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Prediction of Yield and Nitrogen Uptake of Wheat from Net Nitrogen Balance after Rice in Rice–Wheat Cropping System

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*Net nitrogen (N) balance after rice (*Oryza sativa *L.) and its relationship with yield and N uptake of succeeding wheat crop was studied in a greenhouse. Three urea-enriched green manures, namely dhaincha (*Sesbania aculeata *L.), cowpea (*Vigna unguiculata *L.), and guar (*Cyamopsis tetragonoloba *L.) were compared with split application of urea in a rice–wheat cropping sequence. After rice, a negative N balance was measured in all treatments; however, the N balance values were greater with urea than with green manures. The N balance was positively correlated with the N content but negatively correlated with lignin content and carbon (C)–N ratio of the green manures. Lignin content was a better index than C/N ratio for predicting the net N balance, which described 82.3% of the total variations. Efficiency of residual N utilization by wheat could be determined by estimating the N balance after rice. Net N balance after rice can be used as a yardstick for the prediction of yield and N uptake by wheat crop.*

Keywords C/N ratio, enriched green manure, lignin, net N balance, residual N effects, rice– wheat system

Introduction

Rice (*Oryza sativa* L.)–wheat (*Triticum aestivum* L.) cropping system is a major cereal cropping system in southern Asia, occupying approximately 14 Mha of cultivated land that extends across the Indo-Gangetic Plain (IGP) into the Himalayan foothills (Timsina and Connor 2001). However, the rice–wheat cropping system depletes soil nutrients, particularly the supply of main yield-limiting nutrient nitrogen (N). Fertilizer N use in multiple cropping systems requires a new fertilizer strategy, considering both the energy crisis and increasing gap in fertilizer production and consumption (fertilizer cost increases). Also, there is contradictory evidence regarding the long-term responses of rice and wheat to N fertilizer in the continuous rice–wheat rotation. For example, N application significantly increased grain and straw yields and uptake of N by both crops when sown at the optimum time in a sequence at Pantnagar, India (Singh and Modgal 1978). In contrast, also in India, when sowing of wheat was delayed after the harvest of rice, N fertilizer decreased N uptake by wheat (Kapur et al. 1985). Information about utilization of the residual N by the following crop and its prediction of N availability in the soil before sowing is important for decreasing N fertilizer use. In this study, the relationship between the N balance after

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rice and yield and N uptake of the following wheat crop was examined to optimize the N application and predicting the yield of wheat after rice.

Green manures are forage or leguminous crops that are grown and their succulent leafy materials are turned into the soil to add organic matter, improve soil fertility, and smother weeds. However, the time required for conversion of complex organic molecules to ammonium and nitrate ions, called mineralization, will depend on many factors (Jarvis et al. 1996). Apart from the direct effect, green manures exert influence on the availability of other nutrients; for example, lupins grown in P-deficient soil were found to extrude protons and organic acids such as citric acid, increasing the mobility and uptake of phosphorus (P) (Shen et al. 2005; Sas, Rengel, and Tang 2001; Neumann et al. 2000). Once incorporated, the green manure provides a pool of fresh organic matter and there are numerous examples where using green manures increases soil organic matter in comparison to treatments where inorganic fertilizers alone are applied (Shepherd, Harrison, and Webb 2002; Campbell et al. 1991). This organic matter provides food to soil microorganisms, encouraging an increase in numbers and activity (Campbell et al. 1991; N'Dayegamiye and Tran 2001).

Materials and Methods

Experimental Soil

A greenhouse experiment was done at the Indian Agricultural Research Institute, New Delhi with a rice–wheat cropping system on a loamy (Typic Ustochrept, Soil Survey Staff 1998) soil (sand 63.2%, silt 19.1%, clay 17.7%, Piper 1966), with pH 8.3, electrical conductivity (EC; 1:2, soil–water, Jackson 1967) 0.2 dS m^{-1}; organic carbon 0.41% (Walkley and Black 1934); available N (Subbiah and Asija 1956), P (Olsen et al. 1954), and potassium (K) (Jackson 1967) 212, 19, and 209 kg ha^{-1}, respectively; cation exchange capacity (CEC) 8.1 cmol (p^+) kg^{-1} (Jackson 1967); total organic N 579 mg kg^{-1} (Bremner 1965); hydrolysable N 441 mg kg^{-1}; nonhydrolysable N 138 mg kg^{-1}; and inorganic N 29.02 mg kg^{-1} (Bremner and Keeney 1966). Soil moisture contents at –0.03 MPa and –1.5 MPa were 21.5 and 7.5%, respectively. Standard analytical methods were followed for physical and chemical analysis.

Enrichment of Green Manures and Treatments

Three green manures [dhaincha (*Sesbania aculeata* L.), cowpea (*Vigna unguiculata* L.), and guar (*Cyamopsis tetragonoloba* L.)] were grown for 50 days without or with 10 and 30 kg N ha^{-1} as starter dose. To enrich the green manures for narrowing down the C/N ratio, 1.0 (10 kg urea ha^{-1}) and 3.0% (30 kg urea ha^{-1}) urea solution were sprayed on those green manures, which were grown with 10 and 30 kg N ha^{-1} as starter dose, respectively, three times on alternate days starting from 14 days before incorporation in soil to create the enrichment levels of E_1 and E_2. The green manures grown without a starter dose of N were not sprayed with urea solution (E_0). Crop response and efficiencies of these nine sources of enriched green manures were compared with split application of urea (half at transplanting and a quarter at 30 and 65 days after transplanting, DAT). Each of the 10 sources of N (nine sources of enriched green manures and urea) were applied at the rates of 107.1 (L_1), 214.3 (L_2), and 321.4 (L_3) mg pot^{-1} (soil weight basis) 10 days before transplanting of 30-day-old rice seedlings (Pusa Basmati I) in glazed porcelain pots of 4 kg capacity, keeping three hills (two plant per hill), during *kharif* (summer) season. At the time of transplanting, 71.4 mg pot^{-1} phosphorus pentoxide (P_2O_5) and 107.1 mg pot^{-1} dipotassium oxide (K_2O)

were applied (soil weight basis) through aqueous solution of monopotassium phosphate (KH_2PO_4) and potassium chloride (KCl) (K from both the sources was duly accounted for). Six healthy plants of wheat (HD 2329) were grown during *rabi* (winter) on the residual N status with uniform basal doses of 107.1 mg pot^{-1} P_2O_5 and 71.4 mg pot^{-1} K_2O. No other plant-essential nutrients added to the pots. During rice season, pots were irrigated as and when required to maintain 3 cm of standing water throughout the growing period until 2 weeks before harvesting, when the water was cut off. For wheat, irrigation was applied to maintain a near-field-capacity moisture regime. Rice was harvested at 135 days after transplanting and wheat at 110 days after sowing (weather parameters during rice–wheat growing period is provided in Figure 1). Plants were cut off at maturity at soil level, separated into straw and grain, and oven dried to constant weight for further analysis.

The experiment was laid out in a completely randomized block design with three replications.

Plant Analysis

The carbon and hydrogen in the green manures were estimated by the dry combustion method (Culmo 1969), total N by the micro-Kjeldahl method (AOAC 1960), P and K by spectrophotometry and flame-photometric methods, respectively (Yoshida et al. 1976), and the cellulose and lignin by wet digestion method (Van Soest 1963). Chemical compositions of green manures are given in Table 1.

Net N Balance

The KCl-extractable soil N content was estimated at the beginning (initial) and after the harvest of rice according to procedures described by Bremner and Keeney (1966). Crop removal of N by rice and wheat was also determined. The N balance (mg pot^{-1}) was calculated by using the following formula:

$$\text{N balance} = \text{Nf} - (\text{Ni} + \text{Na} - \text{Nr})$$

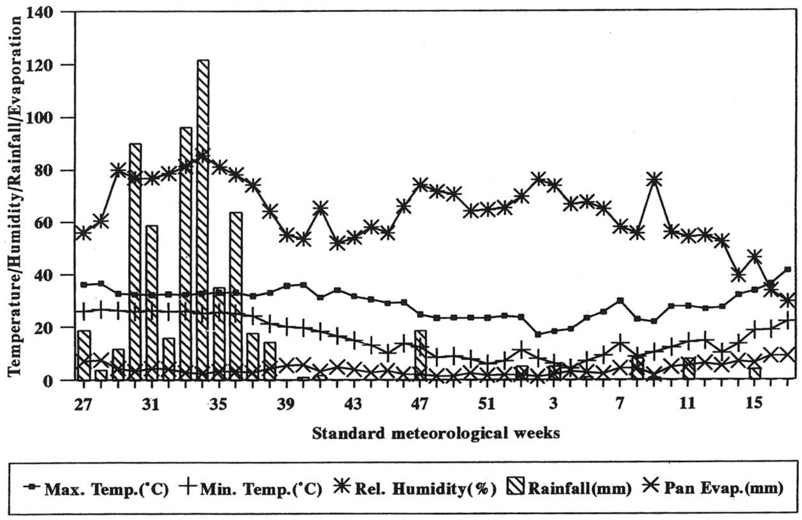

Figure 1. Weather parameters during the rice–wheat growing period.

Table 1
Chemical composition and the C/N ratio of the dhaincha, cowpea, and guar green manures used in the greenhouse study

	Dhaincha			Cowpea			Guar		
Attribute	E_0	E_1	E_2	E_0	E_1	E_2	E_0	E_1	E_2
Nitrogen (%)	2.03	2.12	2.35	1.56	1.78	1.98	2.75	2.83	3.01
Phosphorus (%)	0.22	0.26	0.28	0.26	0.25	0.28	0.23	0.27	0.25
Potassium (%)	2.02	2.03	2.12	2.17	2.12	2.18	2.02	1.98	2.13
Carbon (%)	42.10	42.00	42.00	44.40	44.50	44.00	42.00	42.10	41.90
Hydrogen (%)	5.98	6.20	6.03	6.08	6.21	6.17	5.90	6.11	6.09
Cellulose (%)	7.80	7.76	7.95	6.51	6.76	7.01	8.01	7.79	8.03
Lignin (%)	17.01	16.92	16.50	17.50	17.80	17.10	16.60	16.10	15.80
C/N ratio	20.74	19.81	17.87	28.46	25.00	22.22	15.27	14.88	13.92

Notes. E_1 is created by application of 10 kg N ha^{-1} as starter dose and spraying 1.0% urea solution (10 kg urea ha^{-1}) three times on alternate days starting from 14 days before incorporation in soil. E_2 is created by application of 30 kg N ha^{-1} as starter dose and spraying 3.0% urea solution (30 kg urea ha^{-1}) three times on alternate days starting from 14 days before incorporation in soil. E_0 is the control (no urea was added either as starter dose or spray). Data are the mean of three replications.

where Ni is the initial soil N (mg pot^{-1}), Na is the total N added to rice (mg pot^{-1}), Nr is the total N removal by rice (mg pot^{-1}), and Nf is the final soil N content after harvesting of rice (mg pot^{-1}).

To assess the effect of green manure properties on net N balance after rice, linear regression analysis were carried out using N content, lignin content, and C/N ratio of green manures as independent variable and net N balance after rice (Y) as dependent variable.

Results and Discussion

Nitrogen Balance

Green manures (when grouped together) were inferior to urea in terms of N removal by rice (Table 2). However, N removal from the treatment of 3% urea-enriched guar was as good as split N application of urea. Interaction between green manures and enrichment treatments was significant and 3% urea-enriched guar was found to be superior (Table 3). Guar, among the green manures and enrichment treatment with spraying of 3% urea, was superior in terms of N removal. Significant increase in N removal was observed with increasing N levels. A significant interaction between sources and levels of N existed (Table 4). This might be attributed to the faster N mineralization of guar N due to lower lignin content and C/N ratio (Dey and Jain 1996; Dey and Jain 1997). The N balance was found to be net negative irrespective of sources of green manures and levels of N application and N-enrichment levels of the green manures. The results indicate gaseous loss by mechanisms such as denitrification and volatilization of N during rice growth. Loss of N was greater from urea-treated pots than from green manure–treated ones. Comparatively lower loss of N from green manure treatment might be ascribed to the organic acids produced during decomposition of green manures, which in turn retarded volatilization losses. Green manures followed the order of decreasing N loss in the sequence of

Table 2
Net N balance after rice harvest as influenced by different sources and levels of N and enrichment of sources of green manures

	Nitrogen (mg pot^{-1})				
Treatment	Added	Crop removal	Initial soil N	Final	Net N balance
Sources					
Urea	214.3	178.4	2432.1	2432.2	−35.74
Dhaincha	214.3	161.2	2432.1	2475.5	−09.64
Cowpea	214.3	147.2	2432.1	2484.2	−15.01
Guar	214.3	177.1	2432.1	2465.2	−04.05
Control	0.0	68.0	2432.1	2319.7	−44.44
Enrichment treatment					
E_0	214.3	147.6	2432.1	2482.8	−15.94
E_1	214.3	161.2	2432.1	2475.2	−09.94
E_2	214.3	176.7	2432.1	2462.8	−06.86
N level (mg pot^{-1})					
L_1	107.1	118.7	2432.1	2403.0	−17.49
L_2	214.3	166.9	2432.1	2468.6	−10.87
L_3	321.4	204.8	2432.1	2537.6	−11.10
CD ($P = 0.05$)					
Control vs rest	—	14.8	—	—	—
Urea vs green manure	—	8.6	—	—	—
Enrichment level	—	0.5	—	—	—
N level	—	4.7	—	—	—
Source × N level	—	14.8	—	—	—

Notes. E_1 is created by application of 10 kg N ha^{-1} as starter dose and spraying 1.0% urea solution (10 kg urea ha^{-1}) three times on alternate days starting from 14 days before incorporation in soil. E_2 is created by application of 30 kg N ha^{-1} as starter dose and spraying 3.0% urea solution (30 kg urea ha^{-1}) three times on alternate days starting from 14 days before incorporation in soil. E_0 is the control (no urea was added either as starter dose or spray).

cowpea > dhaincha > guar. With the increase in N-enrichment levels of green manures, the loss of N was found to be minimized. Greater net N balances of green manures, which increased in magnitude with increase in enrichment levels as compared to urea suggested the feasibility of urea-enriched green manures for soil sustainability in a rice–wheat system.

Relationship between N Balance after Rice and Properties of Green Manures

Net N balance after rice was positively correlated ($P = 0.01$) with the N content (r = 0.832) and negatively correlated with the lignin content (r = –0.907) and C/N ratio (r = –0.776) of green manures. Linear models between the net N balance and characteristics of green manures (Table 5) showed that the N content, lignin content, and C/N ratio could describe 69.2, 82.3, and 60.3% of the total variations in net N balance, respectively. The linear equations suggest that lignin content is a better index for prediction of net N balance than C/N ratio or N content of green manures.

Table 3
Interaction of sources of green manures with N enrichment among grain yield, dry-matter yield, and total N uptake in rice crop

Enrichment level	Grain yield (g pot^{-1})				Dry-matter yield (g pot^{-1})				Total N uptake (mg pot^{-1})			
	Dhaincha	Cowpea	Guar	Mean	Dhaincha	Cowpea	Guar	Mean	Dhaincha	Cowpea	Guar	Mean
E_0	8.3	7.9	9.4	8.6	18.0	16.9	19.6	18.2	145.4	134.8	162.5	147.6
E_1	9.0	8.5	10.3	9.3	18.7	17.8	20.6	19.0	157.6	145.8	180.3	161.2
E_2	10.2	9.4	10.5	10.0	20.6	19.1	21.2	20.3	180.6	161.0	188.6	176.7
Mean	9.2	8.6	10.1		19.1	17.9	20.5		161.2	147.2	177.1	
CD (P = 0.05)	G = 0.2	E = 0.2	GXE = 0.2		G = 1.0	E = 1.0	GXE = NS		G = 0.5	E = 0.5	GXE = 0.9	

Notes. E_1 is created by application of 10 kg N ha^{-1} as starter dose and spraying 1.0% urea solution (10 kg urea ha^{-1}) three times on alternate days starting from 14 days before incorporation in soil. E_2 is created by application of 30 kg N ha^{-1} as starter dose and spraying 3.0% urea solution (30 kg urea ha^{-1}) three times on alternate days starting from 14 days before incorporation in soil. E_0 is control (no urea was added either as starter dose or spray). NS is not significant.

Table 4
Interaction of N sources of green manure and urea with levels of N applied on N removal by the rice crop

Sources	L_1	L_2	L_3	Mean
Urea	126.5	180.9	227.7	178.4
Dhaincha	117.2	163.1	203.1	161.2
Cowpea	109.8	151.2	180.7	147.2
Guar	126.5	181.8	223.1	177.1
Control				68.0

Notes. L_1 is 107.1 mg N pot^{-1}, L_2 is 214.3 mg N pot^{-1}, and L_3 is 321.4 mg N pot^{-1}. CD P = 0.05; N level = 4.7; Sources × N level = 14.8.

Table 5
Linear models between the net N balance and chemical characteristics of green manures

Parameter	Linear model	$R^2 \times 100$
N content (%)	Y = –32.187 + 9.508 X	69.2*
Lignin content (%)	Y = 126.224 – 8.139 X	82.3*
C/N ratio	Y = 7.336 – 0.907 X	60.3

*Significant at $P = 0.01$.

Effect of Residual N on Wheat Crop

Yield and N uptake by the following wheat crop have been used as an index of residual effect of added N in the preceding crop. The beneficial effect of added N in the rice season on the following wheat crop was apparent as the N-amended soil significantly produced greater grain and dry-matter yield than the control (Table 6). Green manures were found to be more beneficial than urea. Application of N in the preceding rice season resulted in a significant increase in grain and straw N content of wheat over the control. Among the green manures, guar was found to be superior to others in increasing the N content. A steady response was observed with the increase in enrichment level of green manures (Table 7). Residual effect of green manures in wheat was found to be more than that of urea. Total N uptake was greatest with guar followed by dhaincha and cowpea. Significant response was observed with the increase in the level of enrichment treatment of green manures. Significant interaction of green manures with enrichment treatment was observed for grain yield in wheat crop, and guar enriched with 3% urea recorded the greatest grain yield. Positive effects of green manures to the wheat crop when applied to the preceding rice season were also observed by other workers (Bharadwaj and Dev 1985; Zhu, Liu, and Jian 1984).

Effect of Net N Balance after Rice on Wheat

The contribution of net N balance after rice on wheat crop was found to be quite substantial as confirmed by the fact that it was positively and significantly correlated ($P = 0.01$) with grain yield (r = 0.85), dry-matter yield (r = 0. 85), grain N uptake (r = 0.88), and total N uptake (r = 0.88) by wheat.

Table 6
Total dry matter, grain yield, and N uptake by succeeding wheat crop

Treatment	Grain yield ($g\ pot^{-1}$)	Dry matter ($g\ pot^{-1}$)	N uptake ($mg\ pot^{-1}$)		
			Grain	Straw	Total
Sources					
Urea	4.20	8.48	45.37	20.01	65.37
Dhaincha	4.34	8.76	48.86	21.40	70.27
Cowpea	4.28	8.65	47.40	20.70	68.10
Guar	4.41	8.90	50.11	21.98	72.09
Control	3.28	6.65	30.50	14.15	44.65
Enrichment treatment					
E_0	4.29	8.66	47.46	20.93	68.40
E_1	4.34	8.75	48.75	21.26	70.00
E_2	4.40	8.89	50.16	21.89	72.06
N level					
L_1	3.99	8.10	43.49	19.00	62.49
L_2	4.33	8.73	48.47	21.16	69.63
L_3	4.66	9.38	53.39	23.52	76.90
CD ($P = 0.05$)					
Control vs rest	0.11	0.52	1.40	0.62	1.61
Urea vs green manure	0.06	0.30	0.81	0.36	0.93
Enrichment treatment	0.04	0.17	0.20	0.28	0.97
N level	0.03	0.16	0.44	0.20	0.51
Source × N level	NS	NS	NS	NS	NS

Notes. E_1 is created by application of 10 kg N ha^{-1} as starter dose and spraying 1.0% urea solution (10 kg urea ha^{-1}) three times on alternate days starting from 14 days before incorporation in soil. E_2 is created by application of 30 kg N ha^{-1} as starter dose and spraying 3.0% urea solution (30 kg urea ha^{-1}) three times on alternate days starting from 14 days before incorporation in soil. E_0 is the control (no urea was added either as starter dose or spray). L_1 is 107.1 mg N pot^{-1}, L_2 is 214.3 mg N pot^{-1}, and L_3 is 321.4 mg N pot^{-1}. NS is not significant.

The linear regression equations developed from the relationship between yield and uptake parameters of wheat as a function of net N balance after rice in rice–wheat cropping system (Table 8) can effectively describe 72.3, 72.1, 77.5, and 77.6% of total variations in grain yield, dry-matter yield, grain N uptake, and total N uptake of residual wheat. In general, if a linear regression equation can describe more than 66% of total variations, then that particular equation is considered as good fit. Thus, all the four equations were good fit. Therefore, net N balance after rice could be effectively used as an indicator for the prediction of yield and N uptake by wheat crop. Indirectly, it also threw light on the net N requirement for the succeeding wheat crop in rice–wheat system.

Conclusions

Soil N balance after harvesting of rice can be predicted by lignin content of green manures and determining the residual N utilization by the succeeding wheat crop in a rice–wheat cropping system. A linear model developed with yield/uptake of wheat as a function of net

Table 7
Interaction of sources of green manures with N-enrichment treatment on the grain yield, dry-matter yield, and the total N uptake by the wheat crop

Enrichment level	Grain yield (g pot^{-1})				Dry-matter yield (g pot^{-1})				Total N uptake (mg pot^{-1})			
	Dhaincha	Cowpea	Guar	Mean	Dhaincha	Cowpea	Guar	Mean	Dhaincha	Cowpea	Guar	Mean
E_0	4.3	4.3	4.3	4.3	8.7	8.6	8.8	8.7	66.7	66.8	69.7	68.4
E_1	4.3	4.3	4.4	4.3	7.8	8.6	8.9	8.8	70.0	68.0	72.0	70.0
E_2	4.4	4.3	4.5	4.4	8.7	8.7	9.1	8.9	72.1	69.5	74.6	72.1
Mean	4.3	4.3	4.4		8.8	8.7	8.9		70.3	68.1	72.1	
CD ($P =$ 0.05)	G = 0.04	E = 0.04	GXE = 0.06		G = 0.17	E = 0.17	GXE = NS		G = 1.0	E = 1.0	GXE = NS	

Notes. E_1 is created by application of 10 kg N ha^{-1} as starter dose and spraying 1.0% urea solution (10 kg urea ha^{-1}) three times on alternate days starting from 14 days before incorporation in soil. E_2 is created by application of 30 kg N ha^{-1} as starter dose and spraying 3.0% urea solution (30 kg urea ha^{-1}) three times on alternate days starting from 14 days before incorporation in soil. E_0 is control (no urea was added either as starter dose or spray). NS is not significant.

Table 8
Relationship among yield of grain, dry matter, and N uptake of wheat (Y) as a function of net N balance after rice (X) in rice–wheat cropping system

Parameter	Linear model	$R^2 \times 100$
Grain yield (mg pot^{-1})	Y = 4.573 + 0.021 X	72.3*
Dry matter yield (g/pot)	Y = 9.220 + 0.042 X	72.1*
Grain N uptake (mg/pot)	Y = 52.942 + 0.383 X	77.5*
Total N uptake (mg/pot)	Y = 75.956 + 0.535 X	77.6*

*Significant at $P = 0.01$.

N balance after rice in a rice–wheat cropping system that could effectively describe 72.3, 72.1, 77.5, and 77.6% of total variations in grain yield, dry-matter yield, grain N uptake, and total N uptake of residual wheat. Researchers have another tool and dimension in net N balance after rice that could be effectively used as an index for the prediction of yield and N uptake by a succeeding wheat crop and a tool for optimizing N application in succeeding wheat crop grown in sequence after rice.

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