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Nitrogen Dynamics Under Long Term Lantana Camara (L.) Residue and Fertilizer Application in a Rice-Wheat Cropping System

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NITROGEN DYNAMICS UNDER LONG TERM *LANTANA CAMARA* (L.) RESIDUE AND FERTILIZER APPLICATION IN A RICE-WHEAT CROPPING SYSTEM

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□ *Long term effects of lantana (*Lantana camera *L.) residue and fertilizer application were studied on nitrogen (N) fractions in a Typic Hapludalf under rice-wheat cropping at Palampur, India (32° 6'N, 76° 3'E). After 12 crop cycles, lantana and fertilizer application showed an additive effect on the buildup of different N fractions. Hydrolyzable-N constituted 86% of total organic-N and 84% of total-N. All fractions of N except unidentified-N, non-hydrolyzable-N, and total-N were strongly interdependent and had a positive influence on grain yield and N uptake in rice and wheat crops. Serine+threonine-N was the most important fraction contributing towards grain yield and N uptake in rice and wheat. Fertilizers at 66% of recommendation plus lantana at 10 t ha^{-1} maintained higher available-N than that under 100% fertilizers alone; the N content was same as 12 years before. Inclusion of lantana indicated net saving of 33% fertilizers plus higher yields and sustained soil health.*

Keywords: nitrogen fractions, nitrogen uptake, lantana, fertilizers, integrated nutrient management, rice-wheat

INTRODUCTION

Nitrogen (N) is deficient in soils worldwide to varying degrees and is the nutrient applied from external sources in maximum amounts (Wade, 2009). In a quest to achieve high crop yields, particularly rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.), farmers in many parts of the world tend

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to apply N far in excess of requirements (Prasad, 2005; Pathak et al., 2006). This is particularly true in rice-wheat cropping system in India, leading to lower N fertilizer recovery efficiency (Katyal et al., 1985, Bijay-Singh and Yadvinder-Singh, 2003). Rice and wheat grown in annual rotation constitute the most important cropping system from the point of food security in India. Both rice and wheat are exhaustive feeders, and the double cropping system is heavily depleting the soil of its nutrient content. Even with the recommended rate of fertilization in this system, a negative balance of the primary nutrients still exists, particularly for nitrogen. The system, in fact, is now showing signs of fatigue and is no longer exhibiting increased production with increases in input use. Evidence of declining partial or total factor productivity is already becoming available (Hobbs and Morris, 1996). Causes for this decline include changes in biochemical and physical composition of soil organic matter, and macro-and micronutrient imbalances due to inappropriate fertilizer applications (Ladha et al., 2000). Productivity level of rice-wheat cropping system cannot be sustained unless the declining trend in soil fertility resulting from the nutrient mining by these crops is replenished adequately. Although use of chemical fertilizers is the fastest way of counteracting the pace of nutrient depletion, but ever-increasing energy cost, limited input availability, and rising fertilizer prices coupled with many other factors deter the farmers from using these inputs in balanced proportions and in recommended quantities. Further, long-term experiments have revealed that continuous use of chemical fertilizers alone is not sufficient to maintain the long-term soil health to sustain crop productivity (Subba Rao and Srivastava, 1998; Ladha et al., 2003).

Soil management comprising integrated nutrient management (INM) increases nitrogen use efficiency as organic-N sources interact positively with fertilizer-N (Olesen et al., 2004; Vanlauwe et al., 2002). Organic nutrient sources exert strong influence on soil productivity and N dynamics in soil-plant system (Schmidt and Merbach, 2004). It is well documented that not only the nutrient status of soil but different chemical pools in which N occurs plays an important role in the nutrition of crop plants. Thus, an understanding of N transformation after organic material incorporation in combination with chemical fertilizers on long-term basis is essential in developing nutrient management practices that can lead to more efficient use of nutrients in a cropping sequence to realize sustainable productivity improvement and enhanced profitability.

Lantana (*Lantana camara* L.) is a fast growing obnoxious weed in India. Because of its fast growth, lantana has turned into a serious weed, with a danger of encroaching on cultivated lands. It has no value as cattle feed because it contains toxins such as 'lantidine', which causes tymphany disease if eaten by cattle. Its growth and foliage are maximum during wet season (June-September) when rice is cultivated. Keeping in view its abundance and limited alternate use, a long-term field experiment with rice-wheat cropping system was initiated to study its utility as an alternate organic source of nutrients and evaluating its effect on soil N transformation.

MATERIALS AND METHODS

Study Site

A long term field experiment was started in 1988 in a silty clay loam soil (Typic Hapludalf) at the experimental farm of the Himachal Pradesh Agricultural University, Palampur, India (32°6′N, 76°3′E,1300 m above mean sea level). The experimental soil had 300 g kg^{-1} clay, 540 g kg^{-1} silt, 160 g kg^{-1} sand, 5.6 pH, 8.80 g kg^{-1} organic carbon, 12 cmol kg^{-1} cation exchanage capacity, 0.12 g kg^{-1} available N [alkaline potassium-dichromate, or potassium permanganate ($KMnO_4$)-oxidizing fraction], 8.0 mg kg^{-1} Olsen's phosphorus (P), and 0.08 g kg^{-1} ammonium acetate-extracted potassium (K). The site lies in the Palam valley of Kangra district at foothills of Dhauladhar ranges and represents the mid-hill wet-temperate zone of the North-West Himalayas. The mean annual rainfall in Palampur is about 2,312 ± 618 mm, with the wettest months being June to September.

Experimental Detail

A long term field experiment was started during kharif/rainy season (mid-June to mid-September) 1988 to study the effect of four levels of lantana incorporation (0, 10, 20, and 30 Mg ha^{-1} on fresh weight basis) and three tillage practices (no puddling, puddling and soil compaction) for rice. It was laid out in a completely randomized block design with 12 treatments, replicated thrice (plot size 10 m^2). The residual effect of lantana incorporation and tillage practices were evaluated on the succeeding wheat crop every year up to rabi/post-rainy season (November-April) 199219–93. During kharif 1993, however, the experiment was modified and the tillage practices were replaced with three levels of N (50, 75, and 100% of the recommended 90 kg N ha^{-1}) for rice. Nitrogen levels for wheat were 100, 75, and 50% of the recommended 120 kg N ha^{-1}. These treatments were maintained until rabi 1996–1997. From kharif 1997, the fertilizer levels were further modified to 33, 66, and 100% of the recommended N and K (40 kg ha^{-1}) to rice. Phosphorus application was skipped. N, P, and K application to wheat was also modified as 66% of the recommended levels (120, 90, and 30 kg N, P, and K ha^{-1}, respectively). Entire K for rice was applied at transplanting, 50% N 10 days after transplanting, and the remaining 50% N in two splits at 20 and 40 days after transplanting. For wheat, all P and K and 50% N were applied at sowing, and the remaining 50% N top dressed in two equal splits at crown root initiation and flowering stages.

The fertilizers used were urea, single super phosphate, and muriate of potash for N, P, and K, respectively. Lantana biomass from wastelands was collected and incorporated 10 to 15 days before transplanting rice. Lantana twigs were chopped into small pieces (4 to 5 cm), spread uniformly over the entire plot, and incorporated in the surface soil (0 to 0.15 m) using spades. Each plot was then irrigated and left as such for 10 to 15 days, dug again, and mixed up manually. Tender twigs of Lantana contained on a dry weight basis 403 g kg^{-1} carbon (C), 22.3 g kg^{-1} N, 2.0 g kg^{-1} P, 14 g kg^{-1} K with a C/N ratio of 21.

Soil Sampling and Analysis

Soil samples were collected from the 0–0.15 m layer (treatment-wise) after 12 cycles of rice-wheat cropping (i.e., after the wheat harvest in 2000). The soil samples were mixed thoroughly, air dried in shade, crushed to pass through 2 mm sieve, and stored in sealed plastic jars for analysis. After processing, soil samples were analyzed for available N (alkaline $KMnO_4$ method) and different inorganic and organic forms of N. The sequential extraction procedure as given by Bremner (1965) was employed for different N fractions including nitrate-nitrogen (NO_3^--N), ammonium-nitrogen (NH_4^+-N), hydrolyzable-NH_4^+-N (Hy-N), hexosamine-N (H/a-N), serine+threonine–N (S/T-N), amino acid-N (A/a-N), total hydrolyzable-N (THy-N), unidentified-N (Un-N) and non-hydrolyzable-N (Nh-N).

Statistical Analysis

The data were subjected to standard analysis of variance (ANOVA) of completely randomized block design (Gomez and Gomez, 1984) and the means of the treatments were tested using least significant differences at 5% level probability by using the IRRISTAT data analysis package (International Rice Research Institute, 2000). Nitrogen uptake computed from crop yields was correlated with different forms of N and the interdependency among different forms of N was also determined.

RESULTS AND DISCUSSION

Nitrogen Fractions

Inorganic N

Lantana incorporation for 12 years at 10, 20, and 30 Mg ha^{-1} increased NH_4^+-N by 25, 34, and 47% and NO_3^--N by 62, 79, and 87%, respectively, as compared to no lantana incorporation (Table 1). Similarly, fertilizer application at 66 and 100% of recommended levels increased NH_4^+-N by 26 and 46% and NO_3^--N by 23 and 33%, respectively, as compared with treatment receiving 33% of recommended fertilizer dose. The comparatively low NO_3^--N content in comparison to NH_4^+-N in the present study might be

TABLE 1 Effect of fertilizer application and lantana incorporation on inorganic forms of soil N

Lantana addition (Mg ha^{-1})	Fertilizers applications (% of the recommended dose) 33	66	100	Mean	Fertilizers applications (% of the recommended dose) 33	66	100	Mean
	NH_4^+-N (mg kg^{-1})				NO_3^--N (mg kg^{-1})			
0	22.6	25.7	29.7	25.3	7.7	9.1	10.0	8.9
10	25.3	32.1	37.2	31.5	12.3	14.9	16.3	14.5
20	26.4	36.0	39.3	33.9	13.3	16.9	17.7	16.0
30	29.0	38.0	49.5	37.2	13.9	17.3	18.7	16.7
Mean	25.8	32.4	37.7		11.8	14.6	15.68	
CD (P = 0.05)	F = 1.19	L = 1.38	L X F = 2.39		F = 0.69	L = 0.80	L X F = NS	

attributed to NO_3^--N losses due to denitrification as well as leaching (Kumar, 2003). Combined application of fertilizers and lantana incorporation at higher levels increased both the inorganic forms of N over their individual application. Earlier studies (Manivannan and Sriramachandrasekharan, 2009) have also reported such additive effect of lantana incorporation and fertilizer application in the build-up of inorganic N forms in the long term lantana amended soils.

Organic N

Among the organic N fractions, hydrolyzable-N was the dominant fraction (86%) followed by non-hydrolyzable-N (14%) (Table 2). The hydrolyzable-N was further fractionated into five forms viz., hydrolyzable-NH_4^+-N, amino acid-N, serine+threonine-N, hexosamine-N, and unidentified-N. Among hydrolyzable-N fractions, NH_4^+-N was the most dominant fraction followed by amino acid-N, serine+threonine-N, and hexosamine-N the least. Increasing levels of lantana incorporation significantly increased all the hydrolyzable-N fractions except unidentified-N, which remained unaffected. The maximum increase was observed in total amino acid-N [serine+threonine-N + amino acid-N] (9-38%) followed by hexosamine-N (4-16%) and minimum in hydrolyzable-NH_4^+-N (3–11%). The buildup of total amino acid-N in the soil depends upon the rate of mineralization and the rate at which it replenishes from the protein fraction of added organic material (Sihag et al., 2005). Since lantana was continuously incorporated over the last 12 years, the replenishment of total amino acid-N might have been much higher in comparison to its mineralization and thus showed an increase in this form of N.

On decomposition, the proteins and nucleic acids (which are derivatives of purine and pyrimidine) and large number of other organic compounds (out of which lantidine is a major fraction) should have resulted in the buildup of hydrolyzable-NH_4^+-N (Kyuma, 2004). Similarly, fertilizer

TABLE 2 Effect of fertilizer application and lantana incorporation on organic forms of soil N - hydrolyzable-N

Lantana addition (Mg ha^{-1})	Fertilizers applications (% of the recommended dose)				Fertilizers applications (% of the recommended dose			
	33	66	100	Mean	33	66	100	Mean
	Hydrolyzable- NH_4^+-N (mg kg^{-1})				Hexosamine-N (mg kg^{-1})			
0	383	406	423	404	127	143	153	141
10	393	413	437	414	135	148	157	147
20	396	450	467	437	137	168	177	161
30	410	453	483	448	140	170	180	163
Mean	395	431	452		135	157	167	
CD (P = 0.05)	F = 8	L = 9	L X F = 16		F = 9	L = 11	L X F = NS	
	Amino acid-N (mg kg^{-1})				Serine+threonine-N (mg kg^{-1})			
0	407	420	443	423	118	135	155	136
10	423	433	447	434	123	148	162	144
20	427	460	472	451	142	167	179	162
30	432	477	493	464	162	180	182	174
Mean	422	448	460		136	158	169	
CD (P = 0.05)	F = 8	L = 9.00	L X F = 16		F = 20	L = 23	L X F = NS	
	Total hydrolyzable-N (mg kg^{-1})				Unidentified-N (mg kg^{-1})			
0	1482	1528	1571	1527	447	423	396	422
10	1518	1546	1608	1537	443	403	406	417
20	1557	1638	1638	1611	455	393	350	399
30	1601	1654	1718	1658	457	374	370	406
Mean	1539	1591	1634		451	398	385	
CD (P = 0.05)	F = 13	L = 15	L X F-27		F = NS	L = NS	L X F = NS	

application at 66 and 100% of recommended levels also increased the hydrolyzable-NH_4^+-N (9-14), amino acid-N (6-9%), serine+threonine-N (16-24%) and hexosamine-N (17-24%) as compared with the 33% of recommended fertilizers dose. A positive interaction was seen in lantana and fertilizer levels in building up hydrolyzable-NH_4^+-N and amino acid-N. A better growth of heterotrophic microbial population under acidic pH conditions might have resulted in the recovery of amino acid-N and hydrolyzable-NH_4^+-N at higher levels of residue and fertilizer addition (Mohapatra and Khan, 1987).

Non-hydrolyzable-N also increased by 16, 9, and 10% at 10, 20, and 30 Mg ha^{-1} lantana application, respectively, over no lantana (Table 3). An increase in non-hydrolyzable-N in soil under incorporation of organic materials is attributed to mobilization of N through microbial decomposition of organic sources (Singh et al., 2001; Sarawad et al., 2001). However fertilizers application at higher levels of 66 and 100% of recommended decreased this form as compared with 33% fertilizer dose. The decrease in non hydrolyzable-N with the application of increased levels of fertilizer might be attributed

TABLE 3 Effect of fertilizer application and lantana incorporation on organic forms of soil N - non-hydrolyzable-N

Lantana addition (Mg ha^{-1})	Fertilizers applications (% of the recommended dose) 33	66	100	Mean
	Non-hydrolyzable-N (mg kg^{-1})			
0	248	242	222	237
10	283	273	270	275
20	270	241	265	259
30	271	258	252	260
Mean	268	253	252	
CD (P = 0.05)	F = 11	L = 13	L X F = NS	

to conversion of non-hydrolyzable-N to hydrolyzable forms of N in the soil (Singh et al., 1999).

Available and Total N

The amount of available-N in the soil depends upon the amount of different organic and inorganic N fractions as well as on the rate of mineralization of these forms. The available-N under different treatments varied from 235 to 320 mg kg^{-1} (Table 4). Incorporation of lantana as well as the application of fertilizers significantly increased the content of available-N (6–18%).

Similarly total-N in soil varied from 1759 to 2033 mg kg^{-1} under different treatments. The incorporation of lantana at the rate of 10–30 Mg ha^{-1} increased total-N by 5–10% over no lantana treatment. Similarly, the application of fertilizers at 66 and 100% of recommended dose increased total-N content by 3 and 5%, respectively. The comparatively less increase in total-N due to increased level of fertilizer application in comparison to its increase under lantana incorporation was understandable as applied inorganic N is subjected to many losses such as leaching, volatilization and denitrification

TABLE 4 Effect of fertilizer application and lantana incorporation on total and available N

Lantana addition (Mg ha^{-1})	Fertilizers applications (% of the recommended dose)				Fertilizers applications (% of the recommended dose			
	33	66	100	Mean	33	66	100	Mean
	Available-N (kg ha^{-1})				Total-N (mg kg^{-1})			
0	235.2	250.9	260.6	248.9	1759	1802	1833	1798
10	239.6	264.2	287.1	263.6	1839	1865	1931	1878
20	245.7	278.6	295.6	273.4	1866	1931	1960	1919
30	277.0	282.2	320.1	293.1	1915	1966	2033	1975
Mean	249.4	269.0	290.9		1845	1891	1939	
CD (P = 0.05)	F = 17.1	L = 19.8	L X F = NS		F = 7	L = 9	L X F = 15	

TABLE 5 Coefficient of correlation (r) among different nitrogen fractions

	NH_4^+-N	NO_3^--N	Hy-N	H/a-N	S/T-N	A/a-N	THy-N	TN	Un-N	Nh-N
NH_4^+-N	1.00									
NO_3^--N	0.38**	1.00								
Hy-N	0.91**	0.41**	1.00							
H/a-N	0.85**	0.29*	0.84**	1.00						
S/T-N	0.40**	0.20	0.47**	0.42**	1.00					
A/a-N	0.50**	0.21*	0.66**	0.49**	0.36**	1.00				
TN	0.01**	0.10	0.13	0.13	0..02	0.19	1.00			
THy-N	0.39**	0.18	0.42**	0.49**	0.15	0.22*	0.04**	1.00		
Un-N	−0.42	−0.12	−0.56	−0.46	−0.26	−0.38	−0.09	−0.17	1.00	
Nh-N	−0.27	−0.06	−0.26	−0.26	−0.19	−0.07	−0.08	−0.21	−0.02	1.00

*Significant at 5 percent of significance; **significant at 1 percent of significance.

(particularly under low land rice conditions). The higher build up in total-N content due to lantana incorporation was on expected lines as the present experiment was started in the year 1988 and lantana is being incorporated to rice crop every year. The accumulated amount of lantana over the years coupled with low rate of decomposition under wet temperate conditions might have resulted into significant build-up of total-N content in the soil. (Sharma and Verma, 2001; Kumar, 2003).

Available and total N content (in line with different fractions) under 66% of recommended fertilizer dose plus 10 t ha^{-1} lantana incorporation was significantly higher in comparison to 100% of chemical fertilizers alone. This increase was still higher with 20 and 30 Mg ha^{-1} lantana application along with 66% of recommended fertilizers. These results are of special interest as one could not only maintain, but also enhance the N content in soil with the incorporation of lantana by way of net saving of 33% of recommended dose of fertilizers. Earlier studies (Singh et al., 2008) have also reported such fertilizer economy with organic residue (farmyard manure or vermicompost or green manuring with *Sesbania aculeata* addition.

Interdependency Among N Fractions

Relationships between different inorganic and organic soil N fractions were studied to know their interdependency. All the fractions of N were strongly interdependent except unidentified-N, non-hydrolyzable-N and total-N which did not appear to depend on any other fraction of N (Table 5). Among different forms of N, hydrolyzable-NH_4^+-N was most important variable contributing to the total variation in the linear stepwise regression (data not given). The linear stepwise regression data revealed that the hydrolyzable-NH_4^+-N was the most important variable contributing to the total variation in the regression of NH_4^+-N (82% variation), NO_3^--N (12% variation), hexosamine-N (44% variation), amino acid-N (23% variation),

TABLE 6 Effect of long term lantana incorporation and fertilizer application on total N uptake (kg ha^{-1}) by rice and wheat

Treatment	Rice		Wheat	
	Kharif 2000	Kharif 2001	Rabi 2000–01	Rabi 2001–02
Lantana addition (Mg ha^{-1})				
0	64.4	61.8	60.2	70.1
10	71.2	73.2	65.4	93.9
20	80.9	82.9	69.8	103.1
30	85.1	102.7	76.9	112.5
Mean	75.4	80.2	68.1	94.9
CD (P = 0.05)	4.8	9.8	4.0	16.9
Fertilizer application (% of recommendation)				
33	65.9	69.7	57.7	80.0
66	79.2	85.5	72.0	99.6
100	81.0	88.1	74.5	105.2
Mean	75.4	81.1	68.1	94.9
CD (P = 0.05)	5.5	8.5	3.4	14.6

unidentified-N (32% variation), non-hydrolyzable-N (11% variation). For a variation in the regression of hydrolyzable-NH_4^+-N (82% variation) the most important variable was NH_4^+-N; for serine+ threonine-N (71% variation) it was $NH4^+$-N; and for total hydrolyzable-N (24%), it was the hexosamine-N.

Nitrogen Uptake

The uptake of N increased significantly with lantana incorporation as well as with increased levels of fertilizers (Table 6). The increase in N uptake by rice at 10, 20, and 30 Mg ha^{-1} lantana application was 11, 26, and 32% during season-1 (kharif/rainy 2000) and 18, 34, and 66% during season-2 (kharif/rainy 2001) as compared with no lantana application. The corresponding N uptake values in wheat were 9, 16 and 28% during Season-1 (rabi/post-rainy 2000-01 season) and 34, 47, and 60% during Season-2 (rabi/post-rainy 2001-02 season). Such an increase in N uptake by rice and wheat due to the incorporation of lantana may be attributed to increased N availability in the soil and better root proliferation which resulted in the increased absorption of water and nutrients from larger areas and greater depths (Sharma et al., 2005). Similarly, fertilizer application at 66 and 100% of recommended dose increased N uptake in rice by 20-23% during season 1 and 23-26% during season 2 when compared with 33% recommended fertilizer dose. In wheat, the N uptake increased by 25–29% during season-1 and 25–32% during season-2 under higher fertilizer levels over 33% level. The increase in N uptake either with lantana addition or

TABLE 7 Effect of long term lantana incorporation and fertilizer application on rice and wheat yield (t ha^{-1})

Crop	Lantana addition (Mg ha^{-1})	Fertilizers applications (% of the recommended dose) 33	66	100	Mean	33	66	100	Mean
Rice				2000			2001		
	0	2.47	2.78	3.08	2.78	2.80	3.42	3.72	3.34
	10	2.83	3.13	3.36	3.11	3.38	3.82	4.19	3.80
	20	3.13	3.40	3.57	3.36	4.09	4.77	4.69	4.52
	30	3.37	3.88	3.77	3.61	4.59	5.17	4.98	4.91
	Mean	2.95	3.25	3.42		3.72	4.37	4.34	
	CD (P = 0.05)	F = 0.10	L = 0.09	L X F = 0.18	F = 0.15	L = 0.13	L X F = 0.26		
Wheat				2000–2001			2001–2002		
	0	1.24	1.44	1.73	1.47	1.29	1.63	1.95	1.62
	10	1.38	1.52	1.87	1.60	1.57	1.78	2.17	1.84
	20	1.54	1.93	2.01	1.83	1.92	2.33	2.33	2.19
	30	1.84	2.02	1.98	1.94	2.17	2.46	2.37	2.33
	Mean	1.50	1.74	1.90		1.73	2.05	2.21	
	CD (P = 0.05)	F = 0.07	L = 0.06	L X F = 0.13	F = 0.06	L = 0.05	L X F = 0.10		

Source: Sharma et al., 2009

with fertilizer application was mainly because of increase in rice and wheat yields (Sharma et al., 2009) under these treatments (Table 7).

Relationship of N Fractions with Crop Yield and Nitrogen Uptake

Simple correlation study revealed that all inorganic and organic N fractions except unidentified-N, non-hydrolyzable-N and total-N had a significant and positive influence on grain yield and N uptake by rice and wheat (Table 8). Among different N fractions, serine+threonine-N seemed to be the most important N fraction contributing towards grain yield (0.881**) and N uptake (0.749**) in wheat crop. Similarly, this fraction was also the most important N fraction contributing to grain yield (0.899**) and N uptake (0.794**) in rice. Earlier studies (Pathak and Sarkar, 1995) have found positive correlation of amino acid and amino sugar-N with grain yield and N uptake by wheat. Sharma and Verma (2001), however, reported that the most important variable contributing to the total variation of available-N was amino acid-N.

Relative contribution of each N fraction towards crop yield and N uptake was determined using linear stepwise multiple regression (data not given). The R^2 values indicated that about 78% of the total variation in grain yield and 56% in N uptake by wheat could be explained on the basis of

TABLE 8 Coefficient of correlation (r) between different yield parameters and different N fractions

N fractions	Wheat Grain yield	Wheat Total N Uptake	Rice Grain yield	Rice Total N Uptake
$NH_4{}^+$-N	0.816**	0.682**	0.806**	0.763**
$NO_3{}^-$-N	0.254*	0.216*	0.271*	0.186*
Hy-N	0.787**	0.702**	0.753**	0.702**
S/T-N	0.881**	0.749**	0.899**	0.794**
A/a-N	0.341**	0.265*	0.333**	0.379**
H/a-N	0.495**	0.554**	0.445**	0.449**
TN	0.077	0.084	0.135	0.168
THy-N	0.399**	0.195	0.372**	0.153
Un-N	−0.435	−0.406	−0.426	−0.424
Nh-N	−0.141	−0.0625	−0.137	−0.225

*Significant at 5 percent of significance; **significant at 1 percent of significance.

serine+threonine-N in soils. The corresponding values in rice were 81 and 63%, respectively.

CONCLUSIONS

Continuous lantana and fertilizer application after 12 years showed up an additive effect in the buildup of different N forms. Overall, hydrolyzable-N constituted 86% of total organic N and 84% of total-N. All fractions of N except unidentified-N, non-hydrolyzable-N and total-N were strongly interdependent and had a positive influence on grain yield and N uptake by rice and wheat crops. Serine+threonine-N was the most important fraction contributing towards grain yield and N uptake in rice and wheat. Interestingly, available-N content under 66% of recommended fertilizer dose plus 10 t ha^{-1} lantana incorporation was significantly higher in comparison to 100% of chemical fertilizers alone. The lantana residue and fertilizer management at this level maintained the same fertility level as before 12 years, but accompanied with enhanced yields and uptake, indicating thereby the sustainability of the practice. The increase in soil N was still higher with 20 and 30 Mg ha^{-1} lantana at 66% of recommended fertilizers. These results are of special interest as one could not only maintain, but also enhance the N content in soil with the incorporation of lantana by way of net saving of 33% of chemical fertilizers without compromising on yield.

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