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Effect of conservation tillage, residue and nitrogen levels on soil nitrogen fractions and their contributions in nitrogen uptake in castor (*Ricinus communis*)

D SUMA CHANDRIKA[1], K L SHARMA[2], S VIDYAVATHI[3], MUNNALAL[4], T SATISH KUMAR[5] and K USHA RANI[6]

Central Research Institute for Dryland Agriculture, Saidabad P O Santoshnagar, Hyderabad, Telangana 500 059

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ABSTRACT

This experiment was conducted in rainfed semi-arid tropical Alfisol at Hayathnagar Research Farm of Central Research Institute for Dryland Agriculture, Hyderabad, India, during the period 1995 to 2014 to study the long-term effect of conservation agricultural practices on organic and inorganic N fractions in soil, their contribution to available N pool and N uptake in castor (*Ricinus communis* L.). The experiment was conducted in a strip split-split plot design with conventional tillage (CT) and minimum tillage (MT) as main factors, surface application of sorghum stover @ 2 tonnes/ha (SS), fresh gliricidia loppings @ 2 tonnes/ha (GL) and 'no' residue (NR) as sub-factors and levels of N, viz. 0 (N_0), 30 (N_{30}), 60 (N_{60}) and 90 (N_{90}) kg N/ha as sub-sub factors. The results of the study revealed that increasing N levels influenced exchangeable ammonical N and nitrate N. Practice of conservation tillage, application of residues and nitrogen significantly influenced the hydrolysable organic N fractions in the soil. Among these, aminoacid N, hexosamine N, hydrolyzable NH_4^+ and unidentified N constituted 52%, 8%, 13% and 27% of total hydrolysable N. Linear regression relationship between castor yield and total soil N and N uptake ($R^2 = 0.998$) was found significant. Further, inter correlations between N fractions indicated free mobility among the N fractions. Hence, the build up of N in these pools can be significantly influenced by adoption of appropriate conservation agricultural practices on long term basis in rainfed Alfisols which are highly deficient in available soil N.

Key words: Alfisol, Castor yield, Conservation tillage, N uptake, Organic N fractions

Nitrogen is present in the soil in two major forms: organic and inorganic. A greater amount of nitrogen occurs in organic form. The inorganic form of N is considered as labile form of N and is susceptible to losses by way of runoff, leaching, ammonia volatilization, denitrification and fixation in clay lattices. Organic forms of N can be categorized as hydrolyzable N (Hydrolyzable NH_4, amino acid N, amino sugar N, acid soluble humin) and Non-Hydrolyzable N (Fixed NH_4, insoluble humin), whereas, the inorganic N fractions can be categorized as ammonical N (NH_4-N), nitrate N (NO_3-N) and nitrite N (NO_2-N). The hydrolyzable N fraction is subjected to mineralization and is transformed to mineral N. The distribution of these forms in soils is important in understanding the conditions controlling their availability to growing crops. The transformation of one form to another under specific soil conditions determines their availability to plants (Luce *et al*. 2013). The continuous addition of organic manures along with chemical fertilizers may stimulate mineralization and immobilization of plant nutrients, thereby affecting their amounts in different organic and inorganic forms in soil (Sihag *et al*. 2005). A few studies also have quantified the impacts of conservation tillage on mineralizable N. It was also observed that application of residues in long term conservation tillage treatments significantly influenced the yield and uptake of nitrogen by the crop (Malhi *et al*. 2006). In an another study, Sharma *et al*. (1992) reported that, significant inter correlation coefficients (r^2) between different N fractions indicated free mobility between the N fractions and significant contribution of Hydrolyzable N and unhydrolyzable N fractions towards N availability pool in Inceptisol soil. Organic soil N fractions including non hydrolysable N were highly significantly correlated with soil mineralizable N (Sammi reddy *et al*. 2003).

The rainfed Alfisol soils of Southern India, which are predominantly characterised by low organic matter, low soil fertility especially, plant available nitrogen (<280 kg N/ha), low water holding capacity and poor soil physical conditions,

[1]Ph D Scholar (e mail: sumachandrika@gmail.com), JNTU, Hyderabad; [2]Prinicipal Scientist and National Fellow (e mail: klsharma@crida.in), CRIDA, Hyderabad; [3]Associate Professor, (e mail: vidyasom@gmail.com), IST, JNTU, Hyderabad; [4]Research Associate (e mail: munnalalsingh10@gmail.com); [5]Senior Research Fellow (e mail: satishram84@gmail.com, [6]ACTO (e mail: usharani.kurra_99@gmail.com), CRIDA, Hyderabad.

do not support good crop growth unless, adequate amount of nitrogenous fertilizers are applied. Intensive tillage, poor recycling back of crop residue to the soil after crop harvest, high soil temperature during summer leading to faster decomposition of the organic matter could be some of the predominant reasons of low soil organic matter (SOM) and low plant available nitrogen in these soils. Consequent to these natural and man-made causes, yields of rainfed crops such as, sorghum and castor grown in these soils is considerably low and need appropriate soil management. Considering the above, the present study was undertaken with the specific objectives (i) to investigate the long term effect of conservation tillage, residue application and different levels of N on the status of organic and inorganic fractions of N and (ii) to establish the quantitative relationship of various N fractions with castor yield, nitrogen uptake and plant available nitrogen pool in rainfed semi-arid tropical Alfisol soils.

MATERIALS AND METHODS

The study was conducted at Hayathnagar Research Farm of Central Research Institute for Dryland Agriculture, Hyderabad, India. Experimental soils belong to Hayathnagar soil series (Typic Haplustalf), which are slightly acidic (pH 5.3). These soils have a sandy surface layer, with increasing clay content in the sub-soil. Soils were initially low in organic C (3.7 g/kg) and available N ($KMnO_4$ oxidizable N) (145.6 kg/ha) and medium in available P s (Olsen's P) (12.5 kg/ha) and K (1N ammonium acetate extractable K) (179.2 kg/ha). The experiment was started during the year 1995 in a strip split-split plot design with two tillage practices as the main treatments, three residue levels as sub-plot treatments and four nitrogen levels as the sub-sub plot treatments with three replications, castor (*Ricinus communis* L.) variety DCS 9 was used as test crop. The strip consisted of two tillage treatments, viz. (i) conventional tillage (CT) with two ploughings before planting + one plough planting + harrowing + operation for top dressing and ii) minimum tillage which included weeding occasionally with blade harrow or chemical spray and only seeding with tractor drawn planter/farm plough. In the CT strip, during the pre monsoon showers, the field was ploughed using a tractor drawn cultivator followed by one disk ploughing to a depth of 10-12 cm. The three residues treatments included (i) dry sorghum stover (SS) (N content of 5 g/kg and C: N ratio of 72) applied @ 2 tonnes/ha (ii) fresh gliricidia loppings (*Gliricidia maculata*) (GL) (N content of 27.6 g/kg on dry weight basis and C: N ratio of 15) @ 2 tonnes/ha (fresh weight) and (iii) no residue (NR). The four nitrogen levels were: (i) 0 kg N/ha (N_0), (ii) 30 kg N/ha (N_{30}), (iii) 60 kg N/ha (N_{60}) and (iv) 90 kg N/ha (N_{90}). Nitrogen was applied in two equal splits, one at sowing and another at 45 days after sowing while phosphorus was applied to each crop at 30 kg P_2O_5/ha at the time of sowing. Castor was sown in the 3rd week of June and was harvested during February.

After the 17th year of experimentation, soil samples were collected from 0-20 cm depth. The samples were air dried and passed through 2 mm sieve. The analysis of available soil N, total N (Micro-Kjeldahl method), soil inorganic N fraction and organic N fractions, viz. total hydrolyzable N, ammonium N, amino sugar N and amino acid N (Bremner 1965). Castor grain, husk and stover samples were dried at 60^o C, finely powdered and digested in a diacid mixture of HNO_3 and $HClO_4$ in 3:1 ratio. Nitrogen was determined by modified Micro-Kjeldahl method (Jackson 1973).

The effect of tillage residues and N levels on organic and inorganic N fractions was evaluated by analysis of variance (ANOVA). The data was tested at the level of significance of 95%. Statistics calculations were performed by IBM SPSS Statistics 19.

RESULTS AND DISCUSSION

Among the inorganic fractions, exchangeable ammonical nitrogen varied from 17.1 to 42.1 mg/kg while the nitrate-N varied between 3.89 and 13.4 mg/kg across the management treatments. Significantly highest ammonical N was observed under conventional tillage (32.5 mg/kg) than under minimum tillage (26.8 mg/kg). Application of residues, viz. sorghum stover and gliricidia loppings performed equally well in maintaining significantly highest inorganic N fractions when compared to 'no residue' application (Table 1). Significant increase in inorganic N fractions was observed with combined application of organic and inorganic N sources (Shilpasree *et al*. 2012). Both the ammonical and nitrate N fractions significantly improved with increase in N levels applied to the soil. Treatments which received N @ 90 kg/ha, recorded 87% higher exchangeable ammonical nitrogen compared to N_0 treatment. However, the interaction effects of tillage, residues and N levels did not influence the contents of ammonical and nitrate N fractions in these soils. Yadav and Singh (1991) also found significant increase in inorganic N fractions with increasing rates of N application.

The organic N fractions were estimated as the total hydrolyzable N which constituted hydrolyzable ammonical N, hexosamine N, amino acid N, and unidentified N. Total hydrolyzable N fraction varied from 333.6 to 648.9 mg/kg of soil across the management treatments. On an average, significantly highest total hydrolyzable N was observed with application of sorghum residues (508.5 mg/kg) followed by gliricidia loppings (481.6 mg/kg) compared to 'no residue' plots (440.4 mg/kg). Further, significant increase in total hydrolyzable N was observed with increase in N levels, with the highest value recorded in plots receiving N @ 90 kg N/ha (577.2 mg/kg). Of all the interactions studied, the interaction between tillage and residue was found to be significant. Similarly, Duraiswamy (1992) also observed increased amounts of organic N fractions under integrated nutrient management treatments. This indicates that inorganic and organic N undergoes a series of transformation process thereby contributing to soil organic N pools. Appel and Mengel (1993) confirmed that the soil organic N fractions reflected the soils microbial activities, and contributed to easily-mineralizable N pools in soils.

Table 1 Long-term effect of tillage, residues and N levels on nitrogen fractions (mg/kg).

Tillage	Residues	N levels	Exchange-able NH_4-N	Nitrate-N	Total Hydrolyz-able N	Hydrolyz-able NH_4-N	Hexosa-mine N	Amino acid N	Unidenti-fied N	Fixed ammonical N	Total N (kg/ha)
Conventional tillage	Sorghum stover	N0	22.2	6.55	367.8	49.4	26.7	212.6	79.1	105.1	1696.3
		N30	34.1	9.68	434.0	60.2	36.6	228.3	108.9	123.0	1973.9
		N60	38.3	11.6	576.1	69.4	47.4	259.9	199.4	135.8	2191.5
		N90	40.4	12.7	597.3	73.1	53.4	273.2	197.6	145.4	2334.6
	Gliricidia loppings	N0	20.1	7.16	382.9	49.5	26.6	221.5	85.3	109.7	1702.9
		N30	32.1	10.0	470.4	59.8	34.5	231.9	144.2	128.8	1891.6
		N60	39.2	12.9	526.1	63.9	45.0	242.3	175.0	137.8	2240.5
		N90	42.1	13.4	605.0	70.6	57.5	262.6	214.2	144.9	2253.4
	No residue	N0	19.9	4.61	337.8	42.6	20.9	178.8	95.5	97.8	1566.0
		N30	31.8	4.31	416.3	54.6	29.3	189.0	143.3	117.8	1770.8
		N60	33.8	5.66	457.2	60.6	36.5	192.8	167.3	123.5	1906.8
		N90	35.9	7.75	504.0	68.6	45.8	215.4	174.1	129.9	1973.1
Minimum tillage	Sorghum stover	N0	18.8	7.97	375.8	47.7	31.3	228.5	68.3	111.4	1800.0
		N30	27.8	9.47	512.4	67.8	39.4	270.0	135.3	162.9	1994.3
		N60	34.1	11.5	555.8	78.0	49.1	282.9	145.8	171.1	2231.5
		N90	36.4	12.4	648.9	83.6	61.3	288.5	215.5	179.6	2398.9
	Gliricidia loppings	N0	19.1	7.78	377.9	51.5	30.8	235.5	60.0	108.6	1732.2
		N30	24.3	9.96	436.7	65.0	38.0	260.6	73.2	177.2	1979.3
		N60	29.3	11.6	505.6	72.8	47.4	303.8	81.6	181.7	2280.4
		N90	33.3	12.7	548.4	78.4	59.3	308.0	102.7	183.8	2344.7
	No residue	N0	17.1	4.12	333.6	41.2	24.7	194.1	73.5	101.5	1631.4
		N30	23.8	3.89	426.0	48.5	36.8	256.2	84.5	141.2	1808.8
		N60	26.2	5.07	489.2	66.9	34.9	264.6	122.7	154.1	2109.6
		N90	31.8	6.96	559.4	64.7	48.8	287.0	158.9	170.4	2145.8
Tillage			NS	NS	NS	0.91	NS	12.17	7.22	3.62	50.30
Residue			NS	0.24	4.50	0.54	0.35	3.62	2.65	2.66	28.49
Nitrogen			3.45	0.73	18.92	3.82	2.86	10.81	12.83	6.71	80.21
T × R			NS	NS	NS	NS	NS	NS	3.75	NS	NS
T × N			NS	NS	NS	NS	NS	NS	NS	9.48	NS
R × N			NS	NS	NS	NS	NS	NS	NS	NS	NS
T × R × N			NS	NS	NS	NS	NS	NS	31.44	NS	NS

On an average, hydrolyzable ammonical N constituted 13% to the total hydrolyzable N and varied from 41.2 to 83.6 mg/kg across the management treatments. Sorghum stover application recorded significantly highest hydrolyzable ammonical N content of 66.1 mg/kg followed by gliricidia loppings (63.9 mg/kg). Higher hydrolyzable ammonical N content was observed with increase in N levels. Sharawad and Dhyan Singh (2005) observed that long term use of optimum dose of NPK either alone or in conjunction with FYM resulted in a significant increase in the amount of hydrolysable N fraction in soil which is the most important source of nitrogen for plants and microorganisms

Hexosamine N fraction contributed up to 8% towards total hydrolyzable N fraction and varied from 20.9 to 59.3 mg/kg across the various management treatments. Significant influence of the application of residues and N levels on hexosamine N was observed. Application of both sorghum stover as well as gliricidia loppings performed equally well in influencing the hexosamine N fraction in soil and maintained significantly highest hexosamine N content of 43.1 mg/kg and 42.4 mg/kg, respectively, compared to 'no residue' application (34.7 mg/kg) This fraction was found highest with N applied @ 90 kg/ha (54.4 mg/kg of soil). The contribution of amino acid N towards total hydrolyzable N was the highest (52%) that varied from 178.8 to 308 mg/kg across the management treatments. Tillage, residues as well as N levels significantly influenced the amino acid N fraction. On an average, significantly higher amino acid N content was observed under minimum tillage (265.0 mg/kg) followed by conventional tillage (225.7 mg/kg). Application of sorghum stover and gliricidia residues recorded higher amino acid N content to the extent of 255.5 mg/kg and 258.3 mg/kg, respectively, compared to control (222.2 mg/kg).

Application of 90 kg N/ha recorded significantly highest amino acid N (272.4 mg/kg). The quantum of unidentified N was to the extent of 27% to the total hydrolyzable N in the soil. From the data, it was observed that the unidentified N fraction was significantly higher under conventional tillage (148.7 mg/kg) while under minimum tillage, it was only 110.2 mg/kg. On an average, the unidentified N fractions were found to be significantly lower with the application of gliricidia loppings (117.0 mg/kg) followed by 'no residue' application (127.5 mg/kg) while it was slightly higher under sorghum stover application (143.7 mg/kg). Similar to other fractions, the unidentified N fraction also increased with increase in N levels. Fixed ammonical N, which represents the nitrogen retained in the clay lattices, varied between 97.8 to 183.8 mg/kg across the management treatments and was significantly influenced by tillage, residue application as well as varying N levels. Fixed ammonical N was significantly higher under minimum tillage (153.6 mg/kg) compared to conventional tillage (125.0 mg/kg). This fraction was observed to be highest under gliricidia loppings application (146.6 mg/kg), which was at par with sorghum stover application (141.8 mg/kg) compared to control (129.5 mg/kg). Nitrogen levels applied @ 60 and 90 kg/ha recorded fixed ammonical N to the extent of 150.7 and 159.0 mg/kg, respectively, while N applied at 30 kg/ha recorded 141.8 mg/kg (Table 1). Interaction effects of tillage, residues and N levels did not show much influence on fixed ammonical N. Sekhon *et al.* (2011) recorded marked increase in total N, hydrolysable N and non-hydrolysable N with continuous application of organic manures for 7 years.

Total nitrogen content varied from 1 566 to 2 344 kg/ha across the management treatments and was significantly influenced by residues and N levels. Tillage did not show any significant influence on total nitrogen. Both sorghum stover and gliricidia loppings treatments were at par with each other which maintained total N to the extent of 2 078 kg/ha and 2 053 kg/ha, respectively. Total N content in soils increased with increase in N levels and was highest at N applied @ 90 kg/ha (2 242 kg/ha). These results are in confirmation with Tang *et al*. (2006) who reported that long term application of manure and fertilizer effectively increased the content of organic N forms and total N.

Table 2   Yields of Castor bean, husk and stover as influenced by tillage, residues and N levels

Tillage	Residues	N levels	Castor bean yield	Castor husk yield	Castor stover yield
Conventional tillage	Sorghum stover	N0	1460.5	322.6	1767.2
		N30	1924.3	386.2	1943.6
		N60	2053.9	482.9	2279.8
		N90	1938.0	462.2	2147.3
	Gliricidia loppings	N0	1078.3	381.4	1304.7
		N30	1252.0	434.3	1264.5
		N60	1847.3	458.4	2050.5
		N90	1656.4	477.8	1835.3
	No residue	N0	690.9	258.1	836.0
		N30	1034.9	314.3	1045.2
		N60	1366.5	408.0	1516.8
		N90	1165.6	462.1	1291.5
Minimum tillage	Sorghum stover	N0	603.2	344.3	729.92
		N30	1720.4	358.2	1737.6
		N60	2027.9	507.0	2250.9
		N90	2238.0	462.9	2479.7
	Gliricidia loppings	N0	719.9	382.3	871.1
		N30	1662.7	411.8	1679.3
		N60	1846.8	502.9	2049.9
		N90	2060.0	458.8	2282.5
	No residue	N0	558.5	307.9	675.8
		N30	1318.0	320.9	1331.2
		N60	1766.6	465.5	1961.0
		N90	1650.7	483.5	1829.0
Tillage			6.61	4.52	7.13
Residue			3.42	1.88	3.95
Nitrogen			13.04	6.77	14.69
T × R			4.84	2.66	5.59
T × N			18.44	9.57	20.78
R × N			22.58	11.72	25.45
T × R × N			31.94	NS	35.99

Nitrogen uptake by castor bean, husk and stover

Tillage, residues and N levels showed significant influence on castor bean, husk and stover yields. During the year 2012, minimum tillage recorded significantly higher castor bean yield (1 514.4 kg/ha) compared to conventional tillage (1 455.7 kg/ha) (Table 2). The increase in yield recorded in minimum tillage over conventional tillage was to the extent of 4%. Among the residues, application of sorghum stover @ 2 tonnes/ha recorded significantly higher castor yields followed by Gliricidia application compared to no residue application (1 194 kg/ha). The castor yields were 46% (1 745.8 kg/ha) and 27% (1 515.4 kg/ha) higher with application of sorghum stover and gliricidia, respectively, over no residue application. Application of nitrogen at 30, 60 and 90 kg/ha recorded significantly higher yields to the extent of 74%, 113% and 109%, respectively, over no nitrogen application. Of all the treatment combinations, significantly higher yield was observed with MTSS90 (2 238 kg/ha) followed by MTGL90 (2 060 kg/ha). It was also observed that husk and stover yields were significantly influenced by tillage, residues and N levels.

The N uptake varied from 13.6 to 77.86 kg/ha in castor bean, from 0.86 to 2.16 kg/ha in castor husk and from 2.18 to 10.41 kg/ha in stalks. The total N uptake by all the three components of castor varied from 16.8 to 90.3 kg/ha across the management treatments (Table 3). Tillage and N levels significant influenced the N uptake in bean, husk and stover. Residues significantly influenced the uptake of N in castor

Table 3 Nitrogen uptake by castor bean, husk and stover (kg/ha) influenced by tillage, residues and N levels.

Tillage	Residues	N levels	N Uptake by bean	N Uptake by husk	N Uptake by stover	Total N uptake by plant
Conventional tillage	Sorghum stover	N0	40.58	1.11	5.45	47.14
		N30	63.86	1.58	6.57	72.01
		N60	71.82	1.97	7.89	81.68
		N90	69.72	1.87	8.34	79.93
	Gliricidia loppings	N0	30.19	1.40	4.81	36.40
		N30	41.08	1.77	4.78	47.64
		N60	63.09	1.89	7.77	72.75
		N90	59.13	2.10	6.47	67.70
	No residue	N0	16.00	0.86	2.25	19.10
		N30	33.35	1.17	3.02	37.55
		N60	44.97	1.58	4.47	51.03
		N90	39.34	1.83	4.15	45.32
Minimum tillage	Sorghum stover	N0	16.42	1.25	2.63	20.29
		N30	53.18	1.49	6.41	61.08
		N60	72.79	2.09	7.27	82.15
		N90	77.86	2.03	10.41	90.30
	Gliricidia loppings	N0	18.95	1.38	3.19	23.52
		N30	55.92	1.64	6.63	64.19
		N60	64.83	2.16	8.46	75.45
		N90	74.27	2.01	8.98	85.26
	No residue	N0	13.67	1.04	2.18	16.89
		N30	43.36	1.23	4.90	49.49
		N60	56.23	1.82	7.74	65.80
		N90	59.78	1.86	7.21	68.84
Tillage			2.42	0.04	0.028	NS
Residue			1.89	0.02	NS	0.30
Nitrogen			4.16	0.06	0.019	3.46
T × R			NS	NS	NS	1.84
T × N			NS	0.093	NS	4.90
R × N			NS	NS	NS	NS
T × R × N			NS	NS	NS	NS

bean and husk. On the whole, the total N uptake by the whole plant varied from 16.8 to 90.3 kg/ha across the treatments and was significantly influenced by the residues and varied N levels. The interaction effects between tillage and residues (T×R) and tillage and N levels (T×N) were found to be significant.

Inter-correlations among different N fractions

Inter-correlations were also worked out among different N fractions (Table 4). Exch. NH_4^+- N showed significant correlation with all the N fractions except with amino acid N. The significant positive association between different N fractions in this study indicates the dynamic relationship between the fractions. Sharma *et al.* (1992) also observed significant inter-correlation coefficients (r^2) between different fractions which indicated free mobility between the N fractions. Further, these results also indicate the significant contribution of Hydrolyzable N and unhydrolyzable N fractions towards N availability pool.

Relationship between castor yield with available N, total N and N uptake

The relationship between castor yield with available N, total N and N uptake has been worked and was found to be significant (R^2= 0.998).

Y_{Castor} = 1082.684 - 0.365 (Available N) -0.557 (Total N)* +28.076 (N uptake) **......(R^2 = 0.998)

Relationship between total N uptake by castor and nitrogen fractions

In the present study, relationship between different fractions (hydrolysable, non–hydrolysable and inorganic N fraction) with total N uptake by castor crop was developed using multiple regressions. In the regressions, total N uptake was considered as dependent variable (Y) and N fractions as independent variables (X1, X2, X3, ——————Xn). The regression functions were fitted individually for each component of soil management treatments such as, conventional tillage (CT), minimum tillage (MT), sorghum residue application @ 2 tonnes/ha (SS), *Gliricidia* lopping (GL) application @ 2 tonnes/ha, No residue application (NR) and different levels of N (N_0 N_{30}, N_{60}, N_{90}). Equations were also fitted by taking the pooled observations for all the three management factors (72 plots).

Table 4 Correlation coefficients among different N fractions of soil Nitrogen

	Exchangeable ammonical N	Nitrate N	Hydrolyzable N	Hexosamine N	Amino acid N	Fixed ammonical N	Unidentified N
Exchangeable N	1						
Nitrate N	0.729*	1					
Hydrolyzable N	0.900**	0.841**	1				
Hexosamine N	0.871**	0.828**	0.970**	1			
Amino acidN	0.651	0.823**	0.910**	0.893**	1		
Fixed Ammonical N	0.717*	0.698*	0.914**	0.872**	0.950**	1	
Unidentified N	0.959**	0.603	0.829**	0.833**	0.537	0.595	1

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).

Table 5 Relationship between total N uptake by castor crop and Nitrogen fractions under different tillage, residues and N levels

	R^2	Regression equation
Total N uptake vs N fractions (all mean data)	0.902	- 93.47 + 2.016 (Exch. N)** - 0.12 (Nitrate N) + 0.557 (Hyd. NH_4. N) - 0.833 (Hexosamine N) + 0.316 (Amino acid N)* +0.122 (Fixed. Amm. N) - 0.04 (unidentified N)
Total N uptake vs N Fractions (CT)	0.771	-36.55 + 0.926 (Exch. N) +2.198 (Nitrate N)* + 0.410 (Hyd. NH_4. N) - 0.287 (Hexosamine N) + 0.141 (Amino acid N) – 0.007 (Fixed. Amm. N) -0.19 (unidentified N)
Total N uptake vs N fractions (MT)	0.915	-70.621 + 1.862 (Exch. N)** - 0.666 (Nitrate N) +0.274 (Hyd. NH_4. N) + 0.29 (Hexosamine N) + 0.79 (Amino acid N) + 0.308 (Fixed. Amm. N)** - 0.019 (unidentified N)
Total N uptake N fractions (SS)	0.949	-26.415 + 2.057 (Exch. N)** - 0.899 (Nitrate N) + 0.471 (Hyd. NH_4. N) - 0.597 (Hexosamine N) - 0.084 (Amino acid N) + 0.280 (Fixed. Amm. N)* + 0.097 (unidentified N)
Total N uptake vs N fractions (GL)	0.928	-43.828 + 1.168 (Exch. N) + 2.129 (Nitrate N) + 0.452 (Hyd. NH_4. N) + 0.150 (Hexosamine N) - 0.007 (Amino acid N) + 0.181 (Fixed. Amm. N) - 0.127 (unidentified N)
Total N uptake vs N fractions (NR)	0.809	-47.329 + 0.118 (Exch. N) - 4.648 (Nitrate N)* + 0.361 (Hyd. NH_4. N) + 0.350 (Hexosamine N) + 0.089 (Amino acid N) + 0.330 (Fixed Amm. N) + 0.143 (unidentified N)
Total N uptake vs N fractions (N0)	0.809	-81.014 + 3.916 (Exch. N)* + 0.727 (Nitrate N) – 0.122 (Hyd. NH_4. N) - 0.981 (Hexosamine N) + 0.339 (Amino acid N) - 0.228 (Fixed. Amm. N) + 0.150 (unidentified N)
Total N uptake N fractions (N30)	0.780	41.022+0.182 (Exch N) + 2.327 (Nitrate N) +0.251 (Hyd. NH_4. N) +0.690 (Hexosamine N) -0.136 (Amino acid N) +0.041 (Fixed Ammonical N) -0.192 (unidentified N)
Total N uptake vs N fractions (N60)	0.855	-87.112 + 0.720 (Exch. N) - 0.854 (Nitrate N) + 0.184 (Hyd. NH_4. N) + 0.301 (Hexosamine N) + 0.208 (Amino acid N)* + 0.246 (Fixed. Amm. N) + 0.179 (unidentified N)
Total N uptake vs N fractions (N90)	0.868	-102.808 + 1.472 (Exch. N) + 0.708 (Nitrate N) + 0.124 (Hyd. NH_4. N) + 0.447 (Hexosamine N) + 0.135 (Amino acid N) + 0.339 (Fixed. Amm. N) - 0.045 (unidentified N)

Exch. N- Exchageable ammonical N; Hyd. NH_4. N- Hydrolyzable ammonical N, Fixed. Amm. N-Fixed ammonical N.

N uptake by castor was significantly influenced by the simultaneous influence of various N fractions, with the coefficient of multiple determination (R^2) varying from 0.771 (N uptake with CT) to R^2= 0.949 (N uptake with SS) (Table 5). In majority of the soil management situations, exch. NH_4^+-N significantly contributed towards N uptake by castor. The NO_3–N and Amino acid N also played an important role in contributing towards N uptake of castor. The R^2 value 0.902 explained the simultaneous significant influence of various N fractions on N uptake in castor in these rainfed Alfisol soils. It was clearly observed that beside inorganic N fractions, some of the hydrolyzable and unhydrolyzable fractions also play a significant role in plant N uptake. Hence, building up of N in these pools by following appropriate soil and nutrient management practices should be the prime strategy in improving the nitrogen economy in tropical soils.

Simple (linear) quantitative predictive relationship

Simple quantitative relationships were also worked out between total N vs total hydrolyzable N and total N uptake vs total hydrolysable N (Table 6). The linear regression coefficients (R^2) of these relationships were 0.882 and 0.915, respectively. From these simple functions, it was understood that total hydrolzable N played an important role in contributing towards total N uptake by castor crop and total N in soil.

The present study clearly showed a significant effect of long term effect of tillage, residues and N levels on soil N fractions and their contribution to the available N pool in soil and towards plant N uptake. The long term practice of tillage and application of residue also significantly influenced the total N uptake by castor. It was clearly observed that beside inorganic N fractions, some of the hydrolyzable and unhydrolyzable fractions also played a significant role in plant N uptake. A strong correlation between castor yield with total N and total uptake has been observed. Hence, build up of N in these pools by following appropriate soil and nutrient management practices should be the prime strategy in improving the nitrogen economy in tropical soils. Among the different combinations of soil management practices, the order of superiority of was MTSSN90 > MTGLN90 > MTSSN60 > CTSSN60 > MTGLN60. Thus, these practices can be recommended to the farmers/growers in tropical Alfisol regions as strategy to improve N economy

Table 6 Relationship between total hydrolysable N with total N in soil and Total N uptake by Castor under different tillage, residues and N levels

	R^2	Regression equation
Total N vs Total hydrolyzable N	0.882	746.768 + 2.625 (Total hydrolyzable N)**
Total N uptake vs Total hydrolysable N	0.915	-53.097 + 0.230 (Total hydrolyzable N)**

of the soil by way of improving the quantum of N in different chemical fractions/pools, beside getting higher crop yield.

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