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Nitrogen dynamics and crop growth on an alfisol and a vertisol under rainfed lowland rice-based cropping system

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Abstract

Crop rotation experiments were conducted over 2 years to quantify N supply-demand under rainfed lowland rice–chickpea and rice–fallow cropping systems on a loam Alfisol and a clay Vertisol in India. Significant differences among N rates (0, 40, 80, and 120 kg N ha^{-1}) and soils were observed with rice for grain yield, total biomass and grain N uptake in both years. Low N response, low grain yield, low N uptake, and a short grain filling phase during the 1995 wet season was due to post-heading water stress. The stress was more pronounced on the Vertisol and at high N rates. This resulted in lower N content at maturity than at heading. The loss of biomass N from plant implied that apparent N recovery (AR) and physiological nitrogen use efficiency (PNUE) may differ significantly based on whether maximum N accumulation or total N uptake at maturity was used. Plant N recovery, both by the N difference method and ^{15}N technique, revealed much lower recovery of fertilizer N (21–27%) with rainfed lowland rice than with irrigated dry-season rice. The residual effect of N applied to the preceding rice crop was nonsignificant on all yield, growth, and N uptake parameters of chickpea. The performance of chickpea was better on the Alfisol than the Vertisol, principally due to soil physical attributes. The better performance and longer growth duration during 1994–1995 dry season as opposed to the 1995–1996 season was attributed to higher rainfall (92 mm versus 39 mm) and rainfall during the critical pod-filling to maturity phase. Mineralization and nitrification of N was negligible during the rice–fallow period due to the dry conditions and low organic matter content. This was corroborated by the similarities in N balance between rice–chickpea and rice–fallow system. The PNUE of rice was 33 to 57 kg grain per kg N absorbed compared with 25 to 27 kg grain per kg N absorbed of chickpea, owing mostly to higher N concentration of chickpea grain and the higher energy cost due to biological N fixation.

Keywords: Rice; Chickpea; Fallow; N dynamics; N balance; ^{15}N; Alfisol; Vertisol

1. Introduction

Lowland rice (*Oryza sativa* L.) and rice-based cropping sequences are the most predominant cropping systems in Asia. The erratic rainfall, differences

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in soil and hydrological properties, and relief make rainfed crop production and nutrient dynamics highly season- and location-specific. The occurrence of moisture stress or flooding in rainfed rice-based cropping systems result in poor utilization of applied nutrient compared to the irrigated rice system (Singh et al., 1995).

Nitrogen is generally the most limiting nutrient in high-yielding rice systems, and adequate N supply is required throughout the active growing period. Many strategies have been developed in irrigated rice systems to increase utilization of applied N fertilizer through improved agronomic management on proper timing, rate, placement and sources of fertilizer (Prasad and De Datta, 1979; De Datta and Craswell, 1982; De Datta and Patrick, 1986; Fillery and Vlek, 1986; De Datta and Buresh, 1989; Cassman et al., 1993; Singh et al., 1995). The relevance of this work to rainfed systems is questionable because of lack of water control in rainfed environment.

Rainfed lowland rice cropping systems are characterized by variable wetting and drying periods. This situation promotes nitrification and subsequent uptake and/or loss of N due to leaching and denitrification. Drying and rewetting of soils also promote mineralization of N (Cabrera, 1993). The net effect on crop N uptake would depend on how much of the mineralized- and nitrified-N was absorbed by the crop and how much was leached beyond the rooting zone or denitrified on reflooding. Ammonia volatilization and runoff are predominant loss pathways in lowland rice (De Datta and Buresh, 1989; Daftardar and Savant, 1995). The key to improving the efficiency of N and reducing losses is the congruence of N supply with plant N demand.

In irrigated rice systems, large soil N losses occur during the post-rice fallow period (Buresh et al., 1989; George et al., 1993). While some of the research findings from irrigated environments contribute to N research and management strategies in rainfed lowlands, the highly variable moisture and in some instances temperature regime dictate that such research be conducted in the relevant environment. Our objective was to quantify N supply-demand in rainfed-lowland rice–chickpea (*Cicer arietinum* L.) and rice–fallow cropping systems on two soils with different water holding characteristics. The role of post-rice chickpea – an important food crop in the region versus post-rice fallow – in improving soil-N capture was also evaluated. Plant growth, development, and N dynamics were closely monitored over two complete annual crop cycles on the two soils.

2. Materials and methods

2.1. Experimental site

A rotation experiment involving rice–fallow and rice–chickpea was conducted during the 1994–1995 and 1995–1996 seasons on two soil types – a clayey fine montmorillionitic hyperthermic Udic Chromosterts (Vertisol) and a loamy mixed hyperthermic Udic Haplustalfs (Alfisol) – at the experimental farm of Indira Gandhi Agricultural University (IGAU) (21.23°N, 81.65°E), Raipur, India. The two fields were less than 1 km apart. The initial soil physical and chemical properties for 0 to 70 cm soil depth are provided in Table 1, while rainfall distribution is characterized by a distinct dry season (Fig. 1).

2.2. Experimental design

During the wet season of 1994, the experiment was laid out in both fields as a randomized complete block design with four N levels (0, 40, 80 and 120 kg N ha^{-1}) and four replications with a plot size of 10 m × 8 m. Based on soil status and plant removal, blanket application of 26 kg P ha^{-1} as single superphosphate (SSP) and 25 kg K ha^{-1} as K_2SO_4 were applied at puddling. Zinc was applied only once in 1994 at the rate of 10 kg Zn ha^{-1} as $ZnSO_4$. Urea-N was applied in three equal splits to improve fertilizer efficiency. A day before transplanting one-third of urea-N was basally incorporated to reduce volatilization and run-off losses from the floodwater. The first urea topdressing at 3 to 5 days before panicle initiation (PI) coincided with N demand for maximum spikelet formation. The final topdressing at heading ensured adequate N supply for grain filling.

Three to four 20 day-old rice seedlings (Var. IR36) were transplanted on 20 and 21 July in 1994 (Fig. 1) at 20 cm × 10 cm hill spacing. ^{15}N microplots (0.8 m× 0.8 m) were located in 120 kg N ha^{-1} plots in all four replications during the 1994 wet-season rice cropping. Soil (0–5, 5–15, 15–30 and 30–50 cm depth)

Table 1
Initial soil properties of Alfisol and Vertisol at IGAU experimental farm, July 1993

Depth (cm)	pH water (1 : 2.5)	pH KCl (1 : 2.5)	Bulk density[a] (g cm^3)	Organic C (g kg^{-1})	Total N (g kg^{-1})	Mineral N[b] (mg kg^{-1})	CEC (cmol kg^{-1})	P.S.D. (%)			Soil water content (cm^3 cm^{-3})[c]	
								Sand	Silt	Clay	Lower limit	Drained upper limit
Alfisol												
0–5	7.2	6.4	1.35	5.1	0.76	15.1	30.3	34	30	36	0.189	0.339
0–15	7.4	6.5	1.38	4.1	0.88	18.7	–	28	34	38	0.201	0.358
15–30	8.1	7.0	1.43	4.6	0.63	10.8	–	28	33	39	0.203	0.364
30–50	8.2	7.1	1.45	3.9	0.56	15.1	–	27	33	40	0.209	0.364
50–70	8.2	7.3	1.53	3.2	0.76	16.9	–	26	34	40	0.209	0.365
Vertisol												
0–5	7.4	6.4	1.41	4.9	0.63	17.5	43.2	19	31	50	0.258	0.382
5–15	7.8	6.8	1.43	5.1	0.50	9.6	–	19	32	49	0.260	0.388
15–30	8.1	7.2	1.47	4.2	0.76	15.7	–	18	30	52	0.267	0.390
30–50	8.2	7.2	1.51	4.0	0.88	10.8	–	18	29	54	0.276	0.398
50–70	8.3	7.2	1.56	3.6	0.63	17.5	–	18	26	56	0.284	0.406

[a] Determined at drained upper limit soil moisture content.

[b] Mineral N $= NH_4^+ - N + NO_3^- - N$.

[c] Estimations for extractable soil water limits is based on Ritchie et al. (1987).

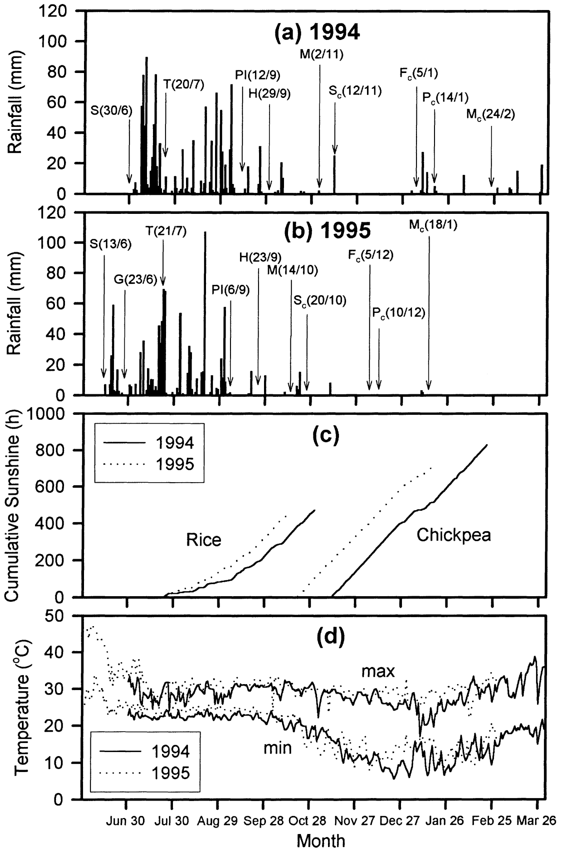

Fig. 1. Rainfall distribution and crop calendar for (a) 1994 and (b) 1995 rice–chickpea cropping. S = sowing, G = germination, T = transplanting, PI = panicle initiaion, H = heading, M = maturity and S_c = chickpea sowing, F_c = first flowering, P_c = first pod formation and M_c = chickpea maturity. Cumulative sunshine hours are from time of transplanting in rice and sowing in chickpea (c).

and plants were sampled separately from ^{15}N microplots.

After harvest of the 1994 wet-season rice, all of the N plots were divided – one-half planted with dry-season chickpea (Var. JG 74) on 12 November and the other half kept fallow. A blanket application of 20 kg N ha^{-1} as urea (as starter for legume) and, based on crop removal, 18 kg P ha^{-1} as SSP and 17 kg K ha^{-1} as K_2SO_4 was basally incorporated immediately prior to chickpea sowing (Fig. 1).

The identity of all the chickpea and fallow plots was maintained such that the treatments they received during the dry (chickpea and fallow) and wet season (rice) remained consistent over the 2 years. For the 1995 rice crop, the treatments were laid out in a split plot design with N rates (0, 40, 80, and 120 kg N ha^{-1}) as main plot and dry season cropping (chickpea, fallow) as subplot with plot size of 8 m × 5 m. The experimental procedure was similar to that of the 1994 rice, except the chickpea residue was incorporated in the chickpea plots before puddling. The fallow–chickpea cycle was repeated after the rice harvest in the 1995–1996 dry season. The planting dates and mean growth stages of rice and chickpea for 1995 and 1995–1996 season are shown in Fig. 1.

2.3. Plant and soil sampling and yield parameters

Dates of all key phenological events and plant and soil samplings were determined for each plot. PI stage was reached when more than five out of ten main culms dissected each day for 3 to 4 days had >1 mm panicle tip visible. Heading and physiological maturity occurred when 50% or more of the selected plants (tagged after transplanting) reached the specified stage. Plant sampling for total dry matter and N uptake was performed at maximum tillering, 3 to 5 days before PI, heading and physiological maturity stages of rice from 12 hills. At physiological maturity, yield components (one-thousand filled grain weight, total number of spikelets [m^{-2}], and spikelet fertility) were determined. Grain (caryopsis + hull) was analyzed separately for N. Grain (unhulled) yield (adjusted to 14% moisture content [MC]) and straw weight (after drying at 70°C to a constant weight) were determined at final harvest stage from a 5 m^2 area. Chickpea biomass and N content were determined at flowering and maturity stages from eight plants. At the final harvest (5 m^2 area) chickpea grain and straw yields were recorded. Straw dry matter was composted for use during the 1995 wet-season rice. Prior to the planting of each crop cycle, previous crop root residue was assumed as 10% of the aboveground biomass, while stubble biomass was determined by random quadrant (1 m × 1 m) sampling. The N content was determined using the Kjeldahl method (Bremner, 1960). Prior to the initial fertilization of the rice crop (I), soil samples were taken from five depths (0–5, 5–15, 15–30, 30–50, and 50–70 cm) in each replication and analyzed for KCl extractable $NH_4^+ + NO_3^- - N$ (presented as mineral N in Table 1) by the method of

Bremner and Keeney (1966). Soil samples were also collected at the five depths over the 2-year period at immediately after rice harvest (AR) during the wet season and after chickpea (AC) harvest in the chickpea and fallow (AF) plots during the dry season. These samples were only from those plots which had received 0 (N_0) and 120 (N_{120}) kg N ha^{-1} while under rice cropping and analyzed for KCl extractable $NH_4^+ + NO_3^- - N$.

Soil moisture and water table data were recorded during the wet season. Tensiometers were installed at 15 cm depth and piezometers at 40 cm depth. Daily rainfall, hours of sunshine, and maximum and minimum air temperature were also recorded. Water holding characteristics of the soils – drained upper limit ($cm^3\ cm^{-3}$) and lower limit of plant available water ($cm^3\ cm^{-3}$) – were calculated from sand, silt and clay percentage, bulk density, and organic matter content as described by Ritchie et al. (1987).

The following parameters were calculated using the following equations:

$$\text{Harvest index (HI)} = \frac{\text{Grain yield}}{\text{Total biomass}} \times 0.86$$

$$\text{Physiological N use efficiency (PNUE)} = \frac{\text{Grain yield}}{\text{Total N uptake}} \times 0.86$$

$$\text{Agronomic N use efficiency (ANUE)} = \frac{(\text{Grain yield with N application} - \text{Grain yield from zero N plots})}{\text{N applied}} \times 0.86$$

and

$$\text{Apparent recovery of applied N (AR)} = \frac{(\text{N uptake with N application} - \text{N uptake from zero N plots})}{\text{N applied}} \times 100$$

where factor 0.86 is used to convert grain yield with 14% MC on dry-weight basis.

2.4. Statistical analyses

Analysis of variance (ANOVA) was performed for each year on plant growth indicators and N uptake to evaluate the effect of N rates. A combined analysis of variance using variations of split plot designs (Cochran and Cox, 1957; Petersen, 1985) was used to evaluate the effects of N rates, the soil types (S), and the possible interaction between N rates and soil types. An individual ANOVA was performed to evaluate the effect of cropping sequence (C) and N rates on plant growth and nitrogen uptake. Regression analysis was used to estimate the relationships and trends between grain yield, N uptake, and N applied.

3. Results and discussion

3.1. Rice growth, yield and development

Nitrogen rate had a large impact on grain yield, yield components, and dry-matter production (Table 2). Significant effects of N on fertility percentage and harvest index were obtained only in the 1995 wet season. One-thousand grain weight was the most stable parameter as it was unaffected by N rate and soil type. The effect of previous cropping – chickpea and uncropped fallow, which came into effect from the 1995 wet season – and their interactions with soil and N rate were not significant across all parameters (data not shown). Hence, in further statistical analysis the previous crop effect was not considered.

There were significant differences in crop response on the Alfisol and Vertisol in both years with respect to grain yield, total biomass, grain N uptake, and total N uptake. In addition, panicle number, fertility percentage, and harvest index were effected by soil type in the 1995 wet season (Table 2). During the 1994 wet season, grain yield response to applied N was significant up to 80 kg N ha^{-1} application in both the Alfisol and Vertisol (Fig. 2). In contrast, significant N response was obtained only up to the 40 kg N ha^{-1} rate in the Alfisol during the 1995 wet season. The smaller N response on the Alfisol during the 1995 wet season could be attributed to the amount and distribution of rainfall, 997 mm in 58 days versus 1150 mm in

Table 2
Percent contribution of nitrogen rates (N), soil type (S) and their interaction sum of squares to the total sum of squares and significance of their *F* values of selected parameters at final harvest for 1994 and 1995 wet-season rice

Parameters	% of total sum of squares and significance of *F* values					
	1994			1995		
	N	S	N × S	N	S	N × S
Grain yield (kg ha^{-1})	39^{**}	46^{**}	1 ns	73^{**}	19^{**}	2^{*}
Total biomass (kg ha^{-1})	55^{*}	28^{*}	3^{**}	87^{**}	6^{*}	1 ns
Straw yield (kg ha^{-1})	57^{**}	21^{*}	5^{**}	85^{**}	3 ns	1 ns
Panicle (no.m^{-2})	58^{*}	1 ns	15^{*}	70^{**}	4 ns	0 ns
Fertility (%)	5 ns	16 ns	11^{*}	70^{**}	13^{**}	2 ns
1000 grain weight (g)	5 ns	25 ns	9 ns	5 ns	0 ns	10 ns
Straw N uptake (kg ha^{-1})	40^{**}	18 ns	2 ns	73^{**}	2 ns	2 ns
Grain N uptake (kg ha^{-1})	29^{**}	50^{**}	2 ns	68^{**}	18^{**}	1 ns
Total N uptake (kg ha^{-1})	37^{**}	41^{*}	1 ns	70^{**}	12^{*}	1 ns
Harvest index	18 ns	20 ns	10 ns	54^{**}	36^{**}	3^{*}
PNUE (kg grain kg^{-1} N)	3 ns	3 ns	8 ns	16 ns	15 ns	15 ns
ANUE (kg increment in grain yield kg^{-1} N applied)	17 ns	12 ns	0 ns	76^{*}	6 ns	5^{*}
Apparent recovery (%)	10 ns	2 ns	1 ns	65^{**}	2 ns	1 ns

** – significant at 1% level; * – significant at 5%; ns – not significant.

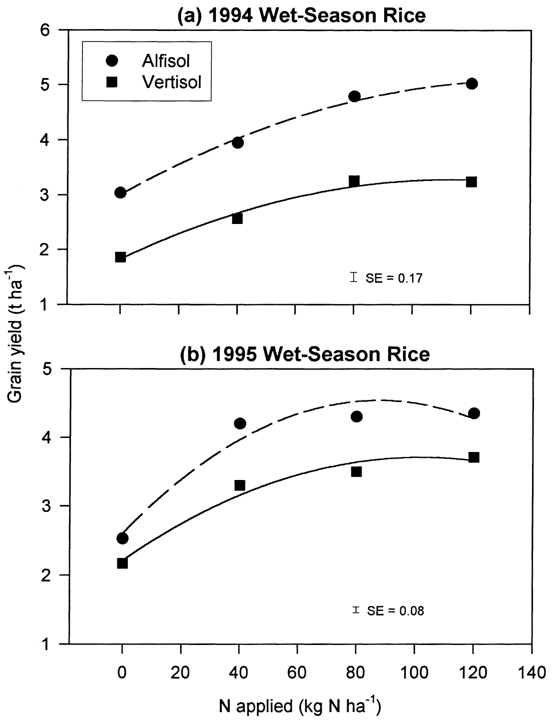

Fig. 2. Rice grain yield response on an Alfisol and a Vertisol as influenced by N application (a) 1994 wet season and (b) 1995 wet season. Standard error bar compares differences in N rate within soils and N × S interaction.

78 days during 1994 wet season (Fig. 1). Differences in post-anthesis rainfall were more pronounced with 39 mm in six rainy days in 1994 versus 15 mm in two rainy days in 1995.

During the 1994 wet season, biomass accumulation at maximum tillering, PI, and heading stages was not significantly different among the two soils; however, less biomass was obtained on the Vertisol at maturity (Fig. 3). Total biomass did not respond to N application rates beyond 80 kg N ha^{-1} on the Vertisol. During the 1995 wet season, the biomass at heading and maturity was in general, smaller on the Vertisol. The lower grain yield (Fig. 2) and total biomass at maturity (Fig. 3) across all N rates on the Vertisol compared to the Alfisol could be attributed to faster receding of ground water, higher matric potential during heading and post-heading period (Fig. 4), and shallow rooting depth on the Vertisol. Root observations from soil samples taken at harvest stage in N_0 and N_{120} plots revealed the maximum rooting depth of 60 cm on Alfisol and 40 cm on Vertisol. In addition, cracks appeared earlier in Vertisol at matric potential of ≥ -60 kPa. These cracks appeared around the rice hills; thus, the roots may be ripped apart and access may be restricted to available soil water, especially in the top layers. There were no soil cracks in Alfisol throughout the growth duration. Soil shrinking and cracking generally result in restricted root devel-

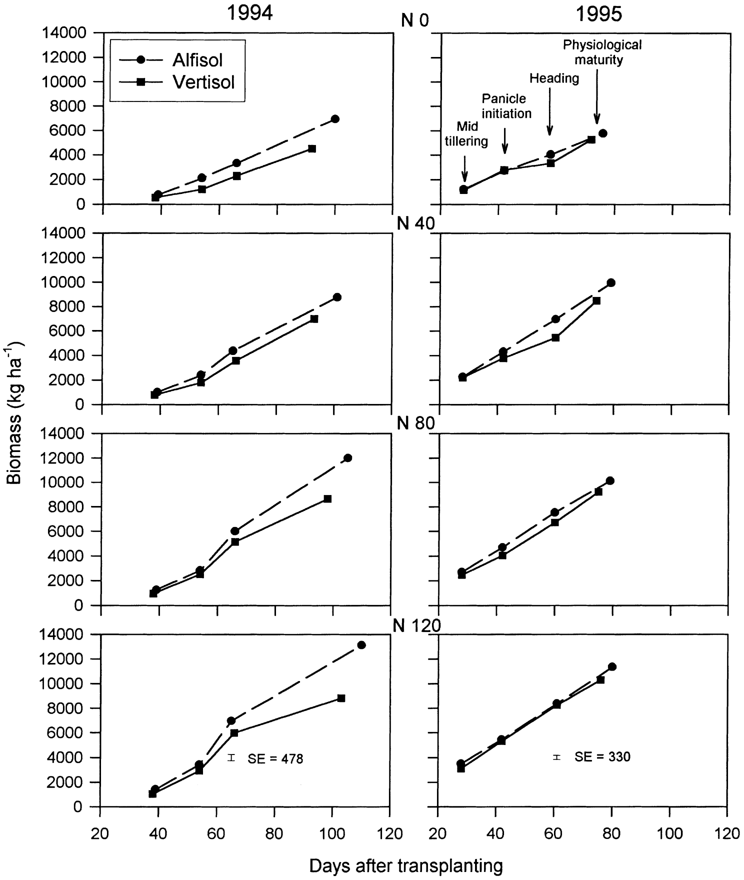

Fig. 3. Biomass accumulation for four N regimes on an Alfisol and a Vertisol during 1994 and 1995 wet season. Standard error bar indicates differences among and within biomass samples, soils and N rate.

opment, which consequently accentuates drought stress (Sanchez, 1973).

The duration to PI and 50% heading in rice was prolonged by up to 5 days with respect to PI and 50% heading on the Vertisol at N_0 (Table 3). The N-deficient plants generally reached PI and heading earlier; however, the apparent delay at high N rates could also be attributed to higher transpiration rate and increased drought intensity with N application. Drought stress at the vegetative stage delays phenological development (Obermueller and Mikkelsen, 1974). In rice, anthesis is delayed even when soil moisture is maintained at field capacity (Senewiratne and Mikkelsen, 1961; Sen and Datta, 1967). Post-heading phase drought stress, particularly during the 1995 wet season, shortened the grain-filling duration. However, the net effect was delayed maturity with respect to maturity at N_0 on the Vertisol (Table 3). The earlier maturity on the Vertisol versus the Alfisol in both the years and in the 1995 versus 1994 wet season in both the soils, reflected a more severe post-heading phase drought stress. Matric potential measurements were not possible beyond -60 kPa using tensiometers (Fig. 4).

Repeated measures of ANOVA over the years revealed significantly greater ($p \leq 0.05$) aboveground biomass at PI and heading stages during the 1995 wet season compared to the 1994 wet season for all N rates and soils. However, at maturity the biomass differences were statistically similar across years with the exception of 80 and 120 kg N ha^{-1} on the Alfisol (Fig. 3). Higher biomass accumulation during the

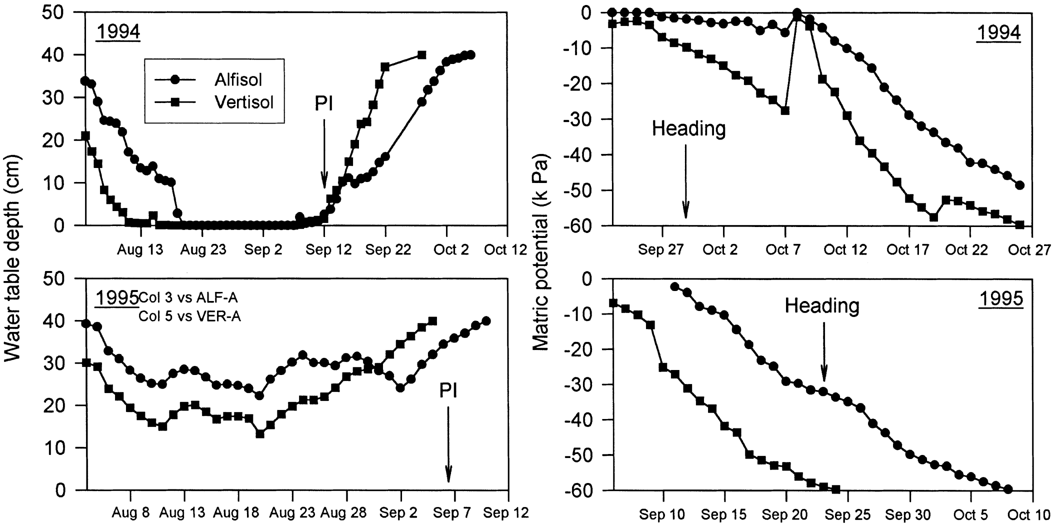

Fig. 4. Seasonal changes in ground water table depth (cm from soil surface) for piezometer installed at 40 cm depth and soil matric potential (k Pa) at 0–15 cm depth in Alfisol and Vertisol (averaged over reps.) during 1994 and 1995 wet season.

Table 3
Comparison of differences in phenological events of IR36 relative to N_0 on Vertisol for different N rates and two soil types during wet season

N Rate (kg ha^{-1})	Delay in phenological events (days) [1]					
	Panicle initiation		Heading		Maturity	
	Alfisol	Vertisol	Alfisol	Vertisol	Alfisol	Vertisol
1994						
0	0.0 b[2]	0.0 b	0.0 b	0.0 b	9.0 cd	0.0 e
40	0.0 b	0.5 b	0.0 b	0.5 b	10.0 c	1.0 e
80	1.5 ab	1.0 ab	2.0 ab	2.5 ab	15.0 ab	6.0 d
120	4.0 a	4.0 a	5.0 a	4.5 a	20.0 a	10.0 c
1995						
0	0.0 b	0.0 b	0.0 b	0.0 b	4.0 cd	0.0 e
40	2.0 ab	1.0 ab	2.0 ab	1.5 ab	7.0 ab	2.5 de
80	2.0 ab	2.5 ab	2.0 ab	2.5 ab	7.5 ab	3.0 de
120	3.5 a	3.5 a	4.0 a	4.0 a	8.5 a	4.5 bcd

[1] With respect to a given phenological event occurring at N_0 on Vertisol.

[2] In a growth stage column, under each layer, means followed by a common letter are not significantly different at the 5% level by DMRT.

early stages in 1995 was associated with longer hours of bright sunshine. The number of cumulative sunshine hours at PI stage during 1994 and 1995 was 135 and 167, and at heading stage 232 and 278, respectively. Although hours of bright sunshine remained high throughout the crop cycle during the 1995 wet season, grain yield and biomass at maturity could have been influenced by moisture stress effects on growth, phenology and nutrient uptake (Fig. 1).

3.2. N uptake, efficiency and recovery in rice

N uptake increased up to the heading stage for all N rates on both the soils and years (Fig. 5). In general, very little N uptake occurred from heading to maturity regardless of N rate. In both the years, however, on the Vertisol at N_{120}, there was a significant decrease in total plant N uptake from heading to maturity. N uptake at maturity increased significantly ($p \leq 0.05$)

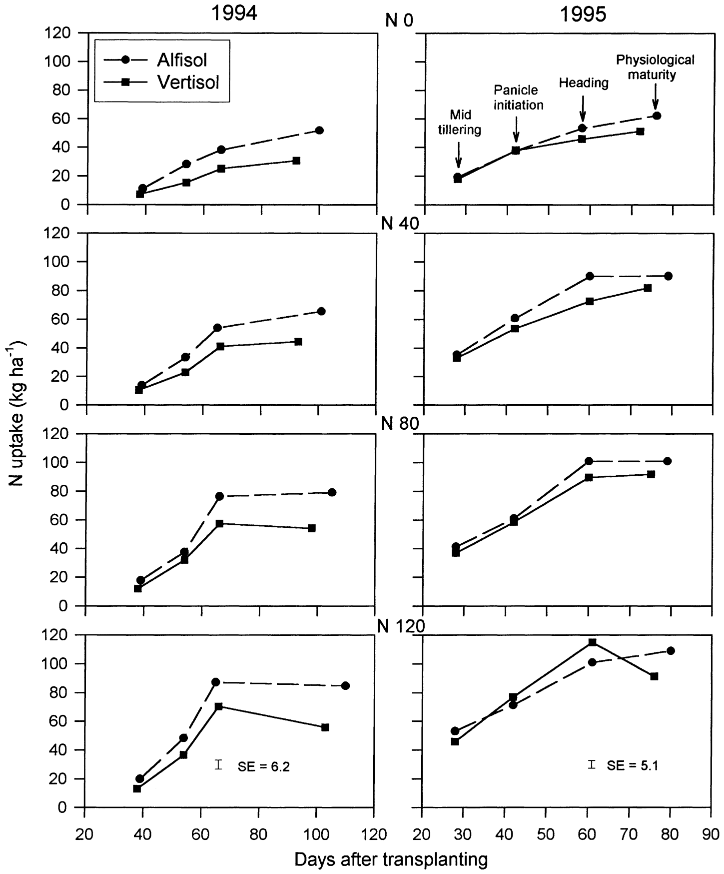

Fig. 5. Plant N accumulation for four N regimes on an Alfisol and a Vertisol during 1994 and 1995 wet season. Standard error bar indicates differences among and within sampling stages, soils and N rate.

from 0 to 80 kg N ha^{-1} in both the years on both the soils. Significant differences ($p \leq 0.05$) in total plant N uptake at maturity and grain N uptake were observed across the soils in both years (Table 2). Post-heading water shortage influenced grain N more than straw N on both the Alfisol and Vertisol.

Higher N uptake during 1995 versus 1994 wet season was associated with large increases in biomass up to heading stage (Fig. 3), adequate rainfall up to that period, and long hours of bright sunshine (Fig. 1). As evident from the significant biomass increase from heading to maturity (Fig. 3), the decline in N uptake during the same period at N_{120} (Fig. 5) was not associated with dry-matter loss. Lower N at maturity relative to heading, particularly at the highest N rate, may be attributed to increased above-ground gaseous N loss (da Silva and Stutte, 1981; Stutte and da Silva, 1981; Chatterjee and Abrol, 1990) and/or translocated N loss through root exudation (Smith et al., 1983). The post-heading period water stress resulted in reduced harvest index (0.34), grain yield, and inefficient remobilization or utilization of N reserve. Stutte and da Silva (1981) hypothesized a regulatory mechanism to account for higher gaseous N losses from rice leaves under temperature stress. A similar mechanism may operate at high N rates when grain N sink size becomes limited by post-heading phase drought stress. ^{15}N studies on direct-seeded rice even with continuous flooding have shown loss of biomass N after flowering (Norman et al., 1992).

The incongruence of maximum N uptake and N uptake at maturity, particularly at high N rates under stress condition, implies that the apparent N recovery (AR) and physiological nitrogen-use efficiency

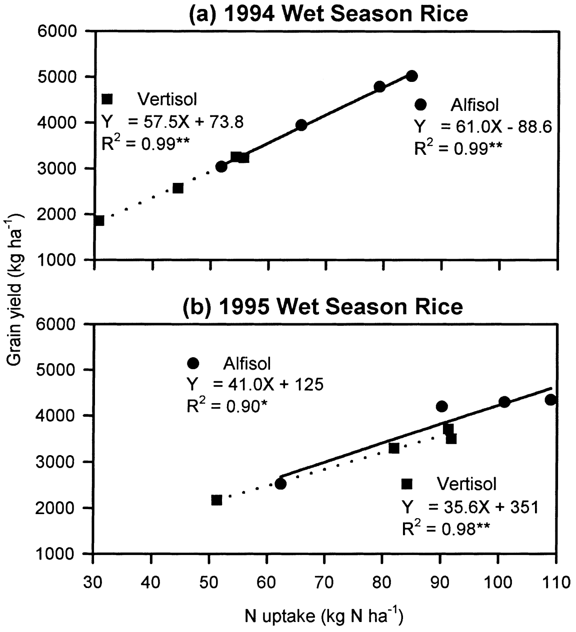

Fig. 6. Grain yield and N uptake relationship on Alfisol and Vertisol during (a) 1994 and (b) 1995 wet season.

(PNUE) may differ significantly based on which of the two N uptake values were used (Table 4). The $PNUE_{mat}$ (based on N uptake at maturity) was generally higher than $PNUE_{max}$ (based on maximum N uptake) on the Vertisol at N_{120}, perhaps giving a biased N-use efficiency. The $PNUE_{mat}$ (Table 4) and the grain yield response to N uptake (Fig. 6) were similar for both the Alfisol and the Vertisol during the 1994 wet season; whereas, in the following wet season the efficiency was lower on both the soils. Low PNUE has been reported for unfavorable rainfed lowland rice (Singh et al., 1995).

As expected, the agronomic N-use efficiency (ANUE) decreased with increasing N rates (Table 4 and Fig. 2). However, significant differences in ANUE due to N application was obtained only during the 1995 wet season (Tables 2 and 4). The ANUE at 40 kg N ha^{-1} was significantly higher on both the soils in the 1995 versus the 1994 wet season because during the 1995 wet season (i) grain yield at N_0 on the Alfisol was significantly lower and (ii) grain yield at N_{40} on the Vertisol was significantly higher than during 1994 wet season.

The soil N-supplying capacity was higher for the Alfisol than the Vertisol (Fig. 6). This may be attributed to higher total N and mineral N content in the top 15 cm soil layer in the Alfisol. Favorable conditions (increased sunshine hours and adequate rainfall) up to the heading stage during the 1995 wet season resulted in higher soil N supply than during 1994 wet season.

3.3. ^{15}N recovery

Plant N recovery from ^{15}N balances at the 120 kg N ha^{-1} rate during the 1994 wet season revealed recovery of 28 and 25% on the Alfisol and the Vertisol, respectively. The apparent recoveries (by N difference) for these treatments were similar – 27% and 21% (Table 4). These recovery efficiencies – both by ^{15}N and N-difference (AR_{mat}, AR_{max}) – are lower than values reported under dry-season irrigated condition (De Datta and Buresh, 1989; Cassman et al., 1993). The low recovery during the 1994 wet season could be due to less bright sunshine hours and late-season water stress. The proportion of fertilizer N retained in roots and soil (0–50 cm) accounted for 38% and 30% of applied N on the Alfisol and the Vertisol, respectively.

The amount of ^{15}N retained in the soil layers: 27.0% in 0–15 cm, 8.2% in 15–30 cm, and 2.8% in 30–50 cm in the Alfisol and 20.6% in 0–15 cm, 9.0% in 15–30 cm, and only 0.4% in 30–50 cm in the Vertisol. Unaccounted fertilizer N (loss) was higher on the Vertisol than the Alfisol (45% versus 34%). These losses were within the reported range of 26 to 64% for lowland rice (De Datta and Buresh, 1989). High losses, specifically as ammonia volatilization, could be attributed to the high pH of the soils (Table 1).

3.4. Growth, yield and N dynamics with chickpea

A residual effect of N applied to the preceding rice crop was significant only for straw yield and straw N of chickpea on the Alfisol during 1994–1995 dry season (Table 5). These variables were also significantly different on the two soils only at N rate of 120 kg ha^{-1} applied to the previous rice crop. During the 1995–1996 chickpea, the residual effect of applied N to the previous rice crop had no effect. The above may be attributed to the low amount, 6–16 kg ha^{-1} of N recycled in rice straw to chickpea (Table 6).

Chickpea performance was better on the Alfisol than the Vertisol, especially during the drier 1995–1996 year (Table 5). The better performance of chick-

Table 4
Nitrogen efficiency parameters based on N uptake at maturity (mat) and maximum N uptake (max)

N Rate (kg N ha^{-1})	Alfisol					Vertisol				
	ANUE (kg yield/kg N applied)	$\mathrm{PNUE}_{\mathrm{max}}$ (kg yield/kg N uptake)	$\mathrm{PNUE}_{\mathrm{mat}}$ (kg yield/kg N uptake)	$\mathrm{AR}_{\mathrm{max}}$ (%)	$\mathrm{AR}_{\mathrm{mat}}$ (%)	ANUE (kg yield/kg N applied)	$\mathrm{PNUE}_{\mathrm{max}}$ (kg yield/kg N uptake)	$\mathrm{PNUE}_{\mathrm{mat}}$ (kg yield/kg N uptake)	$\mathrm{AR}_{\mathrm{max}}$ (%)	$\mathrm{AR}_{\mathrm{mat}}$ (%)
1994										
0	–	51 a	51 a	–	–	–	52 a	52 a	–	–
40	23 a	57 a	57 a	34 a	34 a	18 a	50 a	50 a	34 a	34 a
80	22 a	52 a	52 a	34 a	34 a	18 a	49 a	52 a	34 a	30 a
120	17 a	50 a	52 a	30 a	27 a	12 a	40 b	50 a	33 a	21 a
1995										
0	–	35 a	35 a	–	–	–	36 a	36 a	–	–
40	42 a	40 a	40 a	70 a	70 a	31 a	35 a	35 a	77 a	77 a
80	22 a	37 a	37 a	48 b	48 b	18 b	33 ab	33 a	51 b	51 b
120	15 c	34 a	34 a	39 b	39 b	14 b	28 b	35 a	53 b	33 c

In a column means followed by a common letter are not significantly different at 5% level DMRT.

Table 5
Comparison of chickpea grain yield (kg ha^{-1}), straw yield (kg ha^{-1}), and straw N (kg N ha^{-1}) over four N rates from previous rice crop on an Alfisol and a Vertisol over two seasons

N rates applied to rice (kg ha^{-1})	Alfisol			Vertisol		
	Grain yield	Straw yield	Straw N	Grain yield	Straw yield	Straw N
1994–1995						
0	1638 a	1668 b	13 b	1513 a	1470 a	12 a
40	1638 a	1925 ab	15 ab	1575 a	1643 a	13 a
80	1680 a	2025 ab	15 ab	1583 a	1540 a	12 a
120	1690 a	2265 a	19 a	1683 a	1533 a	13 a
Mean	1639	1970	15	1588	1546	12
1995–1996						
0	1310 a	1318 a	10 a	913 a	853 ab	7 a
40	1185 ab	1305 a	10 a	863 a	865 ab	6 a
80	1195 ab	1295 a	10 a	870 a	798 b	7 a
120	1128 b	1295 a	10 a	928 a	1010 a	8 a
Mean	1204	1303	10	893	881	7

In a column, under each layer, means followed by a common letter are not significantly different at 5% level by DMRT.

pea on the Alfisol could be attributed to its soil physical attributes: higher amount of extractable water (110 mm versus 86 mm from a 70 cm deep profile), few soil cracks of less than 10 cm deep, and lower bulk density at −10 kPa moisture content (Table 1). The bulk density of the Vertisol tended to increase on soil cracking and shrinking. On the contrary, the effect of previous rice cropping – higher yield, uptake, and transpiration – did not result in poor performance of chickpea on the Alfisol. The better performance and longer duration of chickpea during 1994–1995 could be attributed to higher rainfall – 92 mm versus only 39 mm in the 1995–1996 dry season (Fig. 1). During the 1994–1995 season 67 mm of rainfall occurred during the critical, pod-filling to maturity phase.

In contrast to rice, chickpea produced lower dry matter and yield and accumulated less N (Figs. 3 and 5 and Table 5). The PNUE for chickpea ranged from 25 to 27 kg grain yield per kg N absorbed, whereas rice had 33 to 57 kg grain yield per kg N absorbed. Grain legumes generally have lower apparent N utilization efficiency than cereals due to high amounts of energy spent on N fixation (Sinclair and de Wit, 1975). PNUE of both rice and chickpea was lower due to drought.

3.5. *Cropping systems effect*

Based on the performance of the rice during the 1995 wet season, the effect of previous nonrice crop – chickpea or fallow, was nonsignificant on any growth, yield, and nitrogen uptake parameter. The lack of differences may be attributed to the low amount of straw and root biomass residue generated from chickpea and N losses during composting. The maximum N contribution by chickpea residue to the rice crop was 19 to 26 kg N ha^{-1} on the Alfisol and 17 to 19 kg ha^{-1} on the Vertisol (Table 6). Due to the very dry conditions (Fig. 1), N transformation and accumulations of soil mineral N were negligible during the fallow period preceding the wet-season rice (Fig. 7). The experimental site was characterized by a marked dry season. Under such conditions a build-up of mineral N is highly unlikely. Large accumulations of nitrate-N have been reported during fallow period in environment with adequate soil moisture and/or rainfall (Buresh et al., 1989; George et al., 1993). The accumulation of nitrate-N during the fallow period and its subsequent loss with flooded rice culture, thus, are highly variable, depending on rainfall distribution and amount, and may not be as critical in regions with very dry conditions.

Table 6
N balance over two seasons and on two soils in rice–chickpea and rice–fallow systems for 0–70 cm layer (all values are expressed in kg N ha^{-1})

	Fertilizer applied[a]	Average soil N ($NH_4 + NO_3$) before rice	N addition from residue to crop				N removed by the crop				N left in residues after N-rice	Soil available N left after the 2nd nonrice crop	Apparent N balance[b]	Mineralization plus BNF[c]	Mineralization[d]	N Balance[e]	Recovery efficiency (%)[f]
	(A)	(B)	(C)				(D)				(E)	(F)	(G)	(H)	(I)	(J)	(K)
			Rice	N-Rice	Rice	N-Rice	Rice	N-Rice	Rice	N-Rice							
Alfisol																	
Rice–chickpea	40	155	5	8	19	7	52	51	40	40	15	147	110	110	–	0	100
Rice–fallow	0	155	5	8	0	7	52	0	42	0	0	148	66	–	66	0	100
Rice–chickpea	280	155	5	16	26	14	85	54	78	36	15	149	−81	110	–	−191	68
Rice–fallow	240	155	5	16	0	13	85	0	72	0	0	146	−127	–	66	−193	56
Vertisol																	
Rice–chickpea	40	148	5	5	17	6	31	47	37	28	10	139	70	70	–	0	100
Rice–fallow	0	148	5	5	0	6	31	0	34	0	0	142	41	–	41	0	100
Rice–chickpea	280	148	5	10	19	12	56	52	64	27	12	140	−124	70	–	−194	64
Rice–fallow	240	148	5	10	0	13	56	0	61	0	0	142	−157	–	41	−198	53

[a] Sum of two rice and two chickpea crops.

[b] Apparent N balance = (D + E + F) − (A + B + C).

[c] Net mineralization + net BNF = Apparent N balance assuming there is no gain or loss in the rice–chickpea system at low N rate.

[d] Net mineralization = Apparent N balance assuming there is no gain or loss in the rice–fallow system at 0N.

[e] N balance = (D + E + F) − (A + B + C + H + I).

[f] Recovery efficiency (%) = (A + B + C + H + I)/(D + E + F) × 100.

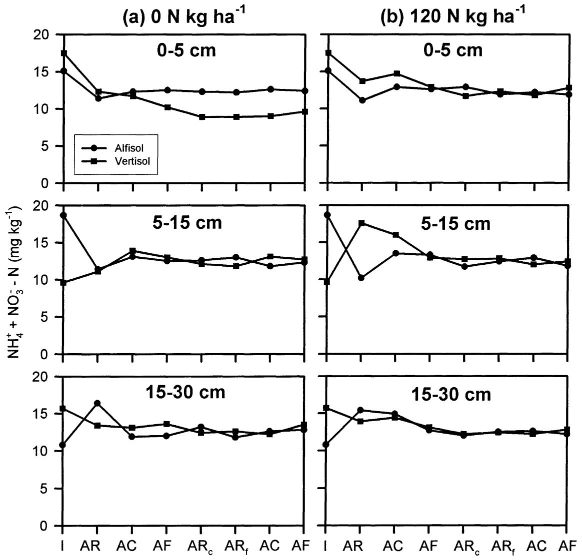

Fig. 7. Changes in soil mineral N during the cropping period 1994–1996 for (a) 0 and (b) 120 kg N ha^{-1} plots. Each data point is mean of four replications. Soil samplings at initial (I), after rice (AR), chickpea (AC), and fallow (AF) stages, and after rice harvest in plots previously under chickpea (AR$_c$) and fallow (AR$_f$).

3.6. Nitrogen balance

The N balance before the start of the 1994 wet-season experiment and at the end of the 1995–1996 chickpea/fallow was computed from the top 70 cm soil layer. The apparent N balance on the Alfisol – without accounting for the N contribution from mineralization and biological nitrogen fixation (BNF) – showed gains of 66 kg N ha^{-1} in rice–fallow N$_0$ plots and 110 kg N ha^{-1} in rice–chickpea low N (N$_0$ for rice +40 kg N ha^{-1} for two chickpea crops) plots (Table 6, column G). On the Vertisol the gains were 41 and 70 kg N ha^{-1} for the rice–fallow and rice–chickpea systems, respectively. At the highest N rate, both systems showed apparent losses of 81 and 127 kg N ha^{-1} on the Alfisol and 124 and 157 kg N ha^{-1} on the Vertisol. These apparent losses are within the range reported for the intensive irrigated rice-based cropping systems in the Philippines (Tripathi et al., 1997).

Based on the assumption that N loss was negligible in the rice–fallow system without N fertilizer application and the gain in the apparent N balance (Table 6, column G) was due to mineralization, net N contribution from mineralization (total mineralization – N losses from organic matter) was estimated (Table 6, column I). Similarly, the gains in the apparent N balance (Table 6, column G) in the rice–chickpea system were credited to the net contribution from mineralization plus BNF (Table 6, column H). The N balance thus computed was very similar in the rice–chickpea and rice–fallow system (Table 6, column J). This may also explain the insignificant difference in performance of rice in rice–fallow and rice–chickpea system. The recovery efficiency at the highest N rate for the rice–fallow system was 53–56% compared with 64–68% for the rice–chickpea system. Similar recovery efficiencies have been reported in rice and nonrice cropping systems (Tripathi et al., 1997; Stanford, 1973). The calculated recovery efficiency of the rice–fallow system may be higher than the actual efficiency due to the assumption that there were no N losses during the mineralization of organic matter and in the rice–chickpea system also due to the assumption that there were no losses of biologically fixed N and the fertilizer N applied to the chickpea crop.

4. Conclusion

Rainfed lowland rice (Var. IR36) performance depended on N rates, soils (Alfisol versus Vertisol), and the extent and distribution of rainfall during the wet season. For instance, the low N response on the Alfisol during the 1995 wet season was indicative of the post-anthesis stage drought effect. Likewise, faster receding of the water table, shallow rooting depth, and the shrinking and cracking of the Vertisol forced more severe drought stress and consequently lower grain yield than the Alfisol in both the years. At high N rates, the late-season drought stress influenced the N accumulation pattern, whereby the maximum N accumulation occurred at the heading stage rather than at maturity. Incongruence between the maximum N accumulation and the total N uptake at maturity implies (i) cautious use of PNUE and AR and (ii) indicates some degree of late-season stress (water, temperature, nutrient, pests). The recovery of fertilizer N, both by N difference and ^{15}N was poor in rainfed rice, however, ^{15}N unaccounted for was similar to the values reported for dry season irrigated rice.

Chickpea performance for the most part was not affected by the residual effect of N applied to the preceding rice crop. Contrary to the results obtained with favorable (moisture-regime) dry season environments where large amounts of nitrate-N accumulated during the fallow period, our results showed no difference in soil mineral N content in fallow and chickpea plots.

The year-to-year variations in a rainfed lowland rice-based cropping system and its effect on crop performance and nutrient dynamics require experimentation for more than 2 years and at different sites. The field work on both the soils has been continued for two additional years. Also, the field research has been complemented by simulation modeling to provide crucial means for extrapolating to other rainfed lowland sites.

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