Plant and Soil 108, 151–162 (1988)

PLSO BNF36

Yields and nitrogen nutrition of intercropped maize and ricebean (*Vigna umbellata* [Thumb.] Ohwi and Ohashi)

K. RERKASEM and B. RERKASEM
Multiple Cropping Centre, Chiangmai University, Chiang Mai 50 002, Thailand

Key words: combined nitrogen, natural abundance, ^{15}N, nitrogen fixation, nitrogen response, nodulation, relative yield, ureide analysis

Abstract

Maize (*Zea mays* L.) and ricebean (*Vigna umbellata* [Thumb.] Ohwi and Ohashi) were grown in intercrop and monoculture on Tropaqualf soils under rainfed conditions in Northern Thailand yearly from 1983 to 1986. De Wit's replacement design was used to compare intercrops and monocultures with a constant plant density equivalent to 80 000 maize or 160 000 ricebean plants ha^{-1}. Combined nitrogen was applied at varying levels to 200 kg N ha^{-1}. In the final two seasons the intercrop ratio of maize:ricebean was also varied. At the time of maize maturity intercrops yielded upt 49 kg ha^{-1} more N in the above ground plant parts than the best monoculture. Dry matter, grain and nitrogen yield of maize and ricebean in intercrop relative to their monoculture yields (RY, relative yield) were significantly greater than their respective share of the plant population. Relative yield totals (RYT) for grain, dry matter and nitrogen were always greater than 1.

Nitrogen uptake per maize plant increased with progressive replacement of maize by ricebean plants. This increase was similar to that obtained by applying combined N. Available soil nitrogen tended to decrease with increasing maize:ricebean ratio. Increasing the maize:ricebean ratio increased the % of nitrogen derived from fixation in ricebean, the increase being equivalent to that obtained by decreasing combined nitrogen application. Approximately the same amount of fertilizer and soil nitrogen was taken up by maize plus ricebean in intercrop as the maize monoculture. The results suggest that the improved nitrogen economy of the intercrop resulted from the strong competitiveness of maize in the use of mineral nitrogen and the enhancement of nitrogen fixation in intercropped ricebean which made it less dependent on the depleted pool of soil nitrogen.

Introduction

The benefit of legume/nonlegume associations on the nitrogen economy of the cropping system has been documented for pasture and crop species (Sanchez, 1976; Vallis, 1976). Symbiotic nitrogen fixation in the legume has often been suggested as the major cause for this benefit (Wiley, 1979). De Wit *et al.* (1966) demonstrated that nitrogen fixation enabled the legume to be less dependent on mineral nitrogen. Some evidence for direct transfer of nitrogen from the legume to the associated nonlegume has also been reported (Agboola and Fayami, 1972; Bandyopadhyay and De, 1986; Eaglesham, 1982).

Ricebean (*Vigna umbellata* [Thunb.] Ohwi and Ohashi] is a common traditional pulse of India and Southeast Asia. It is grown in association with major cereals, *e.g.* rice in Burma (Purseglove, 1974), and maize in Thailand (Chulasai *et al.*, 1985). In Thailand ricebean, mostly intercropped with maize, is grown on about 30 000 ha; for 1985 21 000 tons of beans were exported with a market value of $US 7.9 million (OAE, 1986).

Maize intercropped with ricebean is generally believed to be a more sustainable cropping system than monoculture corn and is presently being recommended to hilltribe farmers in remote areas of Northern Thailand as a cropping system which can sustain productivity in the absence of fertilizers

(Phetchawee *et al.*, 1986 and C Suthi personal communication). Because of its importance, the yield advantage of maize/ricebean intercrop and the dynamics of its nitrogen nutrition were examined.

Materials and methods

The experiments were carried out from 1983 to 1986 under rainfed conditions in Northern Thailand. The soils are silty loams of series Tropaqualfs, derived from old to semirecent alluvium, with pH of 4.8 to 5.8 and low available phosphorus and potassium. Annual rainfall averages 1200 mm, most of which falls from May to September (Chulasai *et al.*, 1985). This period, which constitutes the major growing season, is characterized by an average maximum temperature of 32°C and minimum of 23°C with the longest day of 13 hours on Jun 22.

The replacement series design (de Wit, 1960) was used to compare intercrops with monocultures at a constant overall density of 80 000 maize or 160 000 ricebean plants ha^{-1}. The treatments were factorial combinations of combined nitrogen levels and cropping systems, monocultures and intercrops, arranged in split plot design, with levels of combined nitrogen as the main plots and cropping systems as subplots. Ricebean monoculture in experiments 3 and 4 was supported on 2-m-long bamboo stakes to equal the support provided by corn for the intercropped ricebean. A previous study had established that asymptotic densities for dry matter yield of maize and ricebean in this environment were 53 333–80 000 plants ha^{-1} and 150 000–200 000 plants ha^{-1}, respectively (Rerkasem and Rerkasem unpublished); therefore, one maize plant was considered equal to two ricebean plants. Both maize and ricebean (local red seeded, unnamed cv.) were planted in rows 0.375 m apart. A small drainage furrow was provided every 1.5 m after every 4th row. Monoculture maize was planted with 0.33 m between plants in the row and ricebean at 0.165 m, giving population densities of 80 000 plants ha^{-1} and 160 000 plants ha^{-1}, respectively. The intercrop ratios were achieved by progressive replacement of maize with ricebean plants. Every other maize plant in the two middle rows between the drainage furrows was replaced with two ricebeans to give maize:ricebean ratio of 75:25. For the 50:50 the two entire middle maize rows between the furrows were replaced by ricebean, and for 25:75 mixture all the maize were replaced by ricebean plants except the alternative maize plants in the two middle rows between drainage furrows.

Plants were harvested from 3 m^2 in the center of each plot for dry matter and nitrogen yield of maize and ricebean and maize grain yield at 90–111 days (maize maturity). Ricebean grain was harvested in 2–3 pickings to from 135 to 174 days. Fresh samples were dried at 80°C to a constant weight. Water content of the seeds was determined with a moisture meter. Grain yields were presented on the basis of zero water content. Yields were calculated per hectare and per plant, and relative to respective monoculture yield (RY, relative yield). A species was assumed to perform better in intercrop than monoculture when its RY was greater than its share of the population in intercrop. When the relative yield total (RYT, sum of RY's) > 1 there is an advantage of intercrop over monocultures (de Wit and van den Bergh 1965). For the grain yield of maize and ricebean which were harvested at different times the yield advantage was calculated using area X time equivalency ratio, ATER (Hiebsch and McCollum, 1987), which is similar to RYT but is weighted for the time difference:

$$\text{ATER} = \frac{\text{Ymi} * \text{tm}}{\text{Ymm} * \text{ti}} + \frac{\text{Yri} * \text{tr}}{\text{Yrm} * \text{ti}}$$

Ymi = yield intercropped maize; Ymm = yield mono-maize; Yri = yield intercropped ricebean; Yrm = yield mono-ricebean; tm = maize duration; tr = ricebean duration; ti = intercrop duration; in this study ti = tr [adapted from Hiebsch and McCollum (1987)].

Methods for specific experiments

Experiment 1 (1983) and 2 (1984). These two experiments were carried out sequentially in the same field with soil of the San Sai series of the Tropaqualf in the Multiple Cropping Centre Experiment Station of Chiangmai University. The intercrop maize:ricebean ratio was 50:50 in experiment 1 and 75:25 in Experiment 2. Four levels of combined nitrogen: 0, 50, 100 and 200 kg N ha^{-1} as urea were applied in bands between rows after emergence. There were four replicates; each subplot was

4.5 m × 5.0 m. A basal treatment of 42 kg K ha^{-1} and 22 kg P ha^{-1} as potassium sulphate and triple super phosphate was applied before sowing. Above ground plant parts of both corn and ricebean were harvested for dry matter yield and total Kjeldahl nitrogen at maize maturity, 90–101 days from sowing. Grain yield of maize was also recorded. Ricebean grain was harvested in 2–3 pickings from 135 to 174 days after sowing.

Experiment 3 (1985). This experiment was carried out on a newly cleared upland site at the Chiangmai University Mae Hia Experimental Farm. Using the same species, cultivars and overall density as in Experiments 1 and 2, intercrops of maize:ricebean at ratios 75:25; 50:50 and 25:75 were compared with monocultures of maize and ricebean, at two levels of combined nitrogen, 0 and 100 kg N ha^{-1}. The nitrogen was applied as urea in bands between rows after emergence. Each subplot was 7.5 m × 10 m. There were four replicates for each treatment combination. Ricebean and maize tops and maize grain were harvested for dry matter and nitrogen at 90 days from sowing. Ricebean grain and final dry matter were harvested at 147 days. Nitrogen fixation by the ricebean was measured using ^{15}N natural abundance and ureide analysis (Rerkasem *et al.*, this volume). A composit soil sample, made up of four subsamples, was collected from each plot before maize tasselling at 52 days to the depth of 30 cm and extracted for mineral nitrogen with 2 m*M* potassium chloride. The amount of mineral nitrogen in the extract was estimated by distillation of the extract with MgO Devarda's alloy to ammonia and titration (Bergersen, 1980). There was an unintended three weeks delay between soil sampling and extraction during which the samples were stored at 4°C.

Experiment 4 (1986). This experiment was carried out at the same location as Experiment 3. The land had been planted to soybeans and peanuts in the preceeding two wet seasons, then sown with wheat followed by maize to deplete soil nitrogen before commencing the experiment. To ensure uniformity the maize used was breeder seed of a synthetic cv. Suwan 1. Maize/ricebean intercrops at ratios of 75:25 and 25:75 were compared to monocultures at two levels of combined nitrogen, 20 and 200 kg N ha^{-1}. Nitrogen was applied as ammonium sulphate solution, half at sowing and half at 30 days. Subplot size was 6.0 × 6.5 m. There were six replicates. Each subplot contained a 1.65 m × 3.00 m microplot in which ammonium sulphate enriched with 3.764 and 0.468 atm % excess of ^{15}N for the combined N treatments of 20 and 200 kg N ha^{-1}, respectively was applied. Maize and ricebean were harvested for dry matter and nitrogen yield and maize grain yield at 100 days from sowing. Plant samples from the 1.0 m × 1.5 m center area of the microplots were processed separately for ^{15}N analysis. Sample preparation for ^{15}N analysis was carried out according to Bergersen (1980) except that the ammonia was distilled into 10 ml of 0.02 *N* sulphuric acid instead of boric acid. The distillates were evaporated down to 0.5 to 1.0 ml on a hot plate and dried onto 1.2 cm × 11.2 cm strips of Watman #1 filter paper for packing and mailing. The samples were analyzed for ^{15}N by adding hypobromite directly to the paper in Rittenberg tubes to generate N_2 for the mass spectrometer, with atmosphoric N as standard. (R H Burris, personal communication) Ricebean grain was harvested at 160 days. Sampling for ricebean nodules dry weight and soil mineral N to 30 cm were also carried out at 82 days when maize had reached physiological maturity. The soil was sampled and analyzed for available nitrogen in the same way as in experiment 3 but the delay between sampling and extraction was reduced to one week.

Results

Dry matter yield (Experiments 1, 2, 3 and 4)

At the time of maize maturity, dry matter yields of monoculture maize without combined nitrogen ranged from 8 to 16 t ha^{-1}; whereas those of ricebean varied from 4 to 6 t ha^{-1} (Fig. 1). Dry matter of the monoculture maize increase significantly with increasing levels of combined nitrogen in three of the four experiments, to 14 to 30 t ha^{-1}. Responses varied somewhat from experiment to experiment, and were most pronounced with the Suwan 1 maize. By contrast the monoculture ricebean showed little or no response to combined nitrogen. When intercropped, both maize and ricebean dry matter yields were almost always above the expected yield based on their proportion in the mixture,

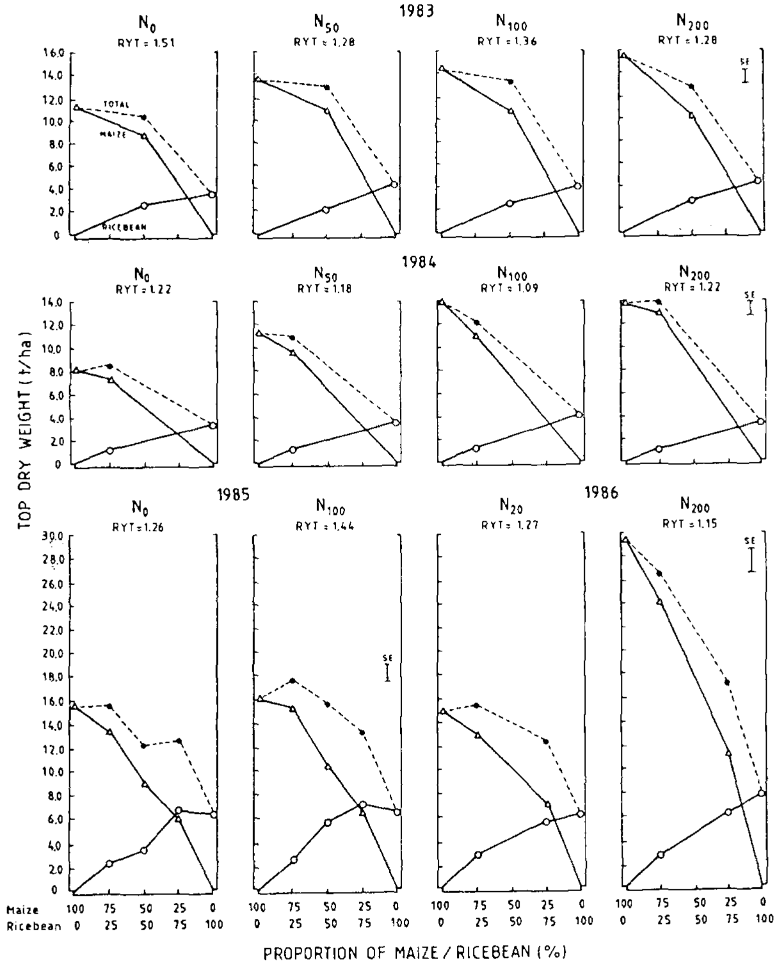

Fig. 1. Effects of combined nitrogen and maize/ricebean proportion on top dry weight. *Bars* represent standard error (SE) of total top dry weight. For (Δ — Δ), (o — o), (• — •), see Figure 3.

implying synergistic effects due to intercropping for both species. Consequently, the RYT values were greater than 1, indicating a dry matter yield advantage of intercropping over monoculture. This intercrop advantage appeared unaffected by combined nitrogen.

Grain yield (Experiment 1, 2, 3 and 4) and ricebean harvest index (Experiment 3 and 4)

Maize was harvested at 90 to 110 days after sowing. With 0 or 20 kg ha^{-1} of nitrogen maize grain yield in monoculture varied from 2.53 to 5.18 t ha^{-1} (Fig. 2). Application of 100 or 200 kg N ha^{-1} increased the yield of maize grain to 4.9 to 8.0 t ha^{-1}. Response to combined nitrogen varied from experiment to experiment. The maize grain yield was reduced by intercropping, but the reduction was proportionately less than the ratio of maize plants that were replaced by ricebean.

The grain yields of ricebean were somewhat variable, ranging from 0.94 to 1.57 t ha^{-1} in monoculture with low (20 kg N ha^{-1}) or no combined nitrogen (Fig. 2). The time to grain maturity of the photosensitive ricebean, which always flowered towards the end of October, varied from 135 to 174 days depending on date of sowing. The application of combined nitrogen, up to 200 kg N ha^{-1}, had no effect on the grain yield of ricebean. In all experiments ricebean consistently yielded the same amount of grain when intercropped, irrespective of maize:ricebean ratios, as in monoculture.

The RYT's for grain yields of the intercrop,

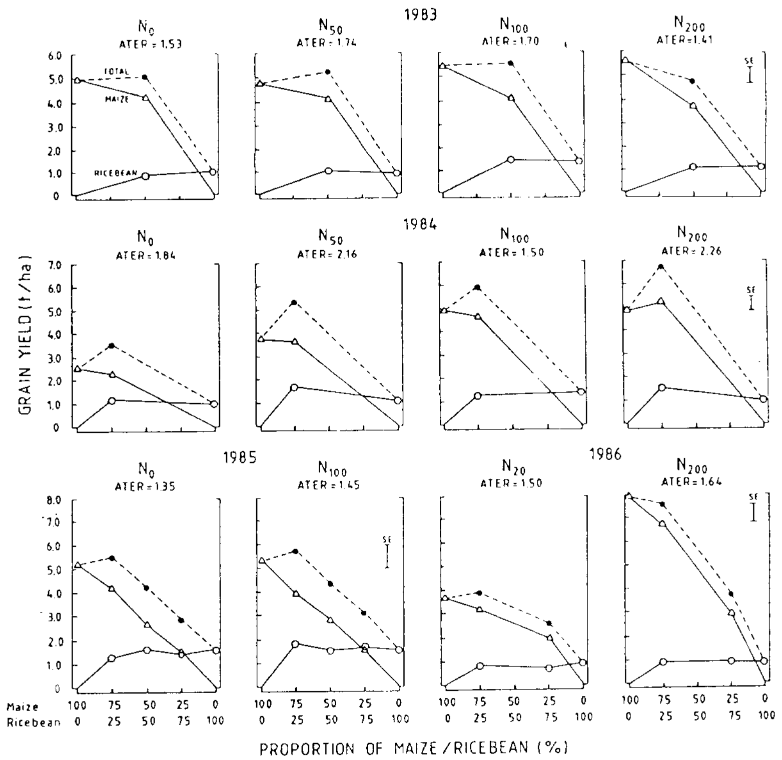

Fig. 2. Effects of combined nitrogen and maize/ricebean proportion on grain yields. *Bars* represent standard error (SE) of the total grain yields. For (Δ — Δ), (o — o), (• — •), see Figure 3.

weighted for the difference in crop duration, abbreviated as ATER (Hiebsch and McCollum, 1987), for all four experiments ranged from 1.231 to 2.263, with a mean of 1.604 ± 0.287. The harvest index of monoculture ricebean ranged from 11 to 24% (Table 1). The ricebean harvest index was increased significantly by intercropping at 75:25 (Table 1). The ricebean grain yield at this maize:ricebean ratio was high, differing little from monoculture or intercrops with higher ratios of ricebean (Fig. 2) despite a marked reduced dry matter yield (Fig. 1).

Nitrogen yield (Experiment 1, 2, 3 and 4)

On a per plant basis, nitrogen content of maize generally increased as much by decreasing the ratio

Table 1. Harvest index (in %) of monocultured and intercropped ricebean (Experiment 3 and 4)

Year	kg N ha^{-1}	Maize:ricebean ratio			
		0:100	25:75	50:50	75:25
1985	0	21.9	29.1	42.7	35.8
	100	23.6	27.9	23.1	55.8
1986	20	11.2	11.4	—	28.3
	200	13.4	11.4	—	24.6
Significant difference ($p <$)		Intercrop ratio (R)	Combined N (N)	R × N	LSD ($p < 0.05$)
1985		0.01	NS[a]	0.05	5.2
1986		0.001	NS	NS	7.19

[a] $p < 0.05$.

Table 2. Effects of combined nitrogen and intercropping on nitrogen content per plant in maize and ricebean

Year	Intercrop ratio Maize:ricebean	Nitrogen yield (g N plant^{-1}) Nitrogen applied (kg N ha^{-1})							
		N0		N50		N100		N200	
		M[a]	R[a]	M	R	M	R	M	R
1983	100:0	1.43	—	1.52	—	1.74	—	2.06	—
	50:50	2.00	0.95	2.18	0.94	3.22	0.87	3.31	0.95
	0:100	—	0.61	—	0.60	—	0.78	—	0.66
1984	100:0	0.70	—	1.19	—	1.59	—	1.68	—
	75:25	1.39	0.69	2.04	0.93	2.91	0.74	3.36	0.58
	0:100	—	0.54	—	0.54	—	0.53	—	0.50
1985	100:0	1.63	—			2.16	—		
	75:25	2.03	1.21			2.57	1.47		
	50:50	1.97	0.84			2.75	1.53		
	25:75	2.71	1.08			3.34	1.34		
	0:100	—	0.84			—	0.84		

		Nitrogen applied (kg N ha^{-1}) 20		200	
1986	100:0	0.92	—	2.87	—
	75:25	1.06	1.72	3.05	1.59
	25:75	2.13	1.06	4.62	1.28
	0:100	—	0.84	—	1.11

	Intercrop ratio (R)	Combined N (N)	R × N	LSD (p < 0.05)
Significant difference (p ±)				
1983	0.001	0.05	NS (p < 0.05)	0.26
1984	0.001	0.001	0.001	0.26
1985	0.001	0.001	0.05	0.42
1986	0.001	0.001	0.01	0.54

[a] M = maize; R = ricebean.

of maize:ricebean as by increasing the rate of application of combined nitrogen (Table 2). For example, in 1985 the monoculture maize had 1.63 g N plant^{-1} without combined nitrogen. Intercropping without combined N at 75:25 increased the nitrogen content to 2.03 g N plant^{-1}, which was similar to 2.16 g N plant^{-1} in the maize that had received 100 kg N ha^{-1}. No such clear effect was seen with ricebean.

Without combined nitrogen the total amount of nitrogen in the above ground parts of maize and ricebean in monoculture at 90–110 days ranged from 56 to 131 kg N ha^{-1} and 86 to 135 kg N ha^{-1}, respectively (Fig. 3). Application of combined nitrogen markedly increased the uptake of nitrogen by maize in all four experiments, with some year to year variations. The biggest response was seen in the fourth experiment when 230 kg N ha^{-1} was taken up by the monoculture maize with 200 kg N ha^{-1} applied. Nitrogen yield in ricebean showed little response to combined nitrogen. As with dry matter the nitrogen yields of both maize and ricebean in intercrop were above the diagonals and the RYT values were > 1. Up to 49 more kg N ha^{-1}, was actually taken up in intercrop than in the highest yielding monoculture. Between 91 days and 147 days there was a marked increase in relative nitrogen yields of intercropped ricebean at 75:25, from 0.36–0.43 to 0.58–0.60 (Table 3). This was a result of a greater accumulation of nitrogen during this period in ricebean at 75:25 than in ricebean at lower maize:ricebean ratios or in monoculture (Rerkasem *et al.*, this volume).

Nitrogen sources (Experiment 3, 4)

The partitioning of ricebean nitrogen into fixed N and that supplied by combined N sources, using natural abundance ^{15}N and ureide analysis techni-

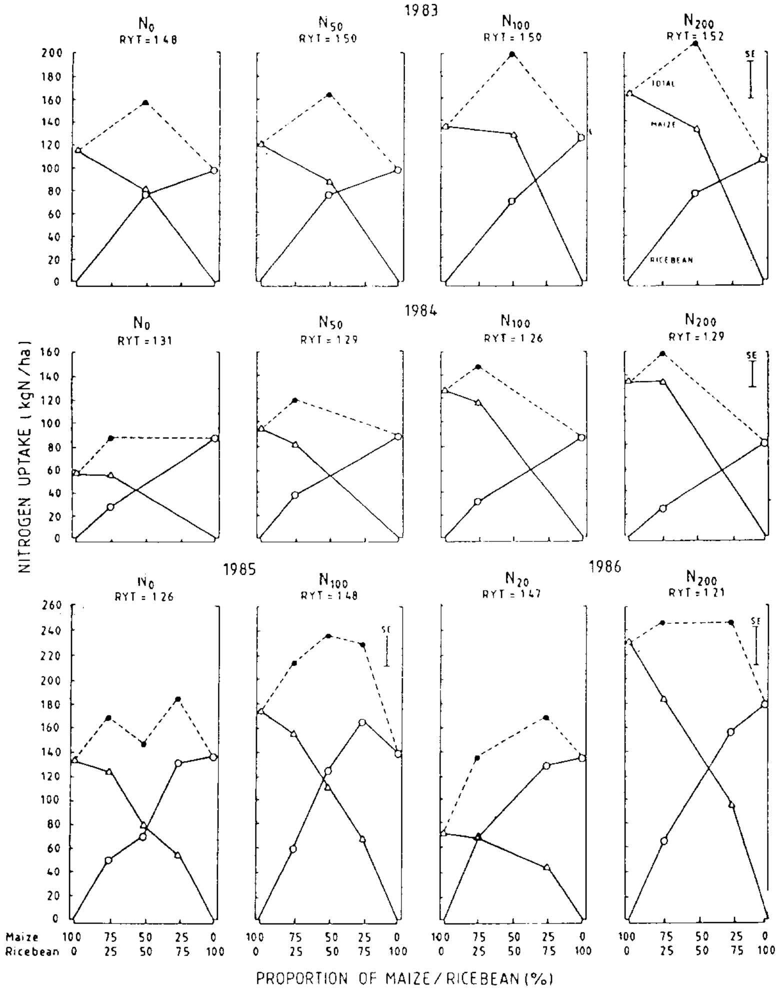

Fig. 3. Effects of combined nitrogen on the uptake of total nitrogen (soil N and fixed) in the top of maize (△—△) and ricebean (○—○) in intercrop and monoculture at corn maturing stage. (●—●) indicates intercrop total.

que is presented elsewhere for experiment 3 (Rerkasem *et al.*, this volume). The use of labelled ^{15}N gave similar results in Experiment 4. The percentage of ricebean nitrogen that came from fixation increased significantly by intercropping at 75:25, but not at 25:75 maize:ricebean (Table 4). With 20 kg N ha^{-1}, 72% of the nitrogen in ricebean monoculture came from fixation. Intercropping, in which 75% of the ricebean was replaced by maize, increased the contribution from fixation to 90%. Increasing the rate of combined N application to 200 kg N ha^{-1}, on the other hand, depressed the percentage of fixed N by 50%. This depression of nitrogen fixation in ricebean by high level of combined N was attenuated by intercropping; with the percent of ricebean N from fixation at 200 kg N ha^{-1} increasing from 36.68% in monoculture to 51.2% at 75:25.

The relative yield of fixed N in intercropped ricebean was higher than the relative yield of total N; but the relative yield of mineral N was lower (Table 3), especially at 50:50 or 75:50. This indicated intercrop advantage in terms of nitrogen fixation, which became more pronounced at the final ricebean harvest. The relative yield of fixed N in ricebean showed a marked increase during the period between maize and ricebean harvests.

Maize and ricebean together in the intercrops took up approximately the same amount of soil and fertilizer N as the monoculture maize (Table 5).

Table 3. Relative nitrogen yield of intercropped maize and ricebean (Experiment 3, 4)

		N yield (kg N ha^{-1})		Relative nitrogen yield of ricebean					
days from sowing	91			91			147		
kg N ha^{-1}	M:R[a]	M	R	Total	Fixed	S + F[b]	Total	Fixed	S + F[b]
Experiment 3 (1985)									
0	100:0	130.6	0.0	—	—	—	—	—	—
	75:25	122.0	48.3	0.36	0.51	0.22	0.58	0.93	0.25
	50:50	78.9	67.1	0.50	0.65	0.37	0.55	0.73	0.38
	25:75	54.2	129.2	0.96	0.93	0.98	0.82	ne[c]	ne
	0:100	0.0	134.6	1.00	1.00	1.00	1.00	1.00	1.00
100	100:0	172.9	0.0	—	—	—	—	—	—
	75:25	154.2	58.9	0.43	0.71	0.29	0.60	1.01	0.30
	50:50	109.2	122.6	0.90	1.41	0.64	1.20	1.76	0.66
	25:75	66.9	161.9	1.19	1.74	0.91	0.99	ne	ne
	0:100	0.0	135.9	1.00	1.00	1.00	1.00	1.00	1.00

		N yield (kg N ha^{-1})		Relative nitrogen yield						
kg N ha^{-1}	M:R[a]	M	R	Maize			Ricebean			
				Total	Soil	Ferti-lizer	Total	Soil	Ferti-lizer	Fixed
Experiment 4 (1986)										
20	100:0	74.3	—	1.00	1.00	1.00	—	—	—	—
	75:25	63.7	69.0	0.68	0.86	0.86	0.46	0.20	0.19	0.54
	25:75	42.5	126.5	0.57	0.58	0.48	0.85	0.85	0.68	0.85
	0:100	—	134.4	—	—	—	1.00	1.00	1.00	1.00
200	100:0	229.5	—	1.00	1.00	1.00	—	—	—	—
	75:25	182.7	59.7	0.80	0.72	0.92	0.46	0.22	0.28	0.61
	25:75	92.5	153.8	0.40	0.38	0.44	0.92	0.77	0.88	1.16
	0:100	—	177.6	—	—	—	1.00	1.00	1.00	1.00

[a] M = maize; R = ricebean.
[b] Soil + fertilizer N; nitrogen sources for maize in Experiment 3 not distinguished.
[c] Not estimated, nitrogen yield declined slightly with time.

However, total nitrogen yield from intercrops exceeded the yield of maize monoculture, and that was accounted for by fixation by the ricebean. At 20 kg N ha^{-1} almost all of the mineral nitrogen taken up by monoculture maize was from the soil, with contribution from fertilizer being quite small (Table 5). An increase in the rate of application of combined N to 200 kg N ha^{-1} caused twenty- to thirty-fold increases in the uptake of fertilizer N, and about doubled the uptake of soil N in maize and ricebean whether grown in monoculture or intercropped. The intercrops did not differ from maize monoculture in their uptake of soil or fertilizer nitrogen, but uptake of soil and fertilizer N by ricebean was about half that of monocultured maize or intercrop total.

Soil mineral nitrogen and nodulation (Experiment 3 and 4)

The amount of extractable mineral nitrogen at 52 days (Experiment 3) and 82 days (Experiment 4) showed significant effects of intercropping and combined nitrogen applications (Table 6). In both experiments the effect of intercrop ratio on available soil N was apparent only when combined nitrogen was applied. The lowest levels of available nitrogen were found under monoculture maize or intercrop with maize:ricebean at 75:25. There was a trend toward increased available nitrogen as maize:ricebean ratios decreased with the highest levels of available N in monoculture ricebean; 182

Table 4. Enrichment of 15N in maize and ricebean tops and estimates of nitrogen derived from fertilizer and fixation (Experiment 4)

$kg\,N\,ha^{-1}$	Intercrop ratio, maize to ricebean	% 15N atom excess		% nitrogen from fertilizer[a]		% nitrogen from fixation[b] Ricebean
		Maize	Ricebean	Maize	Ricebean	
20	100:0	0.3197	—	8.16	—	—
	75:25	0.3222	0.0319	8.22	0.82	90.03
	25:75	0.2642	0.0614	6.74	1.56	76.00
	0:100	—	0.0739	—	1.89	72.02
200	100:0	0.1812	—	46.24	—	—
	75:25	0.2087	0.1014	53.25	25.77	51.20
	25:75	0.1974	0.1202	50.37	30.62	38.97
	0:100	—	0.1250	—	31.90	36.68
LSD ($p < 0.05$)		0.0455	0.0164			9.10
Significant effects						
Nitrogen		$p < 0.001$	$p < 0.001$			$p < 0.001$
Intercrop ratio		NS	$p < 0.001$			$p < 0.001$
Nitrogen × ratio		$p < 0.1$	$p < 0.01$			NS

[a] % nitrogen from fertilizer = (% 15N atom excess in plant/% 15N atom excess in fertilizer) × 100.
[b] % nitrogen from fixation = [1 − (% 15N atom excess in ricebean/% 15N atom excess in maize[c])] × 100.
[c] reference maize from the same intercrop plot; except in monoculture ricebean where maize from 25:75 was used.

ppm N at $100\,kg\,N\,ha^{-1}$ in experiment 3 and 320 ppm N at $200\,kg\,N\,ha^{-1}$ in experiment 4.

The application of $200\,kg\,N\,ha^{-1}$ resulted in a marked reduction of nodule mass of ricebean in monoculture (Table 7), but the effect was removed when intercropped. The dry weight of nodules recovered from monocultured ricebean grown with $200\,kg\,N\,ha^{-1}$ was $29\,mg\,plant^{-1}$, compared with $77\,mg\,plant^{-1}$ with $20\,kg\,N\,ha^{-1}$. When intercropped, ricebean produced comparable nodule mass at both N levels.

Discussion

Intercropped maize and ricebean yields, whether measured in terms of RYT's for dry matter and nitrogen yields for the period of associative growth

Table 5. Sources of nitrogen (in $kg\,N\,ha^{-1}$) taken up by intercropped and monocultured maize and ricebean (Experiment 4)

$kg\,N\,ha^{-1}$	M:R[b]	Maize		Ricebean			Cropping system total			
		F-N[a]	S-N	F-N	S-N	Fixed-N	F-N	S-N	Fixed-N	T-N
20	100:0	6.02	68.32	—	—	—	6.02	68.32	—	74.34
	75:25	5.14	58.58	0.54	6.24	62.19	5.68	64.82	62.19	132.69
	25:75	2.88	39.63	1.90	26.75	97.90	4.78	66.38	97.90	169.06
	0:100	—	—	2.54	35.07	96.79	2.54	35.07	96.79	134.40
200	100:0	105.92	123.56	—	—	—	105.92	123.56	—	229.48
	75:25	97.08	85.65	14.63	13.24	31.78	111.71	98.89	31.78	242.38
	25:75	46.24	46.22	46.53	46.91	60.32	92.77	93.13	60.32	246.22
	0:100	—	—	56.65	65.50	55.45	56.65	65.50	56.65	177.60
LSD ($p < 0.05$)		10.10	16.79	7.04	13.74	9.10	8.70	15.19	9.10	11.37
Significant effects										
Intercrop ratio × N		$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.05$	NS				
Nitrogen ×						$p < 0.001$				
Intercrop ratio						$p < 0.001$				

[a] F-N = fertilizer-N; S-N = soil-N; T-N = total-N.
[b] Maize:ricebean ratio.

Table 6. Effects of maize:ricebean proportion in intercrop and combined nitrogen on available soil nitrogen to 30 cm

$kg\,N\,ha^{-1}$	Intercrop ratio Maize:ricebean	Available nitrogen in soil (ppm)	
		Experiment 3 at 52 days	Experiment 4 at 82 days
0	100:0	60	
	75:25	72	
	50:50	76	
	25:75	66	
	0:100	66	
20	100:0		10
	75:25		15
	25:75		17
	0:100		15
100	100:0	62	
	75:25	58	
	50:50	92	
	25:50	110	
	0:100	182	
200	100:0		61
	75:25		65
	25:75		230
	0:100		320

	Significant difference ($p <$)			LSD ($p < 0.05$)
	Intercrop ratio (R)	Combined nitrogen (N)	R × N	
1985	0.05	0.05	0.05	84
1986	0.001	0.001	0.001	78

or ATER's for grain yields, all indicated a definite advantage of intercropping, compared with their monoculture yields. Similar advantages in legume/nonlegume intercrops have been observed by de Wit *et al.* (1966), Trenbath (1976) and Hiebsch and McCollum (1987). The fact that the yields of both maize and ricebean when intercropped were generally above the diagonals in the replacement diagrammes implies beneficial effects of intercropping for both species. In addition to the advantage in relative terms, there were also absolute advantages in terms of higher nitrogen yield and grain yields at a maize:ricebean ratio of 75:25. Since ricebean grain brings 2.5 to 3.0 times the price of maize grain, due to its higher nutritive value, the farmer can expect a higher economic return from the intercrop, even when the total weight of grain harvested in the intercrop did not exceed that of the monoculture maize.

Table 7. Effects of maize:ricebean proportion in intercrop and combined nitrogen on dry weight of ricebean nodules at 82 days from sowing

	Ricebean nodules dry weight (mg $plant^{-1}$)	
	$kg\,N\,ha^{-1}$	
Maize:ricebean	20	200
100:0	—	
75:25	59	53
25:75	58	88
0:100	77	29
LSD ($p < 0.05$)	47	
	Significant difference ($p <$)	
Intercrop ratio (R)	NS ($p < 0.05$)	
Combined nitrogen (N)	NS	
R × N	0.05	

The priming effect of combined N, which resulted in an increase in the uptake of soil nitrogen with the application of $200\,kg\,N\,ha^{-1}$, has been commonly observed (Jansson and Persson, 1982). The effects were similar on intercropped and monocultured maize and ricebean.

The higher uptake of mineral N per unit area in maize *vs.* ricebean in monoculture; the relative yield of mineral nitrogen in intercropped ricebean which was lower than its proportion of the intercrop population; and a lower amount of available N found under the higher maize:ricebean ratios, suggest that maize is more competitive for mineral nitrogen than ricebean. No evidence of direct transfer of nitrogen from the ricebean to maize was observed in this study, although evidence of such transfer has been reported by others (Eaglesham *et al.*,. 1981 and Bandyopadhyay and De, 1986).

Nitrogen fixation by the legume has been shown to be the basis for the advantage of legume/nonlegume mixtures of pasture species. Although the RYT value for total nitrogen yield of a *Chloris gayana* and *Stylosanthes humilis* mixture was considerably greater than 1, the advantage largely disappeared when the contribution from fixation was discounted (Hall, 1974). The RYT values for dry matter and nitrogen yields of a Panicum and Glycine mixture were over 1.5 when the legume was nodulated, but dropped to 1 without the nitrogen fixing symbiosis (de Wit *et al.*, 1966). Ricebean in the current study derived a larger proportion of its nitrogen from fixation when intercropped with maize than when it was grown in monoculture. In general, the amount of nitrogen in the intercrop that exceeded that in the maize crop, which represents available mineral nitrogen, could be accounted for by the amount fixed by the ricebean.

In this study the intercrop advantage, in terms of dry matter, grain and nitrogen yields, was associated with an enhancement of nitrogen fixation by the legume. This has been previously reported in only one study on a maize/cowpea intercrop where a significant intercrop advantage was reported in association with a slight enhancement of nitrogen fixation (Ofori, Pate and Stern, 1987). In a sorghum/soybean intercrop an enhancement of nitrogen fixation by the soybean was reported without an intercrop yield advantage (Wahua and Miller, 1978a and 1978b). No yield advantage was observed in a maize/cowpea intercrop in which no enhancement of nitrogen fixation was detected (Eaglesham *et al.*, 1981).

Results from the current study indicate that both maize and ricebean contribute towards the observed intercrop advantage. Differential utilization of nitrogen sources by the two species may be responsible for the observed effect. Uptake of mineral nitrogen by the maize may have stimulated the ricebean to depend more on fixation. This may explain why the depression of fixation by 200 $kg\,ha^{-1}$ of combined N was less in the intercropped ricebean than monoculture. Perhaps, as important was the effect intercropping had on prolonging nitrogen fixation by the ricebean after the maize harvest. Effective uptake of mineral nitrogen by the nonlegume should be as important as nitrogen fixation by the legume in legume/nonlegume intercropping systems for the tropics where combined nitrogen can be readily lost by leaching and denitrification (Nye and Greenland, 1960).

The yield advantage and sustainability of maize/ricebean intercrop has been demonstrated in a long term study in Thailand (Phetchawee *et al.*, 1986). At Phraputthabat Field Crop Experiment Station in Central Thailand a total of 23.2 $t\,ha^{-1}$ of maize grain plus 5.3 $t\,ha^{-1}$ of ricebean grain was harvested over six growing seasons with no fertilizer input compared with 11.6 $t\,ha^{-1}$ of maize plus 5.1 $t\,ha^{-1}$ of mungbean from maize followed by mungbean. At the same time, the organic matter content of soil in the intercrop doubled to 1.64% over this period, whereas under maize-mungbean it changed only slightly from 0.83 to 1.10. Available soil nitrogen was 2.6 $mg.100\,g^{-1}$ and 5.7 $mg.100\,g^{-1}$ soil under the intercrop and maize-mungbean respectively in the 5th year.

The yield advantage of intercrops is a reflection of a better use of resources than monocultures (Osiru and Willey, 1972; Spitter, 1980; Trenbath, 1986). Nitrogen fixation is undoubtedly one important factor in the advantage of legume/nonlegume intercrops or pasture mixtures (Harper, 1977; Vallis, 1978; Willey, 1979). Yet this potential advantage cannot be realized if other factor(s) are limiting, as illustrated in the case of potassium deficiency in a pasture mixture of *Chloris gayana* and *Stylosanthes humilis* (Hall, 1974). This study demonstrated how the advantage of maize/ricebean intercrop was related to their nitrogen nutrition. It appears that under the condition of the present study other factors, *i.e.* light, water and other mineral nutrients, were not limiting. The evaluation of the potential and limitations of legume/nonlegume intercropping systems, and hence the potential benefit of nitrogen fixation by the legume, would greatly benefit from an understanding of how intercrops respond to varying levels of these factors.

Conclusion

This study has shown that there is a clear advantage in intercropping maize with ricebean in terms of dry matter, seed and nitrogen yield. The intercrop advantage in nitrogen yield which exceeded the best monoculture yield was due to the efficient use of mineral nitrogen by the maize and enhancement of nitrogen fixation by the ricebean. The effect of intercropping in enhancing ricebean nitrogen fixation was maintained long after the maize harvest. The increased dependence of intercropped ricebean on nitrogen fixation caused a similar amount of nitrogen to be fixed under intercrop and monoculture, despite a higher nitrogen yield in the latter. The overall advantage of the maize/ricebean intercrop is therefore related to an efficient use of mineral nitrogen by the maize and of fixation by the ricebean.

Acknowledgments

Financial support for this research was provided by the US National Academy of Sciences/National

Research Council by means of a grant from the US Agency for International Development. We also wish to thank Prof R H Burris for the Analysis of enriched ^{15}N, Dr Maurice Fried for advice on ^{15}N and Dr Joann Roskoski of NifTAL for assistance in the preparation of this manuscript.

References

Agboola A A and Fayemi A A 1972 Fixation and excretion of nitrogen by tropical legumes. Agron. J. 64, 409–412.

Bandyopadhyay S K and De R 1986 Nitrogen relationships and residual effects of intercropping sorghum with legumes. J. Agric. Sci. (Camb) 107, 629–632.

Bergersen F J 1980 Measurement of nitrogen fixation by direct means. *In*: Methods for Evaluating Biological Nitrogen Fixation. Ed. F J Bergersen, pp 65–110. A Wiley Interscience Publication.

Chulasai L, Rerkasem K, Kaosa-ard, Shinawatra B and Rerkasem B 1985 Profile of Northern Thailand. Chiangmai University, Chiang Mai, Thailand. 124 p.

Eaglesham A R J, Ayanaba A, Ranga Rao V and Eskew D L 1981 Improving the nitrogen nutrition of maize by intercropping with cowpea. Soil Biol. Biochem. 13, 169–171.

Eaglesham A R J 1982 Assessing the nitrogen contribution of cowpea (*Vigna unguiculata*) in monoculture and intercropped. *In* Biological Nitrogen Fixation: Technology for Tropical Agriculture. Eds. P H Graham and S C Harris, pp 641–646.

Jansson S L and Persson J 1982 Mineralization and immobilization of soil nitrogen. *In* Nitrogen in Agricultural Soils. Agronomy No. 22. Ed. F J Stevenson, pp 229–252. ASA/CSSA/SSA, Madison.

Hall R L 1974 Analysis of the nature of interference between plants of different species. I. Concepts and extension of the de Wit analysis to examine effects. Aust. J. Agric. Res. 25, 739–747.

Harper J H 1977 Population Biology in Plants. Academic Press. 892 p.

Hiebsch C K and McCollum R E 1987 Area × time equivalency ratio: a method for evaluating the productivity of intercrops. Agron. J. 79, 15–22.

Nye P H and Greenland D J 1960 The soil under shifting cultivation. Tech. Comm. No. 51. CAB 156 p.

OAE 1986 Agricultural statistics of Thailand. Crop year 1985/86. Centre for Agricultural Economics, Office of Agricultural Economics, Ministry of Agricultural and Co-operatives, Thailand 1986. 285 p.

Ofori F and Stern W R 1987 Relative sowing time and density of component crops in a maize/cowpea intercrop system. Expl. Agric. 23, 41–52.

Ofori F, Pate J S and Stern W R 1987 Evaluation of N2 fixation and nitrogen economy of a maize/cowpea intercrop system using ^{15}N dilution methods. Plant and Soil 102, 149–160.

Osiru D S and Willey R W 1972 Studies on mixtures of dwarf sorghum and beans (*Phaseolus vulgaris*) with particular reference to plant population. J. Agric. Sci. (Camb) 79, 531–540.

Phetchawee S, Vibulsukh N, Theppoolpon M and Masarngsan W 1986 Long term effect of mulching with fertilization under cropping corn-legumes on crop yield and improvement of soil chemical-physical properties. Proc. Inter. Sem. on yield maximization of feed grains through soil and fertilizer management.

Purseglove J W 1974 Tropical Crops Dicotyledons. John Wiley and Son, N.Y., 719 p.

Rerkasem B, Rerkasem K, Peoples M B, Herridge D F and Bergersen F J 1988 Evaluation of the contribution of symbiotic nitrogen fixation of ricebean (*Vigna umbellata* [Thumb.] Ohwi and Ohashi) to the nitrogen yield of maize/ricebean intercrop. Plant and Soil 108, 125–135.

Sanchez P A 1976 Properties and Management of Soils in the Tropics. John Wiley. 618 p.

Singh N B, Singh B B and Nair K P P 1986 Effect of legume intercropping on enrichment of soil nitrogen, bacterial activity and productivity of associated maize crops. Expl. Agric. 22, 339–344.

Spitter L T T 1980 Competition effects within mixed stands. *In* Opportunities for Increasing Crop Yields. Eds. R G Hurd *et al.* pp 219–231.

Trenbath B R 1976 Plant interactions in mixed crop communities. *In* Multiple Cropping. Special Pub. 27. Eds. R I Papendick *et al.* pp 129–170. American Society of Agronomy, Madison, Wis.

Trenbath B R 1986 Resource use by intercrops. *In* Multiple cropping systems. Ed. C A Francis, pp 57–81. Macmillan.

Valis I 1978 Nitrogen relationships in grass legume mixtures. *In* Plant Relations in Pastures. Ed. J R Wilson, pp 190–201. CSIRO Melbourne, Australia.

Wahua T A T, Babalola O and Aken'ova M E 1981 Intercropping morphologically different types of maize with cowpeas: LER and growth attributes of associated cowpea. Expl. Agric. 17, 407–413.

Wahua T A T and Miller D A 1978 Effects of intercropping on soybean N_2 fixation and plant composition on associated sorghum and soybeans. Agron. J. 70, 292–295.

Willey R W 1979 Intercropping—its importance and research needs. Part 1. Competition and yield advantages. Field Crops Abstra. 32, 1–10.

Wit C T de 1960 On competition. Versl. Landbouwkd. Onderz. (Agric. Res. Rep.) 66. 8, 1–82.

Wit C T de and van den Bergh J P 1965 Competition between herbage plants. Neth. J. Agric. Sci. 13, 212–221.

Wit C T de, Tow P G and Ennik G C 1966 Competition between legumes and grasses. Versl. Landbouwkd. Onderz. (Agric. Res. Rep.) 687, 1–30.