments CCP + NC + azolla showed higher available N (309 kg ha^{-1}) which was on par with T_{10} (307 kg ha^{-1}) and T_{14} (301 kg ha^{-1}) treatments. The availability of nitrogen in soil as influenced by various CCP treatments in the order of CCP + NC + azolla> CCP + NC > CCP + azolla> CCP.

Among BF treatments, FYM + NC + BF treatment gave higher available N (317) followed by SR + NC + BF (315 kg ha^{-1}), but both were on par with each other. The FYM + azolla (T_6) registered higher available N (310 kg ha^{-1}) followed by CCP + NC + azolla (309), SR + azolla (306 kg ha^{-1}) and CCP + azolla (301 kg ha^{-1}) treatments. But all the treatments were on par with each other.

The recommended NPK fertilizer treatment (T_2) showed significantly reduced available N (309) compared to FYM

Table 9. Nutrient use efficiency (NUE) at *Kharif* '04.

Treatment		PFP_N	AE_N	RE_N
T_2	Rec. NPK fertilizer	55.5	22.2	60
T_3	FYM	50.2	16.9	49
T_4	SR	44.6	11.3	40
T_5	CCP	44.5	11.2	39
T_6	FYM + NC	63.1	29.8	86
T_7	FYM + NC + Azolla	51.3	18.0	52
T_8	SR + NC	48.1	14.8	52
T_9	SR + NC + Azolla	45.9	12.6	45
T_{10}	CCP + NC	58.9	25.6	70
T_{11}	CCP + NC + Azolla	45.7	12.4	44
T_{12}	FYM + Azolla	52.3	19.0	56
T_{13}	SR + Azolla	45.8	12.5	46
T_{14}	CCP + Azolla	47.0	13.7	48
	Mean	46.6	15.7	49.1

FYM, Farmyard manure; SR, *Sesbaniarostrata*; CCP, composted coirpith; NC, neem cake; PFP_N,partial factor productivity of applied N; AE_N, agronomic efficiency of applied N; RE_N, recovery efficiency of applied N.

+ NC treatment (329 kg ha^{-1}). But T_2 was significantly higher available N (309 kg ha^{-1}) over absolute control (200 kg ha^{-1}). The increase over control was 55%. Among the different growth stages, active tillering stage registered significantly higher available N (323 kg ha^{-1}) followed by panicle initiation stage (317 kg ha^{-1}), but it was significantly higher than post harvest stage (264 kg ha^{-1}). Between the seasons, *Rabi* season showed higher soil available N (301kg ha^{-1}) over the *Kharif* season (299 kg ha^{-1}).

Partial factor productivity (PFP_N)

During *Kharif* season, The PFP_N values have FYM treatments (50.2 to 63.1) SR treatment (44.6 – 48.1) and CCP treatments (44.5 to 58.9) respectively. The treatments (44.6 to 48.1) and CCP treatments (T_2) showed PFP_N value of 55.5. During *Rabi* season, the PFP_N values of FYM treatments (44.5 to 57.5) SR treatments (39.2 to 42.5) and CCP treatments (38.9 to 53.3) respectively. The recommended NPK fertilizer treatment (T_2) showed PFP_N showed PFP_N value of 49.9 (Tables 9 and 11).

Agronomic efficiency (AE_N)

Kharif season, the AEN values of FYM treatments ranged between 16.9 to 29.8 SR treatments 11.3 to 14.8 and CCP treatments 11.2 to 25.6. The recommended NPK fertilizer treatment (T_2) showed AE_N value of 22.2. *Rabi* season the AEN values of FYM treatments ranged between 16.7 to 29.6 SR treatments 11.3 to 14.6 and CCP treatments 11.0 to 25.4, respectively. The recommended NPK fertilizer treatment (T_2) showed AE_N value of 22.1 (Tables 9 and 11).

Recovery efficiency (RE_N)

During *Kharif* season, the RE_N values of FYM treatments ranged from 49 to 86, for SR treatments from 48 to 56 and for CCP treatments from 39 to 70 respectively. The recommended NPK fertilizer treatment showed RE_N value of 60. During *Rabi* season, the RE_N values of FYM treatments ranged from 53 to 96, for SR treatments 48-56 and for CCP treatments 43-73, respectively. The recommended NPK fertilizer treatment showed RE_N value of 69 (Tables 9 and 11).

Physiological efficiency (PE_N)

During *Kharif* season, the PE_N values of FYM + treatments varied from 31.2 to 31.3, for SR treatments (25.2 to 25.6) and for CCP treatments 25.4 to 32.9, respectively. The recommended NPK fertilizer treatment (T_2) showed PE_N value of 33.3. During *Rabi* season, the PE_N values of FYM + treatments varied from 27.8 to 29.3, for SR treatments 20.3 to 23.5 and for CCP treatments 20.6 to 31.4, respectively. The recommended NPK fertilizer treatment (T_2) showed PE_N value of 28.8 (Tables 10 and 12).

Internal efficiency (IE_N)

During *Kharif* season, the IE_N value of FYM treatment ranged from 40.6 - 41.6, for SR treatments 39.0 to 41.6

Table 10. Nutrient use efficiency (NUE) - *Kharif*'04.

Treatment		PE_N	IE_N
T_2	Rec. NPK fertilizer	33.3	42.0
T_3	FYM	31.1	41.9
T_4	SR	25.5	40.6
T_5	CCP	25.8	40.8
T_6	FYM + NC	31.1	39.1
T_7	FYM + NC + Azolla	31.2	41.6
T_8	SR + NC	25.6	39.0
T_9	SR + NC + Azolla	25.2	39.7
T_{10}	CCP + NC	32.9	41.1
T_{11}	CCP + NC + Azolla	25.4	40.0
T_{12}	FYM + Azolla	30.6	41.0
T_{13}	SR + Azolla	24.4	39.2
T_{14}	CCP + Azolla	25.6	39.5
Mean		26.3	37.5

FYM, Farmyard manure; SR, *Sesbaniarostrata*; CCP, composted coirpith; NC, neem cake; PE_N, physiological efficiency of applied N; IE_N,internal efficiency of applied N.

Table 11. Nutrient use efficiency (NUE) - *Rabi*'04.

Treatment		PFP_N	AE_N	RE_N
T_2	Rec. NPK fertilizer	49.9	22.1	69
T_3	FYM	44.5	16.7	53
T_4	SR	39.2	11.3	48
T_5	CCP	38.9	11.0	43
T_6	FYM + NC	57.5	29.6	96
T_7	FYM + NC + Azolla	45.8	17.9	55
T_8	SR + NC	42.5	14.6	56
T_9	SR + NC + Azolla	40.2	12.4	55
T_{10}	CCP + NC	53.3	25.4	73
T_{11}	CCP + NC + Azolla	40.2	12.4	54
T_{12}	FYM + Azolla	46.8	18.9	53
T_{13}	SR + Azolla	40.1	12.3	46
T_{14}	CCP + Azolla	41.4	13.5	48
	Mean	41.4	15.6	53.5

FYM, Farmyard manure; SR, *Sesbaniarostrata*; CCP, composted coirpith; NC, neem cake; PFP_N, partial factor productivity of applied N; AE_N, agronomic efficiency of applied N; RE_N, recovery efficiency of applied N.

and for CCP treatments 40.0 to 40.8, respectively. The recommended NPK fertilizer treatment (T_2) showed IE_N value of 42.0. During *Rabi* season, the IE_N value of FYM treatment ranged from 37.0 to 41.6, for SR treatments from 38.2 to 36.6 and for CCP treatments from 36.9 to 40.2, respectively. The recommended NPK fertilizer treatment (T_2) showed IE_N value of 39.8 (Table 10 and 12).

The partial factor productivity of applied N (PFP_N) is a useful measure of N use efficiency, as it provides an integrative index quantifying total economic output (grain yield) in relation to utilization of N in the system including soil N supply and applied N (Cassman et al., 1996). It reflects both AEN and the balance between the indigenous soil N supply and applied N. The AEN represents the product of PE_N with which the crop utilizes the acquired N to produce more grain and the RE_N. The nitrogen use efficiency with application of 75% chemical fertilizers + weed vermicompost at 2.5 tha^{-1} was better than other combinations closely followed by 50% RDF + 50 % prathista organics (Rama Lakshmi et al. 2012).

The PEP_N, AE_N, RE_N, PE_N and IE_N values were higher

Table 12. Nutrient use efficiency (NUE) - *Rabi*'04.

Treatment		PE_N	IE_N
T_2	Rec. NPK fertilizer	28.8	39.8
T_3	FYM	28.3	41.3
T_4	SR	21.2	38.3
T_5	CCP	23.1	40.2
T_6	FYM + NC	27.8	37.0
T_7	FYM + NC + Azolla	29.3	41.6
T_8	SR + NC	23.5	38.2
T_9	SR + NC + Azolla	20.3	36.6
T_{10}	CCP + NC	31.4	41.0
T_{11}	CCP + NC + Azolla	20.6	36.9
T_{12}	FYM + Azolla	32.1	43.4
T_{13}	SR + Azolla	24.0	40.1
T_{14}	CCP + Azolla	25.3	40.5
Mean		24.0	36.8

FYM, Farmyard manure; SR, *Sesbaniarostrata*; CCP, composted coirpith; NC, neem cake; PE_N, physiological efficiency of applied N; IE_N, internal efficiency of applied N.

in the treatment receiving 90 kg N ha^{-1} through FYM + NC (T_6). The recommended NPK fertilizer treatment showed lesser nitrogen use efficiency compared to organic manure treatment (T_6). Similar observations were earlier reported by Cassman et al. (1996). In the conventional synthetic fertilizer applied treatment, the efficiency was found to be as low as the transformation losses of N was more, whereas the combination of FYM and neem cake could have supplied the nitrogen, the growth element slow and steady so as to match the crop demand resulting in high harvest index ultimately the NUE was high. Similar high N use efficiency for neem cake application was earlier reported by Saravanan et al. (1988). The higher grain and seed yields of rice and greengram with integrated use of different vermicomposts and chemical fertilizers might be attributed to higher availability of macro and micro nutrients and facilitating uptake by plants resulting in better growth and dry matter production and also occurrence of different beneficial microorganisms, presence of growth promoting substances, hormones, enzymes, antibiotics among others in vermicompost. Similar results were reported by Bariket al. (2008) and Datta and Singh (2010).

Conclusion

The ammonical and nitrate nitrogen contents of the soil were increased with the application of different organic manures. Among different organic N sources, incorporation of 90 kg N ha^{-1} in the form of FYM + neek cake, *S. rostrata* + neem cake, composted coirpith + neem cake and FYM + neem cake + azolla recorded higher NH_4-N and NO_3-N contents of soil over the control in *Kharif'04* and *Rabi'04*. Incorporation of FYM + neem cake registered higher available N in both *Kharif'04* and *Rabi'04* seasons. The next best source was *S. rostrata* + neem cake. The nitrogen use efficiency parameters such as PFP_N, AE_N, RE_N, PE_N and IE_N values were higher in the treatment receiving FYM + neem cake.

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