RESULTS

1 Rice Yield and Nitrogen Removed

The application of nitrogen fertilizer, up to 300 kg N/ha, increased nitrogen concentration in the rice plant (Table 1). Grain yield, plant dry matter and total nitrogen uptake, however, responded positively to increase nitrogen fertilizer only to 100 kg N/ha. Without fertilizer nitrogen the grain yield was 2.89 t/ha with a total crop dry matter yield and nitrogen uptake of 5.52 t/ha and 45 kg N/ha, respectively. With 100 kg N/ha, the grain yield increased to 5.04 t/ha, crop dry matter yield to 9.61 t/ha and total nitrogen uptake of 90 kg N/ha. A further increase in the rate of nitrogen fertilizer to 300 kg N/ha decreased both grain and dry matter yields, with no further effect on total nitrogen uptake.

Crop recovery was 45% when 100 kg N/ha was applied, however, it decreased to 14% when 300 kg N/ha was applied. After harvesting rice crop, 22 kg /ha and 159 kg /ha fertilizer nitrogen were left in soil when with the 100 kg N/ha and 300 kg N/ha application rates.

Table 1 Effects of N fertilization on nitrogen concentraion in rice plant, yield, total dry matter and nitrogen removal

N rates (kg/ha)	Plant N %	Yield (t/ha)	Total crop Dry matter (t/ha)	Total crop N (kg/ha)	from Soil	from Fert.	Crop recovery %	Residual* N (kg/ha)
0	0.82	2.89	5.52	45	45	0	-	-
100	0.94	5.04	9.61	90	45	45	45	22
300	1.28	3.35	6.73	86	45	41	14	159
LSD(P<0.05)	0.15	0.29	0.57	9				

* Assumed that one third of applied nitrogen lost from field system (De Datta, 1988)

2 Available Soil Nitrogen

Available soil nitrogen contents increased significantly with the nitrogen fertilization (Fig. 2). The effects also differed between the first sampling at soybean sowing and the second sampling at early seed development. At soybean sowing, effects of soybean starter nitrogen were greater than those of nitrogen applied to the rice.

The residual nitrogen from rice had no significant effect on available soil nitrogen. Without soybean starter nitrogen, available nitrogen in the soil at soybean sowing was 2-4 µg/g. Applying 25 kg N/ha to soybean increased the level of available soil nitrogen to 7-8 µg/g. A further increase in the rate of starter nitrogen to 50 kg N/ha increased available soil nitrogen to 9-10 µg/g following 0 or the 100 kg N/ha applied to the rice crop and 13-14 µg/g after 300 kg N/ha.

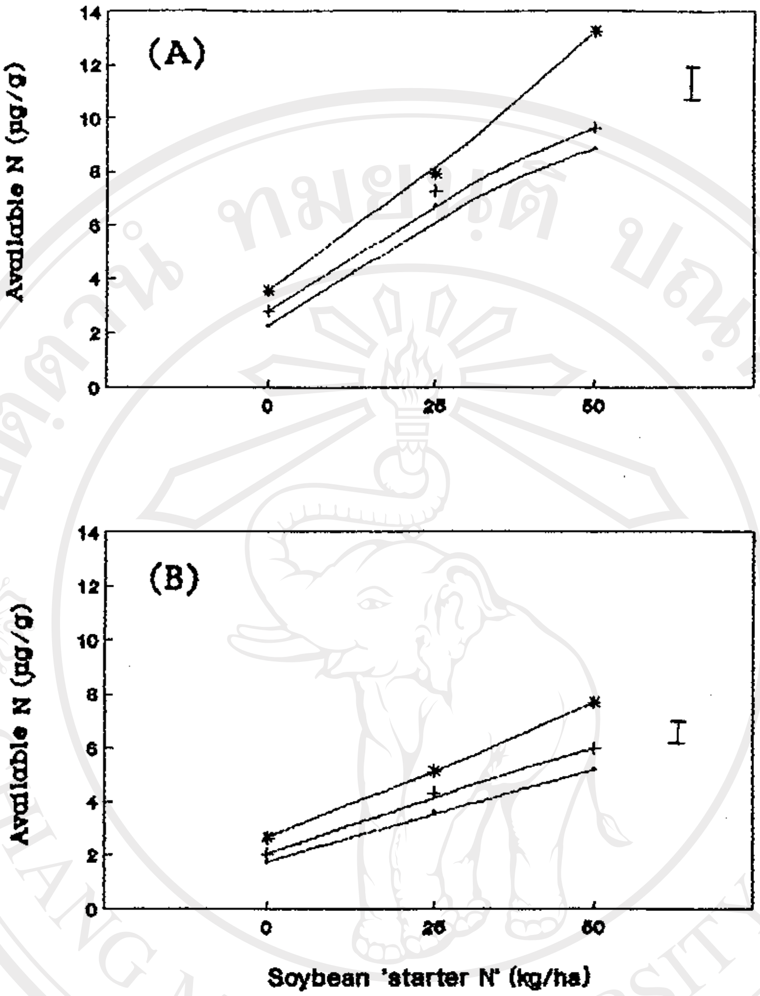

Figure 2 Effects of nitrogen application rates on available soil nitrogen contents at (A) sowing time and (B) seed development stage (R5). Rice was supplied with 0 (·), 100 (+) and 300 kg (*) N/ha. Vertical lines denote LSD's (P<0.05).

3 Soybean dry matter yield and total nitrogen

Soybean dry matter increased with combined nitrogen, either as starter nitrogen to soybean or residual nitrogen from rice (Table 2). At growth stage R1, shoot dry matter significantly increased form the lowest, 1028 kg/ha, in treatment without nitrogen to both rice and soybean, to highest, 1417 kg/ha, in treatment with 300 kg N/ha applied to rice plus 50 kg N/ha to soybean. At growth stage R7, without nitrogen applied to rice, shoot dry matter was 4327 kg/ha with no starter nitrogen, 4822 kg/ha with 25 kg N/ha starter nitrogen, and 5005 kg/ha when 50 kg N/ha starter nitrogen was applied. There were no obvious effects of three levels of starter nitrogen on soybean dry matter following 100 kg N/ha to rice and slight increase with starter nitrogen after 300 kg N/ha was applied.

When rice was not fertilized, starter nitrogen significantly increased nitrogen uptake in soybean. Total crop nitrogen increase from 138 kg/ha to between 155 and 158 kg N /ha when 25 kg N/ha and 50 kg/ha was applied to soybean. There were no effects of starter nitrogen on total soybean nitrogen uptake following supply of 100 or 300 kg N/ha to rice.

Table 2 Effects of nitrogen fertilization on soybean shoot dry matter at R1, R7 and total nitrogen uptake at R7

Treatment		Shoot Dry Matter R1	Shoot Dry Matter R7	Total N[a] R7
		(kg/ha	)	(kg/ha)
R0	S0	1028	4327	138
	S25	1170	4822	155
	S50	1302	5005	158
R100	S0	1175	4748	156
	S25	1218	4958	156
	S50	1330	4848	153
R300	S0	1288	5078	157
	S25	1343	5150	158
	S50	1417	5207	162
LSD(P<0.05)		82	204	11
RN x SYN		**	**	**

a. Did not include fallen leaves nitrogen
** Significance at 1% level
RN N applied to rice
SYN N applied to soybean

4 Nodulation

Nodulation declined with additions of fertilizer either as starter nitrogen to soybean or as a residual from rice (Fig. 3). At 42 days after sowing (V6), the nodule dry weight was closely but negatively related to levels of soil combined nitrogen. Nodulation formation was most abundant in the soil with lowest levels of combined nitrogen treatment, without nitrogen to either rice or soybean, with 83 mg/plant, but was poorest in the soil with highest combined nitrogen treatment, 300 kg N/ha to rice followed 50 kg N/ha to soybean, at 53 mg/plant. Nodule weights were intermediate between these two extremes.

Difference in nodule dry matter among treatments was less pronounced 77 days after sowing (R5). Application of 300 kg N/ha to rice followed by 50 kg N/ha to soybean resulted in a nodule dry weight of 274 mg/plant. Nodule dry weights for the other treatments ranged from 313 to 352 mg/plant.

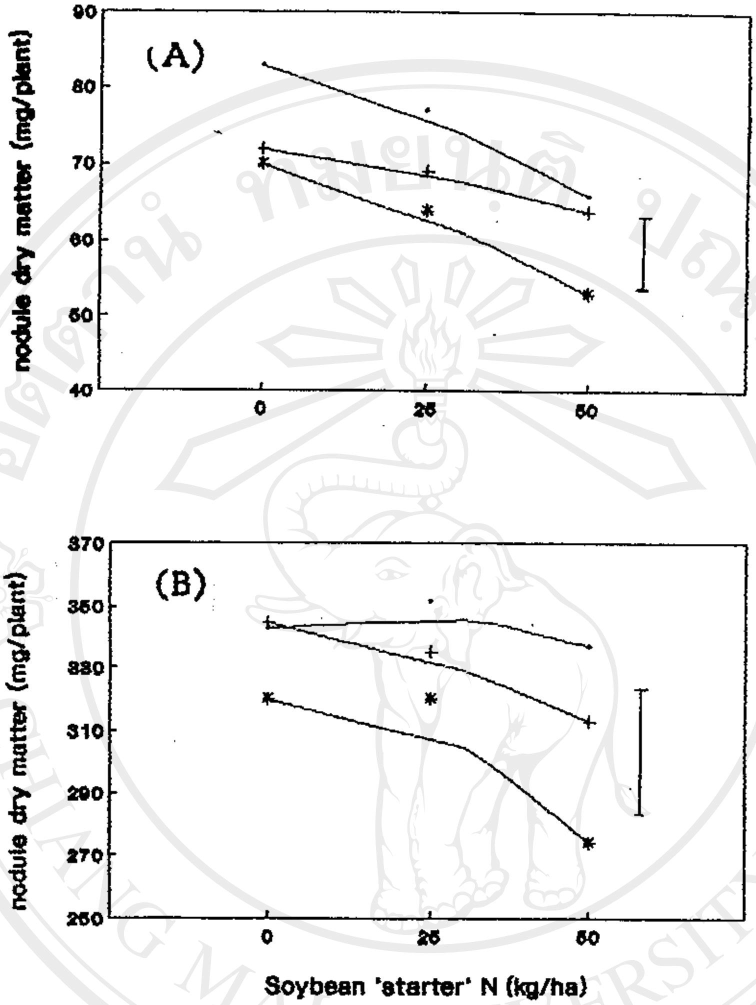

Figure 3 Effects of nitrogen application rates on soybean nodule dry weight at (A) 42 days after sowing (V6) and (B) 77 days after sowing (R5). Rice was supplied with 0 (•), 100 (+) and 300 (*) kg N/ha. Vertical lines denote LSD's (P<0.05).

5 Nitrogen Fixation

5.1 The relative abundance of ureide in xylem sap

The relative abundance of ureide in xylem sap was influenced by the soil mineral nitrogen levels. The effects were more obvious in early growth (Fig. 4). At 42 days after sowing, the relative abundance of ureide declined progressively with increasing levels of starter nitrogen, The treatment of 300 kg N/ha followed by no nitrogen to soybean had the highest value of 67 %, while the treatment of 300 kg N/ha to rice followed with 50 kg N/ha to soybean had the lowest value of 41 %. Similarly trends were observed at 47 days after sowing.

The effects became less obvious after 64 days from sowing and throughout the later stages of reproductive development.

The time taken to reach maximum relative ureide abundance of in xylem sap was also affected by the soil combined nitrogen levels. The two low nitrogen treatments, without nitrogen to either rice or soybean and 100 kg N/ha applied to rice followed by no nitrogen to soybean, reached their highest ureide values 64 days after sowing, while in the other treatments maximum relative ueides occurred after 77 days.

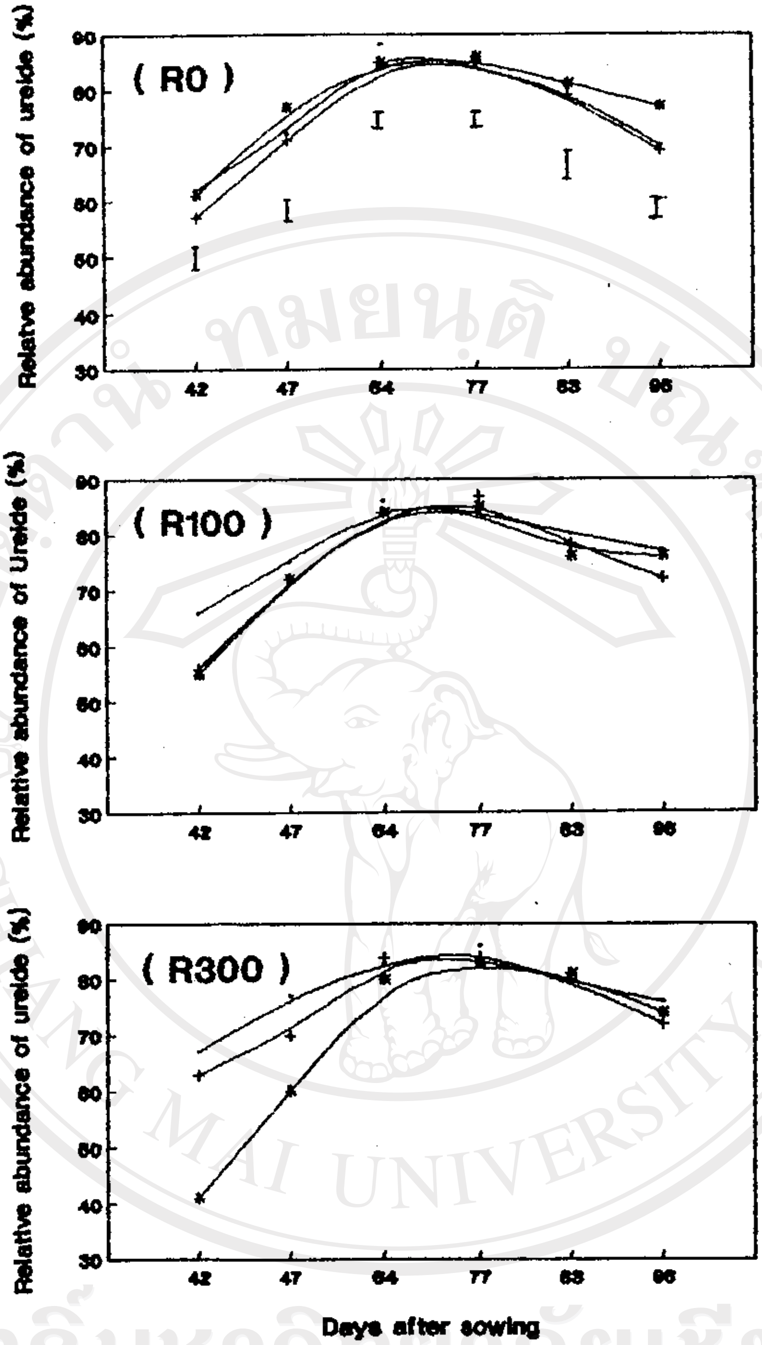

Figure 4 Effects of nitrogen applied to soybean at 0 (•), 25 (+), 50 (*) kg N/ha and rice at 0 (R0), 100 (R100) and 300 (R300) kg N/ha on the changes of the relative abundance of ureide with time. Vertical lines denote LSD's (P<0.05) for each time of sampling.

5.2 The proportion of plant nitrogen derived from nitrogen

There was consistent trend of decreased proportion of plant nitrogen derived from nitrogen fixation with increasing levels of the soil combined nitrogen and (Table 3). This relationship was most pronounced during early growth. At V6, the highest combined nitrogen treatment, 300 kg N/ha applied to rice followed by 50 kg N/ha to soybean, was estimated to have derived only 17% of its nitrogen requirements from nitrogen fixation compared to 27-36% in other treatments.

The difference disappeared between R3-R5, soybean in each treatment derived up to 91% to 97% of their nitrogen from symbiotic nitrogen fixation. The reliance on fixation gradually declined in later growth stages.

On average, over 96 days of growth, soybean derived 81 % of its nitrogen from nitrogen fixation if no fertilizer was applied to either rice or soybean. This average level of fixation did not appear to be affected by starter nitrogen or fertilizer applied to rice until a rate of 300 kg N/ha was used and 25 kg N/ha or 50 kg N/ha starter nitrogen was supplied to soybean.

Table 3 Estimations of the pencertage of plant nitrogen derived from nitrogen fixation, using ureide method, average between two sampling.

Treatment		Sow-V6	V6-R1	R1-R3	R3-R5	R5-R6	R6-R7	Total (%) [c]	DMRT [d]
	[a] Physiological stage	Sow-V6	V6-R1	R1-R3	R3-R5	R5-R6	R6-R7		
	[b] Days after sowing	0-42	42-47	47-64	64-77	77-83	83-96		
R0	S0	32	71	88	97	93	82	81.3	ab
	S25	29	67	86	95	91	81	79.1	ab
	S50	30	73	90	97	95	88	80.1	ab
R100	S0	34	75	89	95	92	87	81.5	a
	S25	27	65	84	96	92	81	79.6	ab
	S50	27	65	86	96	90	83	78.4	ab
R300	S0	36	78	89	95	92	86	81.5	a
	S25	32	69	84	94	92	83	77.8	b
	S50	17	47	75	91	91	85	71.8	c

a Physiological stage
b Days after sowing
c (Sum of fixed N increment)/(Sum of crop N increment)
d Any two means having a common letter are not significantly different at the 5% level of significance

5.3 Total nitrogen increment

Incremental increases in soybean crop nitrogen showed comparatively uniform trends throughout growth for each treatment (Fig. 5). Total nitrogen increments were small before R3, but increased rapidly during the period of R3-R5.

Except for the lowest combined nitrogen treatment, which showed the consistent trend of low nitrogen uptake throughout growth, with a total nitrogen uptake at 145 kg N/ha, all the other treatments had accumulated similar amounts of nitrogen (163 kg to 179 kg N/ha) by R7 (Fig. 5).

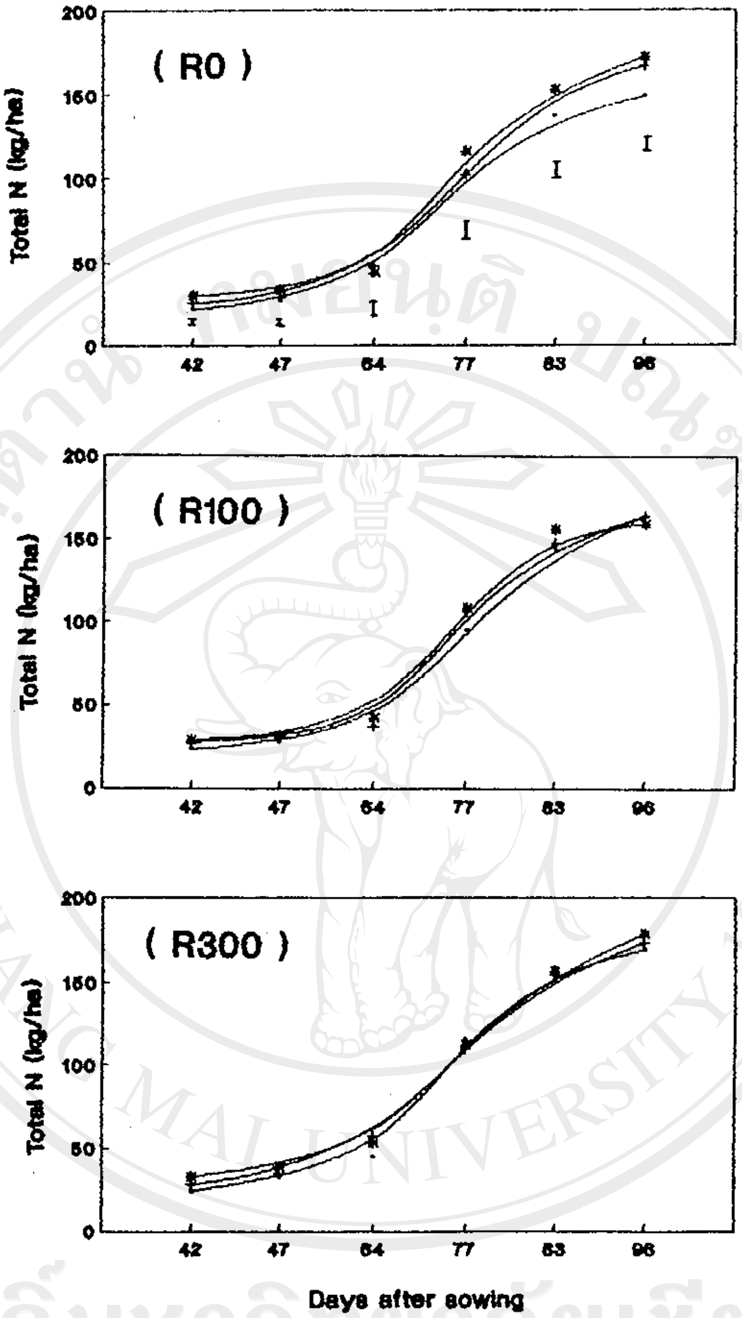

Figure 5 Effects of nitrogen applied to soybean at 0 (·), 25 (+), 50 (*) kg N/ha and rice at 0 (R0), 100 (R100) and 300 (R300) kg N/ha on total nitrogen increment with time. Vertical lines denote LSD's ($P<0.05$) for each time of sampling.

5.4 The amount of nitrogen fixed

The seasonal patterns of nitrogen fixation were similar in all treatments (Fig. 6). Nitrogen fixation was small before R1, increased slightly until R3 and was highest between R5-R6. The amounts of nitrogen fixed declined after R6.

By physiological stage R7, the zero fertilizer treatment had fixed the smallest amount of nitrogen (122 kg N/ha). An application of starter nitrogen alone, increased fixation to 132-140 kg N/ha. Following 100 kg N/ha to rice, starter nitrogen had no effect on soybean fixation (138 kg N/ha, 134 kg N/ha and 130 kg N/ha were fixed when 0, 25 50 kg N/ha starter nitrogen was applied to soybean, respectively). However, with the residual following 300 kg N/ha to rice, nitrogen fixation was significantly decreased from 139 to 128 kg N/ha when up to 50 kg N/ha starter nitrogen was applied.

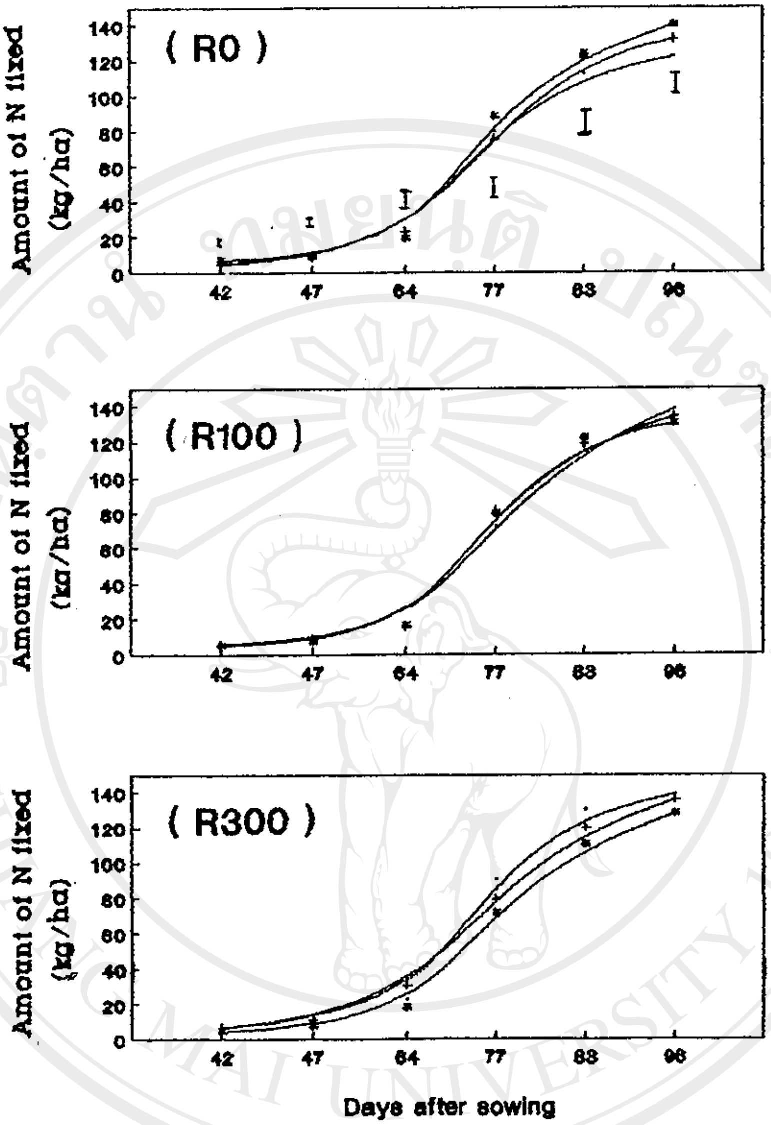

Figure 6 Effects of nitrogen applied to rice at 0 (R0), 100 (R100) and 300 (R300) kg N/ha and soybean at 0 (•), 25 (+), 50 (*) kg N/ha on the amount of nitrogen fixed with time. Vertical lines denote LSD's (P<0.05) for each time of sampling.

6 Soybean Yield and seed nitrogen

Soybean yield and total seeds nitrogen removal increased slightly with the application of starter nitrogen to soybean, seed nitrogen concentration, however, showed no consistent response to increase nitrogen levels (Table 4). At the lowest combined nitrogen treatment, without nitrogen to either rice or soybean, a seed yield of 1.69 t/ha represented a nitrogen removal of 122 kg N/ha in the harvested seed. At the highest combined nitrogen treatment (300 kg N/ha to rice plus 50 kg N/ha applied to soybean) seed yield was 1.91 t/ha and 138 kg N/ha was removed in seed.

7 Nitrogen Balance

7.1 Nitrogen in fallen leaf

The amount of nitrogen in fallen leaves returned to the field showed increased slightly with increasing levels of combined nitrogen (Table 5) . Similar trends were also found for the amount fallen leaf dry matter, and total nitrogen content. The amount of leaf nitrogen returned to the field ranged from 10 kg N/ha, in the treatment of without nitrogen to either rice or soybean, to 16 kg/ha, in the treatment of 300 kg N/ha to rice followed 50 kg N/ha to soybean.

Table 4 Effects of nitrogen fertilizationn on soybean seed yield, total nitrogen content and nitrogen removal

Treatment		Yield (t/ha)	N %	N removal (kg/ha)
R0	S0	1.69	7.23	122
	S25	1.83	7.25	133
	S50	1.84	7.15	131
R100	S0	1.80	7.35	133
	S25	1.84	7.27	134
	S50	1.86	7.21	134
R300	S0	1.82	7.14	130
	S25	1.84	7.21	133
	S50	1.91	7.23	138
LSD(P<0.05)		0.14	0.16	10
RN x SYN		ns	ns	ns

* RN N applied to rice
SYN N applied to soybean
ns not significant

Table 5 Amount of nitrogen returned to field with fallen leaves

Treatment		dry weight (kg/ha)	N %	N (kg/ha)
R0	S0	1000	1.01	10
	S25	1065	1.17	12
	S50	1138	1.25	14
R100	S0	1061	1.12	12
	S25	1073	1.03	11
	S50	1088	1.19	13
R300	S0	1065	1.09	12
	S25	1113	1.31	15
	S50	1125	1.45	16
LSD(P<0.05)		141	0.2	2
RN*SYN		ns	**	**

RN N applied to rice
SYN N applied to soybean
ns not significant
** Significance at 1% level

7.2 Nitrogen balance for soybean

The amount of nitrogen fixed was exceeded by the amount of nitrogen removed in the harvested seed in the extremely high nitrogen treatments (Table 6). Therefore, a net depletion of the soil nitrogen pool would be predicted after growing a soybean crop in these extremes. However, these was a small amount of nitrogen left after harvest seeds in the medium treatments. If the soybean straw was also removed at final harvest, the net apparent nitrogen depletion was predicted in all treatment. Without nitrogen fertilizer added to the rice crop, net soil nitrogen depletion decreased with increasing levels of starter nitrogen. With 100 and 300 kg N/ha, on the other hand, the nitrogen net depletion increased with increasing levels of starter nitrogen to soybean.

The net soil nitrogen depletion was estimated to range from -1 kg N/ha, in the treatment of no fertilizer applied to rice followed with 25 kg N/ha starter nitrogen to soybean, to -10 kg N/ha, where 300 kg N/ha was added to rice and 50 kg N/ha to soybean. The net depletion of soil nitrogen ranged from -6 kg N/ha, in 300 kg N/ha applied to rice followed no nitrogen to soybean treatment, to -32 kg N/ha in 300 kg N/ha applied to rice followed 50 kg N/ha applied to soybean if straw nitrogen removal was also included.

Table 6 Nitrogen balance for soybean, grown after rice fertilized with three levels of N (0, 100, 300 kg N /ha) and supplied with three levels 'starter' N (0, 25 50 kg N/ha)

Treatment	Total N [a]	Seed N	Seed+ Straw N	N fixed	Soybean uptake N for: Soil+ fert. N	(RN+SYN) Fert. N	(SYN) Fert. N	N recovery [b] (%)	N balance: Seed only [c]	Seed+ straw [d]
R0										
S0	145	122	135	122	23	0			0	-13
S25	164	133	152	132	32	9	9	36	-1	-20
S50	169	131	155	140	29	6	6	12	9	-15
R100										
S0	164	133	152	138	26	3			5	-14
S25	166	134	155	134	32	9	6	24	0	-21
S50	168	134	155	130	38	15	12	24	-4	-25
R300										
S0	169	130	145	139	30	7			9	-6
S25	170	133	155	136	34	11	4	16	3	-19
S50	179	138	163	128	51	28	21	42	-10	-35

a. includes fallen leaves, did not include roots and nodules
b. N uptake / amount of N applied to soybean
c. N fixed - Seed N
d. N fixed - (seed N + straw N)
RN N applied to rice
SYN N applied to soybean