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Prior crop and residue incorporation time affect the response of paddy rice to fertiliser nitrogen

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Abstract. Crop residues are an important source of nitrogen (N) for rice (*Oryza sativa* L.). The objective of this research was to determine how the supply of mineral N from different prior crops or fallow might affect the growth and yield of rice. The study also tested whether N use by rice might be improved by timing the application of inorganic fertiliser N to supplement the N mineralised after prior crops. Experiments consisted of fallow, or cereal or legume crops in the dry-season followed by wet-season rice; and fallow, or cereal or legume crops in the wet-season followed by dry-season rice. Urea at one-third of the rate required for optimum rice yield was applied at 3 times during the rice crop: sowing, permanent flood, and/or panicle initiation. The prior fallow and crop treatments significantly influenced the growth and yield of rice crops. After a fallow, the pattern of soil N mineralisation promoted vegetative growth but was limiting during grain-filling. In contrast, after a cereal crop, rice vegetative growth was limited but grain-filling was promoted. Legume prior crops promoted both vegetative and grain growth. The benefits derived from growing the cereal or legume crops before rice, in terms of replacing fertiliser N, were dependent on the time at which fertiliser N was applied to the rice crop. In particular, legume crops frequently nullified the rice growth responses to fertiliser N. The results demonstrated that fallow and prior crops can alter the amount and timing of mineral N supply to a rice crop. Farmers should consider including a legume crop in rotation with rice because legumes supply N, which increases rice yield and reduces the requirement for fertiliser N. Cereal crops also contribute N, although farmers who use a cereal rotation should monitor the soil and crop N status during early rice growth, and supply extra fertiliser N to alleviate N deficiency.

Additional keywords: cropping system, fallow, *Oryza sativa*.

Introduction

Rice can be grown year-round in the Burdekin River Irrigation Area (BRIA) in northern Australia. Weed and insect problems preclude double cropping rice, so it is common for farmers to grow either a wet-season (December–April) or dry-season (July–December) crop in rotation with a fallow. To increase the productivity of the rice cropping system, it is reasonable to grow a cereal or grain legume crop instead of the fallow. Such a strategy may have other impacts since the N in both legume green manure and the residues of grain legume crops has been found to increase the yield of the rice crops (Morris *et al.* 1986; John *et al.* 1989*a,* 1989*b*). In contrast to legume residues, cereal residues have been found to reduce the yield of rice crops (Takahashi and Sasprapa 1986; Mahapatra *et al.* 1991) because soil N is immobilised in the cereal residues during its decomposition, reducing the amount of N available to the rice crop. Both legume and cereal residues improved the long-term fertility of soils in temperate (Ladd *et al.* 1983) and tropical (Azam *et al.* 1986) environments.

The studies by John *et al.* (1989*a*) and Mahapatra *et al.* (1991) suggest that the use of fertiliser N by a rice crop might be more efficient if legume residues are incorporated into the soil. Wilson *et al.* (1989) found that the rate of fertiliser N uptake reflected the demand of the rice crop. In fertilised rice, Bufogle *et al*. (1997) showed that the N needed for maturing grain was provided from native soil N and the remobilisation of N from the rice straw. In temperate (Humphreys *et al.* 1987) and tropical (De Datta and Buresh 1989) environments the timing of fertiliser N applications was found to have a large effect on rice growth and yield.

In mixed cropping systems, where N is derived from the soil, crop residues, and fertiliser, it is, perhaps, an understanding of the timing of N availability from the various sources to the rice crop that is most crucial if N use is to be optimised. The objective of this study was to determine how

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Table 1. Mean daily maximum and minimum temperatures (°C), total rainfall (mm), and mean daily solar radiation (MJ/m^2) for each month during the three-year experimental period

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
						1988						
Max. temp.	33.9	33.4	30.0	29.5	28.1	25.8	25.5	26.9	30.4	34.5	33.7	31.9
Min. temp.	22.1	22.9	22.0	19.7	15.5	11.4	12.7	13.0	13.8	19.2	21.3	22.5
Rain	72	174	129	105	71	9	47	14	0	4	165	372
Radiation	23.9	18.0	19.1	16.3	16.3	18.2	17.6	21.4	26.5	25.7	24.0	23.2
						1989						
Max. temp.	32.8	32.3	31.5	29.0	27.3	23.7	23.2	25.2	30.0	32.7	31.3	32.9
Min. temp.	21.9	21.9	22.0	19.7	18.4	11.7	12.1	11.1	14.5	17.8	21.3	20.3
Rain	104	104	107	233	94	55	60	9	0	15	70	50
Radiation	24.4	21.6	17.4	15.3	13.7	16.4	11.2	22.7	26.1	27.7	22.7	25.8
						1990						
Max. temp.	35.9	36.2	32.3	29.2	26.3	24.1	24.9	26.3	28.3	31.6	33.8	34.5
Min. temp.	23.1	21.4	17.3	16.1	14.6	12.4	10.8	8.3	11.1	16.6	18.7	23.2
Rain	16	25.9	396	194	123	94.0	14	0	0	62	0	299
Radiation	26.8	26.8	16.9	15.8	25.3	18.0	21.3	30.2	31.4	29.0	33.2	24.7

the timing of N supply from prior fallow or crop treatments affects the growth and yield of a rice crop, and, as a consequence, to investigate strategies for when fertiliser N should be applied to the rice crop.

Materials and methods

Field experiments were conducted between 1988 and 1990 at Millaroo Research Station, Queensland Department of Primary Industries (20°03′S, 147°17′E), in northern Queensland, Australia. The soil was Barratta clay, a fine-textured (41% clay) cracking clay (Ug5.29; Northcote 1979) located on the Burdekin River flood plain. The surface soil was strongly and coarsely self-mulching with pH 6.9 (alkaline reaction to 0.9 m), a bulk density of 1.45 g/cm^3, 0.5 g total N/kg, and 9 g organic carbon/kg. Temperature and solar radiation were recorded at the Millaroo meteorological station (approximately 2 km east of the research site), and rainfall was measured at the site (Table 1).

Experimental design and treatments

The experiments investigated (*a*) the supply of N and (*b*) the growth and grain yield of wet- and dry-season rice (cv. Lemont) crops in response to fallow or prior crop (cereal, grain legume or legume green manure) treatments and the timing of fertiliser N application to rice (Table 2). Prilled urea (46% N) was banded (0.17 m apart at a soil depth of 0.12 m) at sowing, broadcast onto the dry soil surface immediately before permanent flood, or broadcast into the floodwater at panicle initiation. Expts 1 and 2 were designed so the effect of applying or not applying fertiliser N at each of 3 times during the rice crop combined with the effect of a prior fallow or crop treatments could be analysed. Fertiliser N was not applied in Expt 3 to show rice responses to prior fallow and crop treatments without the confounding effects caused by fertiliser N.

Expt 1 was a randomised complete block with 3 replications. The treatments were arranged as a 4 × 2 × 2 × 2 complete factorial and consisted of 4 dry-season treatments: fallow, maize (*Zea mays* L. cv. Pioneer 6875), chickpea ‘early’ (*Cicer arietinum* L. cv. Tyson) with residue incorporated immediately after harvest, and chickpea ‘late’ with residue incorporated immediately before rice sowing; 2 levels of fertiliser N applied at sowing to the wet-season rice crop; 2 levels of fertiliser N applied at permanent flood; and 2 levels of fertiliser N applied at panicle initiation. The levels of fertiliser N were 0 and 25 kg/ha (2.5 g/m^2), the latter rate being one-third of the fertiliser N needed for optimal yield of wet-season rice crops in the BRIA (A. K. Borrell, pers. comm.). Thus fertiliser N was applied in 8 factorial combinations, and a range from nil to the optimum rate was achieved.

Expt 2 was a randomised complete block with 3 replications. The treatments were arranged as a 3 × 2 × 2 × 2 complete factorial and consisted of 3 wet-season treatments: fallow, maize (cv. Pioneer 6875), and soybean (*Glycine max* L. cv. Cannapolis); 2 levels of fertiliser N applied at sowing to the dry-season rice crop; 2 levels of fertiliser N applied at permanent flood; and 2 levels of fertiliser N applied at panicle initiation. The levels of fertiliser N were 0 and 60 kg/ha (6.0 g/m^2), the latter rate being one-third of the fertiliser N needed for optimal yield of dry-season rice crops in the BRIA (A. K. Borrell, pers. comm.).

Expt 3 was a randomised complete block with 3 replications. There were 4 wet-season treatments: fallow, maize (cv. Pioneer 6875), soybean (cv. Cannapolis), and lablab (*Lablab purpurea* cv. Rongai) green manure. Fertiliser N was not applied to the dry-season rice.

Statistical methods

Treatment effects were tested by analysis of variance using Biometry Statistical Software (Anon. 1992). Pairwise testing of means for main-effects and interactions was done using the protected least significant difference procedure (l.s.d.) at $P = 0.05$.

Cultural practice

Unimproved pasture had grown on the experimental site for several years. Six months before each experiment started, the soil was cultivated and forage sorghum (*Sorghum bicolor* (L.) Moench cv. Jumbo) was sown in an effort to simulate the removal of soil mineral N by a crop. Immediately before each experiment the sorghum was cut and baled.

Prior crop and fallow plots were 15 m long and 4.5 m wide, incorporating 6 ridges 0.75 m apart and 0.15 m high. In the fallow plots, weeds, when at the 2–3 leaf stage, were controlled by spraying with glyphosate (10 g/L). A basal fertiliser containing (kg/ha) 40 P, 30 K, 30 S, and 6 Zn was applied to the maize and legume plots. The maize plots were fertilised with prilled urea at 180 kg N/ha. Maize seed and legume seed inoculated with N-fixing *Rhizobia* sp. were sown into dry soil and furrow irrigated. Established plant populations were 60 000/ha for maize, 300 000/ha for chickpea, and 200 000/ha for soybean and lablab. The prior crops were furrow irrigated when required to avoid moisture

Table 2. Chronology of the cultural and phenological events in the prior crop treatments and rice crops for three experiments grown in the Burdekin River Irrigation Area, 1988–1990

RI, residue incorporation; F, permanent flood; I, panicle initiation

	Prior crop treatments			Rice crops				
	Sowing	Harvest	RI	Sowing	F	I	Anthesis	Maturity
				Expt 1 (1988–89)				
Maize	1.vi	14.xi	16.xi	9.xii	7.i	20.i	24.ii	12.iv
Chickpea 'early'	1.vi	28.x	31.x					
Chickpea 'late'	1.vi	28.x	6.xii					
				Expt 2 (1988–89)				
Maize	27.xii	26.vi	28.vi	20.viii	12.ix	18.x	15.xi	14.xii
Soybean	27.xii	26.vi	28.vi					
				Expt 3 (1990)				
Maize	13.i	3.vii	4.vii	3.viii	14.ix	—	—	18.xii
Soybean	13.i	25.v	4.vii					
Lablab	13.i	—	4.vii					

stress. On 4 April 1989, the crops in Expt 2 were damaged during the grain-filling stage by cyclone Aivu. On 26 March 1990, the crops in Expt 3 were inundated by water for a period of 24 h.

The grain of maize, chickpea, and soybean crops was mechanically harvested except in Expt 3 where, because of rain, soybean plants were harvested by hand and threshed off-site, and the residues returned to the soil. The lablab crop was cut during the grain-filling stage and left on the soil surface. After harvest or cutting, the residues of all crops were spread evenly over the soil surface. Residues were mechanically incorporated to a depth of 0.1 m (Table 2).

About 3 weeks before sowing the rice crop, a seed-bed was prepared by cultivation and the same basal fertiliser rates used for prior crops were applied again in bands 0.175 m apart and 0.02 m below the soil surface. Rice seed was sown at 125 kg/ha in 0.175-m drills at a depth of 0.01 m below the soil surface. Soil levees (0.20 m high) were then constructed to form rice paddies (12 by 4 m) that overlaid the prior season's treatment plots. Pipes were inserted through a paddy wall to enable irrigation and drainage. The rice paddies were repeatedly flooded and drained to facilitate germination and crop establishment. The paddies were then permanently flooded to a depth of 0.12–0.15 m from the 3-leaf stage until physiological maturity. Immediately before permanent flood, Propanil (360 g/L) was applied at 11.0 L/ha to all plots for the control of weeds, mostly barnyard grass (*Echinochloa colona*) and sedges (*Cyperus iria* and *C. difformis*).

Measurements

Prior crops

Maize, chickpea 'early', and soybean crops were sampled at physiological maturity, whereas the lablab crop was sampled during its grain-filling phase. The above-ground biomass in each plot was harvested from a randomly selected 0.75-m^2 quadrat and partitioned into grain and residue. A second sample of above-ground biomass and roots (to a soil depth of 0.15 m) was also harvested from each plot; in Expt 1 the area of the sample was 0.375 m^2, in Expt 2 it was 3 maize and 9 soybean plants, and in Expt 3 the area of the sample was 0.375 m^2. The roots were washed with deionised water. Plant samples were dried at 70°C until a constant weight, then ground to pass through a 1-mm sieve. The root dry weight of prior crops was estimated from the ratio of the root/above-ground dry weight in the second sample and the above-ground dry weight of the 0.75-m^2 quadrats. The N concentrations of the prior crops were determined by Kjeldahl digestion and colorimetric analysis (O'Neill and Webb 1970). The N contents of the grain and residues (including roots) were calculated as the products of dry weights and N concentrations.

Rice crops

The rice crops were sampled at permanent flood, panicle initiation, anthesis, and physiological maturity. The above-ground biomass was harvested from a randomly selected 0.9-m^2 quadrat in each plot and partitioned into vegetative and grain components. Samples were dried at 70°C until a constant weight. The harvest index of each crop was then calculated as the ratio of the grain dry weight to the dry weight of the above-ground biomass.

Soil

Soil cores were taken at sowing, permanent flood, panicle initiation, anthesis, and maturity of the rice crop. At each time, samples were taken from all prior fallow and crop treatments, but only a subset of the fertiliser N treatments. Samples were always taken from those treatments where fertiliser N had not been applied and where fertiliser N was applied at sowing, permanent flood, and panicle initiation in combination. As well, those treatments with fertiliser N applied only at sowing were sampled at permanent flood; those with fertiliser N only at permanent flood were sampled at panicle initiation; and those with fertiliser N only at panicle initiation were sampled at anthesis.

Three soil cores, each 0.05 m in diameter and to a depth of 0.15 m, were taken from equally spaced positions across the inter-row in each plot and combined. Two subsamples were then taken: one (30–40 g) was dried at 105°C to a constant weight to determine gravimetric soil moisture; the other (8–10 g) was combined with 50 mL 2 M KCl for N determinations. The soil extracts for N determination were shaken for 2 h and centrifuged. The concentration of ammonium-N in the supernatant was determined after Henzell *et al.* (1968) and the concentration of nitrate-N after Best (1976). The bulk density of cultivated and flooded soil was determined by sampling 6 replicate soil cores of known volume at 0.05-m depth increments. Soil cores were dried and the mean bulk density of the 0.0–0.15 m soil layer was calculated. The amount of ammonium-N and nitrate-N in dry soil was calculated as the product of the concentration of ammonium-N and nitrate-N in the supernatant and the dry weight of the soil sample adjusted for gravimetric soil water content and bulk density.

Table 3. Mean dry weight (g/m^2), N concentration (g/kg), and N content (g/m^2) of the residue of maize, chickpea, soybean, and lablab prior crops

The results are means of 24 samples with the standard deviation of means shown in parentheses

Prior crop	Plant component	Dry weight	N conc.	N content
		Expt 1 (Dry-season treatments)		
Maize	Above-ground	880 (111)	4.1 (0.8)	3.6
	Roots	63 (26)	4.6 (2.0)	0.3
Chickpea	Above-ground	273 (62)	14.1 (1.8)	3.9
	Roots	28 (12)	17.7 (3.3)	0.5
		Expt 2 (Wet-season treatments)		
Maize	Above-ground	706 (89)	6.4 (1.6)	4.7
	Roots	100 (18)	3.8 (0.9)	0.4
Soybean	Above-ground	279 (71)	26.2 (2.3)	7.2
	Roots	33 (5)	12.9 (2.6)	0.4
		Expt 3 (Wet-season treatments)		
Maize	Above-ground	886 (217)	7.2 (1.7)	6.4
	Roots	41 (10)	5.2 (1.0)	0.2
Soybean	Above-ground	253 (56)	15.2 (3.9)	3.8
	Roots	15 (3)	9.2 (2.1)	0.4
Lablab	Above-ground	611 (282)	14.5 (2.4)	8.9
	Roots	24 (4)	16.5 (2.3)	0.4

Table 4. Amounts (g/m^2) of nitrate-N and ammonium-N in the soil (0–0.15 m) at sowing and permanent flood of wet-season (Expt 1) and dry-season (Expts 2 and 3) rice crops with three replications

Fertiliser N was not applied to the rice crops. The treatments before rice were: maize, fallow, chickpea with 'early' residue incorporation (Table 2), chickpea with 'late' residue incorporation, soybean, or lablab. At permanent flood, samples were taken before water was applied

Prior fallow and crop treatment	Soil nitrate-N		Soil ammonium-N		
	Sowing	Perm. flood	Sowing	Perm. flood	Panicle initiation
		Expt 1 (Wet-season rice)			
Maize	0.35	0.13	0.32	0.18	0.22
Fallow	4.89	0.20	0.50	0.12	0.12
Chickpea 'early'	3.70	0.23	0.66	0.13	0.10
Chickpea 'late'	2.16	0.17	0.66	0.12	0.08
l.s.d. ($P = 0.05$)	0.97	n.s.	0.18	n.s.	0.09
		Expt 2 (Dry-season rice)			
Maize	0.12	0.35	0.47	0.30	0.36
Fallow	0.11	0.79	0.73	0.16	0.17
Soybean	1.70	2.54	0.86	0.17	0.25
l.s.d. ($P = 0.05$)	0.32	1.45	0.28	0.07	0.07
		Expt 3 (Dry-season rice)			
Maize	0.26	0.01	0.12	0.04	0.02
Fallow	0.66	0.01	0.08	0.04	0.03
Soybean	0.59	0.01	0.24	0.05	0.03
Lablab	0.84	0.01	0.32	0.06	0.03
l.s.d. ($P = 0.05$)	0.16	n.s.	0.07	n.s.	n.s.

n.s., not significant.

Results

Dry weight and N content of prior crop residues

The residues of all prior crops contained large amounts of N (3.9–9.3 g/m^2), although the concentration of N in the different crop residues varied (Table 3). The weight of maize or legume residues was similar in each experiment, although, as expected, maize always produced more residue than the legume crops. In Expt 3, the lablab grain was not harvested, so the lablab crop produced more residue and had a greater N content than soybean. The concentration of N in the residues varied between crops and years, although N was always less concentrated in the maize than legume residues.

Soil mineral nitrogen in rice without fertiliser N

Immediately before the wet-season rice crop (Expt 1) was sown, 4.89 g nitrate-N/m^2 had accumulated in the surface soil after the fallow treatment (Table 4). Growing chickpea before rice reduced the level of nitrate-N especially when the residues were incorporated 'late'. There was minimal soil nitrate-N after maize.

Minimal soil nitrate-N accumulated before the dry-season rice crops (Expts 2 and 3), although in Expt 2 a prior crop of soybean increased the soil nitrate-N. In Expt 3, there was less soil nitrate-N after maize and more after lablab compared with fallow or soybean.

Soil nitrate-N at permanent flood was minimal in Expts 1 and 3 (Table 4), whereas in Expt 2, soil nitrate-N increased between sowing and permanent flood especially after soybean and fallow. At panicle initiation, anthesis, and maturity, there was <0.08 g/m^2 soil nitrate-N in Expt 1, <0.12 g/m^2 in Expt 2, and it was undetectable in Expt 3 (data not presented).

Compared with fallow, a prior crop of maize reduced the amount of soil ammonium-N at sowing in Expt 1 (also a trend in Expt 2), whereas soybean and lablab increased soil ammonium-N in Expt 3 (Table 4). In Expt 3, the amount of ammonium-N after the fallow was much less then it was in Expts 1 and 2. Soil ammonium-N did not differ for prior crop treatments at permanent flood except in Expt 2 where ammonium-N was increased if maize residues had been incorporated (Table 4). In all other treatments and experiments, there was a large reduction in the amount of ammonium-N between sowing and permanent flood. At panicle initiation, maize also increased the amount of ammonium-N compared with fallow or chickpea in Expt 1, and fallow or soybean in Expt 2. At anthesis in Expt 2, the mean amount of ammonium-N was 0.42 g/m^2, otherwise the ammonium-N during later stages of rice growth in all experiments was <0.11 g/m^2 (data not presented).

Fertiliser N effects on soil mineral N

Fertiliser N applied at sowing, permanent flood, or panicle initiation did not affect the level of soil mineral N (nitrate-N

Table 5. Temporal responses of the vegetative and grain dry weights (g/m^2) of wet-season (Expt 1) and dry-season (Expts 2 and 3) rice crops to the main-effects of prior fallow and crop treatments with three replications

Crop treatments were maize, chickpea with 'early' residue incorporation (Table 2), chickpea with 'late' residue incorporation, soybean, or lablab. In Expts 1 and 2, data are the means of 8 fertiliser N treatments. Fertiliser N was not applied in Expt 3. F, permanent flood; I, panicle initiation

Prior fallow and crop treatments	Vegetative dry weight F	I	Anthesis	Maturity	Grain dry weight	Harvest index
			Expt 1 (Wet-season rice)			
Maize	22.7	79	518	533	376	0.411
Fallow	41.1	137	686	602	409	0.402
Chickpea 'early'	35.0	153	786	632	427	0.403
Chickpea 'late'	40.9	182	865	654	427	0.396
l.s.d. (P = 0.05)	7.7	30	105	53	35	n.s.
			Expt 2 (Dry-season rice)			
Maize	5.4	240	860	705	641	0.481
Fallow	7.0	281	925	747	606	0.443
Soybean	6.9	292	967	790	665	0.458
l.s.d. (P = 0.05)	1.1	22	64	39	38	0.011
			Expt 3 (Dry-season rice)			
Maize	5.6	117	552	399	382	0.487
Fallow	14.6	90	385	288	250	0.464
Soybean	20.3	155	574	385	336	0.463
Lablab	14.7	176	647	395	371	0.477
l.s.d. (P = 0.05)	6.1	38	109	67	65	n.s.

n.s., Not significant.

+ ammonium-N) at permanent flood, panicle initiation, or anthesis, respectively. The exception occurred in Expt 2 where fertiliser N applied at sowing increased the soil mineral N at permanent flood by 5.5 g/m^2 after fallow (about 90% of fertiliser N applied), but only 2.8 g/m^2 after the maize crop and 2.6 g/m^2 after the soybean crop (both <50% of fertiliser N applied) (l.s.d. at P = 0.05, 1.9 g/m^2).

Rice growth and yield: effects of prior crop

Prior fallow and crop treatments altered both the amount and timing of growth in the rice crops. In Expts 1 and 2, where fertiliser N treatments were applied to the rice crop, a prior maize crop reduced the vegetative dry weight of the rice crop compared with a fallow (Table 5). Incorporating maize residues did not affect the grain dry weight of rice in Expts 1 or 2; however, it increased the rice harvest index in Expt 2. In Expt 3, where fertiliser N was not applied to the rice crop, maize increased the vegetative growth of rice at anthesis and maturity, and increased both grain yield and harvest index.

Legume prior crops generally increased the growth and grain dry weight of rice compared with a fallow, although the change in growth occurred at different times in the rice crop in the different seasons and experiments. Compared with a fallow, chickpea gave faster wet-season rice growth between permanent flood and anthesis, whereas all legume crops gave faster dry-season rice growth between permanent flood and maturity. Incorporation of legume residues resulted in more grain in the dry-season rice crop, a consequence of both a heavier vegetative dry weight at maturity and an unchanged or larger harvest index than was obtained after the fallow treatments.

Rice growth and yield: effects of fertiliser N

Generally, the vegetative and grain dry weight of rice increased in response to fertiliser N applied at sowing, permanent flood, or panicle initiation (Table 6). The exception was in Expt 1 where fertiliser N applied at sowing had no effect on vegetative dry weight. Growth increased more in the dry-season rice crop (Expt 2) reflecting either the different growth environment or the larger amounts of fertiliser N applied. In both experiments, N applied at permanent flood increased the vegetative dry weight of the rice crop and, to a lesser extent, its grain dry weight; consequently, the harvest index was reduced. In contrast, fertiliser N applied at panicle initiation increased grain dry weight relatively more than vegetative dry weight and there was an increase in harvest index.

Rice growth and yield: interactions between prior crop and fertiliser N

Whereas prior crop treatments were applied before the rice crop, and had important main-effects during the whole rice crop, fertiliser N was applied or not applied as treatments at sowing, permanent flood, and/or panicle initiation, and

Table 6. Increase in the vegetative and grain dry weight (DW) (g/m^2) at maturity, and harvest index of wet-season (Expt 1) and dry-season (Expt 2) rice in response to fertiliser N applied at sowing, permanent flood, or panicle initiation

Fertiliser N at 2.5 g/m^2 was applied in Expt 1, and 6.0 g/m^2 in Expt 2. Data are main-effects that combine the effects of prior fallow and crop treatments, and the application of fertiliser N at other times

Fertiliser N application time	Increase in vegetative DW	Increase in grain DW	Increase in harvest index
	Expt 1 (Wet-season rice)		
Sowing	31	57	0.021
Permanent flood	138	68	–0.023
Panicle initiation	53	88	0.029
l.s.d. ($P = 0.05$)	37	25	0.016
	Expt 2 (Dry-season rice)		
Sowing	113	93	0.000
Permanent flood	403	285	–0.021
Panicle initiation	88	155	0.037
l.s.d. ($P = 0.05$)	32	31	0.009

had shorter-term effects on aspects of growth and yield. The interactions between prior fallow and crop, and fertiliser N treatments serve to identify the times when the growth and yield responses of rice to fertiliser N were otherwise achieved by prior fallow or crop treatments (without fertiliser N). Interactions were small, however, and occurred mostly in those treatments where ≤ 5 g N/m^2 (e.g. fertiliser N applied at sowing and permanent flood, or sowing only, or not at all) was applied to wet-season rice, or ≤ 6 g N/m^2 (e.g. fertiliser N applied at panicle initiation, or not at all) was applied to dry-season rice.

When fertiliser N was not applied at panicle initiation, the vegetative dry weight of wet-season rice at maturity was heaviest after prior crops of chickpea, and heavier after fallow than after maize (Fig. 1). Fertiliser N applied at panicle initiation increased the rice vegetative dry weight after maize and fallow, but not after chickpea.

The yield of wet-season rice also responded to the chickpea 'late' treatment when N was not applied at sowing or permanent flood (Fig. 2). When fertiliser N was applied at either sowing or permanent flood, yield increased in the maize, fallow, and chickpea 'early' treatments but not in the chickpea 'late' treatment.

Rice crops grown after fallow and without fertiliser N at sowing or permanent flood produced similar yields in the wet and dry seasons (Fig. 2); however, yield responses to either prior crop or fertiliser N were larger in the dry-season. The yield of dry season rice was heavier after maize and soybean than after fallow when fertiliser N was not applied at either sowing or permanent flood. Fertiliser N applied at sowing or permanent flood increased yield, but the application at permanent flood had a larger effect, and the responses were larger after fallow. Also, if fertiliser N was applied at permanent flood, there was no response to N applied at sowing.

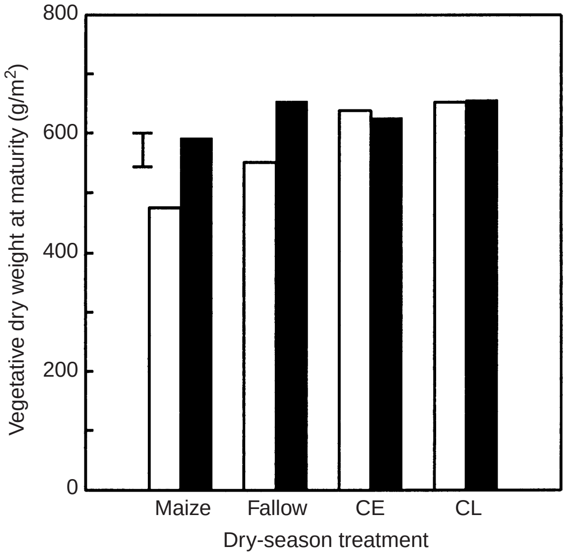

Fig. 1. Interaction between dry-season fallow and crop treatments, and fertiliser N applied at panicle initiation on the vegetative dry weight of wet-season rice at maturity. Dry-season treatments were: maize, fallow, chickpea with 'early' incorporation of residue (CE), and chickpea with 'late' incorporation of residue (CL). Amounts (g/m^2) of fertiliser N were □ 0 and ■ 2.5. Vertical bar indicates l.s.d. ($P = 0.05$) for the interaction.

Discussion

The results of the present study revealed that prior fallow or crop treatments influenced the pattern of N mineralisation both before and during the rice crop. Rapid N mineralisation after the legume crops had both positive and negative effects; early growth of the rice crop was certainly enhanced but excess soil nitrate-N was lost, probably due to denitrification (Zia and Waring 1987) when the crop was repeatedly flooded during rice crop establishment. Since nitrate-N did not accumulate at 0.15–0.30 in the soil profile (data not presented), N loss through leaching was considered unlikely. Nitrate-N that accumulated after the fallow probably experienced the same fate. In contrast, slower N mineralisation after maize possibly protected the N in the maize residues from loss, but also reduced the early growth of the rice crop. Even when 25 kg/ha fertiliser N was applied at sowing in Expt 1, maize reduced the vegetative growth of the rice crop at maturity (Fig. 1). Maize and soybean crops may have immobilised some fertiliser N applied at sowing. These findings are supported by Toor and Beri (1991) who found that rice straw initially immobilised soil and fertiliser N, and Norman *et al.* (1990) who showed that only a small amount of N was mineralised from rice residue that had an N concentration of 8 g/kg. Delaying the incorporation of the chickpea residue in Expt 1 delayed the buildup of soil mineral N and promoted later growth of the rice crop. Ghai *et al.* (1988) found that the benefit of *Sesbania* as a green manure was reduced if the period of its decomposition prior to a rice crop was lengthened.

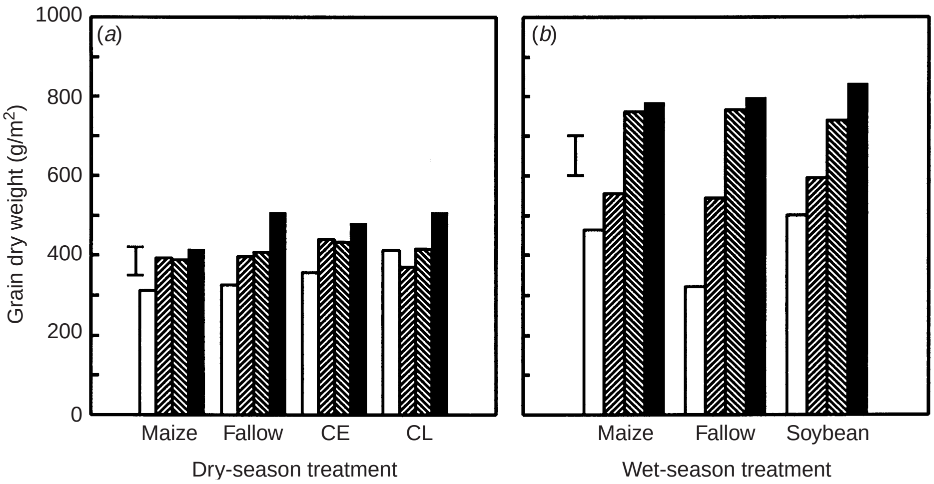

Fig. 2. Interactions between prior fallow and crop treatments, and fertiliser N applied at sowing and/or permanent flood on the grain dry weight of *(a)* wet-season and *(b)* dry-season rice at maturity. Dry-season treatments were: maize, fallow, chickpea with 'early' incorporation of residue (CE), and chickpea with 'late' incorporation of residue (CL). Wet-season treatments were: maize, fallow, and soybean. Fertiliser N treatments were: □ nil N at sowing or permanent flood, ▨ N at sowing, ▧ N at permanent flood, or ■ N at sowing and permanent flood. Amounts of N applied at each application time were 2.5 g/m^2 to wet-season rice and 6.0 g/m^2 to dry-season rice. Vertical bars indicate l.s.d. ($P = 0.05$) for the interactions.

In Expt 3, N mineralisation from crop residues during the later growth of the rice crop may be inferred from the growth of the rice crop (Table 5) since the effects of prior crop were not confounded by fertiliser N. Maize, soybean, and lablab all produced increased vegetative growth compared with the fallow. When fertiliser N was applied, vegetative rice growth was similarly increased by chickpea 'late' in Expt 1, and soybean in Expt 2; however, maize reduced rice vegetative growth in both Expts 1 and 2. It seems reasonable to conclude that maize reduced the rice response to fertiliser N. When compared with fallow, both the lack of a yield decline in rice following incorporation of maize in Expt 1 and the larger harvest index in Expt 2 suggest that incorporation of maize reduced the vegetative response of rice more than its yield response.

Previous reports have found that cereal residues depress (Mahapatra *et al.* 1991) or do not affect (Antil *et al.* 1988) the yields of unfertilised rice crops. The current experiments showed the opposite effect. The increased yield of unfertilised rice with the incorporation of maize residues in Expt 3 is likely to be a response to the 6.4 g N/m^2 in maize residues, which appears to have been available to the rice crop after panicle initiation.

The rice yield responses to legume prior crops were positive (although not always statistically) even when fertiliser N was applied. Yield increases of up to 2.5 t/ha in unfertilised rice crops in response to legume green manures were measured by Morris *et al.* (1986), Buresh and De Datta (1991), and Panda *et al.* (1995). John *et al.* (1989*a*) found benefits from cowpea residues and cowpea grown as a green manure crop. In Expt 2, the vegetative and yield response to soybean (compared with fallow) occurred after anthesis (Table 5), and there were no interactions between soybean and fertiliser N applied at any time of crop growth (data not presented). Therefore, the yield response probably reflects an additional effect of incorporating soybean, in supplying extra N to the rice crop, particularly during the later stages of rice growth. If this was the case then the rice grown after the fallow was probably N deficient during grain-filling.

Utilising prior crops to reduce the amount of fertiliser N applied to rice was the practical goal of this study. Incorporating prior chickpea crops produced wet-season rice growth equal to that obtained by applying fertiliser N at panicle initiation and yield equal to that from fertiliser N applied at sowing or permanent flood. In dry-season rice, fallow gave the smallest yield when fertiliser N was not applied at sowing or permanent flood, although the yield responses to fertiliser N applied at sowing and/or permanent flood were largest after fallow. These data indicate that prior cereal and legume crops replaced, at least in part, the fertiliser N applied at specific times to the rice crop. It follows that less fertiliser N could have been applied at these times without affecting yield. When the maize crop was incorporated, however, the supply of N during the establishment of wet-season rice was reduced and more fertiliser N or a different fertiliser application strategy may have been required. John *et al.* (1989*a*) suggested that the efficiency of urea integrated with green manure or legume residues was strongly influenced by the time and placement of fertiliser application. Similarly, Buresh *et al.* (1993) suggested that the optimal distribution of urea among application timings might depend on whether plant residues were incorporated. These papers and the current study highlight the importance of timing fertiliser N to supplement soil and residue N as an issue requiring further study.

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