Productivity and light interception in upland rice - legume intercropping systems

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The interaction between upland rice and grain legumes (cowpea, groundnut, pigeon pea) in intercropping was investigated on a Vertisol over two years. Generally, intercropping was advantageous with a small reduction in rice yield and a substantial increase in yield of the legume. Pigeon pea-rice systems gave the highest intercropping advantage of 41-74% in the first year. In the second year, high intercropping advantages were recorded for cowpea and pigeon pea intercrops but the indeterminate pigeon pea cv. Hy 3C reduced the expected rice yield by half. High irradiance early in the rainy season increased the growth and yield of both rice and legumes compared to the previous season, but intercrop rice was less competitive than Hy3C. Canopy cover of rice was slowest compared to cowpea and pigeon pea, largely because of the erect leaf arrangement of rice. Intercropping invariably increased the amount of radiation intercepted due to faster canopy cover, *i.e.,* spatial complementarity. It was concluded that determinate legumes are more appropriate for intercropping with upland rice.

Keywords: Intercropping; Rice; Pigeon pea; Cowpea; Land equivalent ratio; Crop performance ratio

Upland rice is grown in India in areas with an annual rainfall greater than 900 mm but average grain yield is less than 1 t ha^{-1}. In regions where it is not possible to increase cropping intensity by sequence cropping, intercropping with legumes is common.

Intercropping upland rice with various legumes such as pigeon pea, green gram, and groundnut has generally increased the total productivity by 30-70% (Parida *et al.,* 1988; Jena and Misra, 1988). Generally intercropping is accompanied by a substantial reduction (35-60%) in rice yield even when the legume forms only one-sixth of the combined plant population. Although there is no reported physiological investigation, several factors could have contributed to this reduction in the yield of intercrop rice. Several dry spells of 2-7 days during the rainy season are probably more damaging to the shallow-rooted upland rice than to legumes, which are relatively drought-tolerant (Misra, 1984). It is also possible that upland rice has a slower initial growth rate than many legumes, which are more competitive because of a faster rate of canopy formation'.

Studies on several dryland cereal-legume intercropping systems have shown that increased productivity can be explained by a better utilization of total intercepted radiation, *e.g.,* in sorghum-pigeon pea intercrop (Natarajan and Willey, 1979) or by an increase in the conversion of intercepted radiation *to* dry matter (DM), *e.g.,* in pearl millet -groundnut intercrop (Marshall and Willey, 1983). Except for the study by Jena and Misra (1987) there has been no attempt to examine the utilization of physical resources by an upland rice-legume intercrop system. Such an investigation is crucial to determine the underlying mechanisms that determine the productivity of upland rice intercropping systems. In this study the rate of canopy development and the utilization of intercepted radiation as a result of interaction between upland rice and several grain legumes are examined.

Materials and Methods

Site

The experiment was conducted in the 1988 and 1989 growing seasons at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India (17°38'N, 78°21'E) on a medium deep Vertisol (black soil) with an available water-holding capacity of approximately 200 mm in the top 150 cm (Singh and Virmani, 1990). Rainfall, radiation data, and irrigation schedule are shown in Table 1.

Treatments and design

Two cultivars each of rice, *Oryza sativa* (cv. IET 7564, IET 7613); cowpea, *Vigna sinensis* (cv. EC 6216, Russian giant, or GC 2); groundnut, *Arachis hypogaea* (cv. ICGS11, FDRS4); and pigeon pea, *Cajanus cajan* (cv. ICPL87, Hy3C) were grown as monocrops and intercrops in 1988. Monocrops of rice, cowpea, groundnut,' and pigeon pea were grown at their recommended optimum plant population densities (Table 2). Groundnut was

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Table 1 Environmental data for Patancheru, Andhra Pradesh, India

Days after sowing (DAS)	1988		1989		
	Rain[1] (mm)	Daily radiation (MJ m^{-2})	Rain[1] (mm)	Irrigation (mm)	Daily radiation (MJ m^{-2})
10	21.1	16.51	16.5	50	20.19
20	114.8	13.51	1.8	40	18.82
30	68.8	13.93	31.6		18.80
40	77.6	11.13	66.2		12.41
50	137.0	16.19	163.8		17.69
60	14.5	15.31	234.5		14.67
70	189.4	12.23	14.6	42	17.83
80	39.6	17.78	17.7	40	16.90
90	82.2	14.10	64.2		12.36
100	33.1	14.79	107.8		18.53
110-190	6.7	16.63	228.8		17.88

[1]Total for 10-day period; 50 mm irrigation supplied at 10 DAS in 1988

omitted in the second year because it provided the lowest intercropping advantage. A monocrop of rice was sown in 20-cm-wide rows spaced 5 cm apart. In the intercrop, five rice rows were alternated with one legume row. The experiment consisted of 12 intercrop treatments during the first year and eight treatments in the second year. The experimental design was a randomised block with four replications. The plot size for each treatment was 9.6 m x 8 m and consisted of eight patterns (five rice rows and one legume row constitute one pattern) of which the middle four patterns were harvested. Crops were sown on 30 June 1988 and 29 May 1989.

A basal dressing of 100 kg ha^{-1} diammonium phosphate (18% N, 20% P) was applied prior to the last cultivation before sowing. The equivalent of 42 kg N ha^{-1} (taking into account the area occupied by both crops) was later top-dressed as urea along the sides of the rice rows at tillering and panicle initiation.

Growth measurements

Plants were harvested for growth analysis at 30-day intervals starting at 30 days after seedling emergence from a 1.2-m^2 area. Growth measurements were made on rice and pigeon pea in both years. Plant material was separated into leaves, stems, pods, and panicles. Leaf area was measured before the material was dried at 80°C to constant weight. Final harvests for grain and total DM of straw or stalks were taken from an area of 28.8 m^2. Harvest dates of the different *crops* are given in Table 3.

To assess the advantage of intercropping, the dry weight yield of harvested material per unit area of a component of the intercrop, 7, was divided by the proportion, *P,* of that component in the intercrop to give the yield per unit area sown to that component *I/P.* This quantity was then expressed as a fraction of the same component in a sole plot, S, to give crop performance ratios (CPR) of I_r/P_rS_r for rice, I_P/P_PS_P for pigeon pea, and I_C/P_CS_C for cowpea. The corresponding total CPR (TCPR) for the whole intercrop is given by Harris *et al.* (1987) as

$$TCPR = (I_r + I_p)/(P_rS_r + P_PS_P).$$

In this study, the 'expected' performance of a component of an intercrop was calculated as the value per unit area in the monocrop multiplied by the sown proportion of that component in the intercrop. Values of CPR exceeding 1.0 imply that a component yielded more DM per unit sown area in the intercrop treatment than in. the sole, plot, and thus performed better than 'expected' based on monocrop yields. Values of total CPR exceeding 1.0 imply that the intercrop plot yielded more than sole plots, with the area for each component identical with the corresponding area in the intercrop plot. The parameters CPR and total CPR were considered more appropriate bases for calculating the biological advantage of an intercrop than the more conventional land equivalent ratio (LER), because an attempt was made to compare the 'efficiency' with which monocrops and intercrops used intercepted radiation to produce dry matter. LER was also computed to compare with results' obtained by other workers.

Light measurements

Light interception was measured every 10 days with a 'mouse' radiation integrator sensitive to total

Table 2 Plant population (plants ha^{-1}) of different crops in mono- and inter-croppinq systems

Crop	Monocrop	Intercrop	% reduction of intercrop over sole crop	Duration of crop (days)
Rice[1]	1000000	832000	16.8	100-105
Cowpea[1]	222000	55000	75.1	60-80
Groundnut[1]	333000	83 000	75.1	120-135
Pigeon pea (ICPL87)	333000	83000	75.1	130-150
Pigeon pea (Hy3C)	83 000	41 500	50.0	160-180

[1]All varieties

Table 3 Harvest dates of different crops

Crop	Cultivar	1988	1989
Rice	IET 7564	10 Oct.	6 Oct.
	IET 7613	10 Oct.	6 Oct.
Cowpea	EC 6216	12 Sept.	6 Sept.
	Russian giant[1]/GC 2	24 Sept.	21 Aug.
Pigeon pea	ICPL87	24 Nov.	23 Nov.
	Hy 3C	30 Dec.	23 Nov...
Groundnut[2]	ICGS11	10 Oct.	—
	FDRS4	10 Oct.	—

[1]Russian giant was replaced by GC2 during 1989
[2]Groundnut was omitted in 1989

solar radiation described by Matthews *et al.* (1987). Crop rows were in a N-S direction and light interception was measured across five rows of rice by placing the integrator (1 m long) across the crop rows. Percentage light interception was calculated from the total radiation measured above and below the crop canopy. Absolute incident energy was recorded with a Kipps-Zonen solarimeter.

Results

Land equivalent ratios (LER)

Partial and total LER of grain yield of rice-legume intercrops in both years are given in Table 4. The duration of growth of the legume component in increasing order was cowpea, groundnut, and pigeon pea. In 1988, association with cowpea (75 days duration) produced the lowest LER of rice with the least partial LER (0.39-0.48) with cv. Russian giant and a total LER of 0.91-0.98. Intercropping with groundnut and pigeon pea gave a similar LER of 0.8-0.9 which was not much different from the expected LER of 0.83. However, the total LER of the rice-groundnut system showed little or no intercrop advantage due to poor groundnut yields. Pigeon pea-rice systems gave the largest total LER because of relatively high LER of intercrop pigeon pea. The late maturing and tall pigeon pea cv. Hy3C-rice system produced the highest total LER even though partial LER of rice was 2-10% less than that of ICPL87.

In 1989, cowpea cv. Russian giant was replaced by an erect branching genotype GC 2 and groundnut was omitted. The new cowpea cv. GC 2 was even less competitive than EC 6216 and rice yield was 12-13% higher than the expected LER. Cowpea cv. EC 6216 was more aggressive than GC 2, but it gave a higher total LER of 1.40-1.49 because of an equally large partial cowpea LER. The relative performance of pigeon pea-rice systems was the best with ICPL87 (1.51-1.63) but the treatment with Hy 3C gave a lower total LER because of severe competition with rice, resulting in partial LER of 0.43-0.52 in 1989. The LER values of cv. ICPL87 were similar to that in the previous year, showing little or no competition with upland rice.

Table 4 Partial and total LER of legume-rice intercrops

	Partial LER of rice[1]				Total LER			
	1988		1989		1988		1989	
Crop	A	B	A	B	A	B	A	B
Rice with cowpea cv. EC 6216	0.65	0.58	0.70	0.71	1.21	1.19	1.49	1.40
Cowpea cv. R. giant/ GC2	0.48	0.39	0.95	0.96	0.98	0.91	1.31	1.33
Groundnut cv. ICGS11	0.86	0.89	—	—	0.99	1.06	—	—
Groundnut cv. FDRS4	0.82	0.90	—	—	1.04	1.12	—	—
Pigeon pea cv. ICPL87	0.85	0.90	0.89	0.87	1.41	1.48	1.63	1.51
Pigeon pea cv. Hy3C	0.73	0.83	0.43	0.52	1.52	1.74	1.25	1.54

[1]Expected LER: rice, 0.83; cowpea, 0.25; groundnut, 0.25; pigeon pea: ICPL 87, 0.25; Hy3C, 0.5
A, IET7613; B, IET 7564

Seasonal effects

In both years, the onset of the rainy season was unfavourable for the growth of rice and, therefore, irrigation was provided once in 1988 and four times in 1989 (Table 1). During the first 30. days, irradiance ranged from 18.8 to 20.2 MJ m^{-2} in 1989 compared to 13.9-16.5 MJ m^{-2} in 1988. Greater tillering and faster growth of rice in 1989 compared to 1988 was associated with higher irradiance (Table 5a). During the next 30 days rainfall in 1989 was twice that of the previous year but the distribution was reversed for the period 70-100 days after sowing (DAS) with 334 mm in 1988 compared to 204 mm in 1989. After the removal of rice there was little rainfall in 1988 but 228.8 mm was received during the same period in 1989. A 1.6- to 1.9-fold increase in total biomass in 1989 compared to 1988 in both rice and pigeon pea cultivars was associated with a combination of high irradiance and greater rainfall (Table 5a and b).

The contrasting responses of the two seasons were examined in more detail by comparing the growth and morphology of rice and pigeon pea at the same growth stages (Tables 5a and b). The height of rice at 30 DAS was similar in both years but at maturity height was 13-19 cm shorter in 1989. In contrast, the height of the pigeon pea was considerably greater at 30 DAS in 1989 but by. 60 DAS the difference was negligible between seasons. Similarly, the number of tillers of rice was 2-3 times greater at 30 DAS in 1989 but the differences declined at maturity. Both pigeon pea cultivars produced 2-3 times more branches at 60 DAS in 1989 compared to 1988 although there was only a small difference at 30 DAS. These differences were reflected in the differences in leaf area index (LAI) of the pigeon pea cultivars between the two seasons. Leaf area index of both pigeon pea cultivars at 60 DAS in 1989 was twice the value in the previous year. Rice cv. IET 7613 had significantly greater LAI (25-30%) than IET 7564 due to broader leaf blades and more leaves per plant. Comparison of performance in the different seasons shows that although the difference in LAI of rice was small at 30 DAS at harvest, LAI was significantly greater (19-65%) than in 1988.

Table 5a Comparison of the growth and yield of monocrop rice stands in 1988 and 1989

Plant parameter and sampling time	1988		SE	LSD (P = 0.05)	1989		SE	LSD (P = 0.05)
	IET7613	IET7564			1ET7613	IET7564		
Plant height (cm)								
30 DAS	30.3	35.3	1.1	3.13	30.0	37.9	1.4	4.05
Maturity	76.3	90.4	1.9	5.41	63.4	71.3	2.4	6.94
No. of tillers plant^{-1}								
30 DAS	1.5	1.4	0.1	0.28	3.6	4.3	0.4	NS
Maturity	5.9	5.8	0.2	0.57	7.5	6.5	0.4	1.16
Leaf area index								
30 DAS	0.41	0.27	0.01	0.03	0.43	0.32	0.03	0.09
Maturity	0.88	0.85	0.03	0.08	1.48	1.01	0.04	0.12
Biomass (g m^{-2})								
30 DAS	55.2	46.6	1.1	3.13	73.8	60.5	2.0	5.78
60 DAS	354.0	329.2	5.4	15.38	341.0	303.0	6.3	18.21
Maturity	757.6	631.8	19.2	54.68	1124.0	981.0	12.3	35.55
Grain (kg ha^{-1})	3807	2938	97.0	276.27	5380	4530	177.0	511.62
Total DM (kg ha^{-1})	6893	5798	116.0	330.39	11240	9810	387.2	1119.20

Table 5b Comparison of the growth and yield of monocrop pigeon pea stands in 1988 and 1989

Plant parameter and sampling time	1988		SE	LSD (P = 0.05)	1989		SE	LSD (P = 0.05)
	ICPL 87	Hy3C			ICPL87	Hy3C		
Plant height (cm)								
30 DAS	36.6	33.7	1.4	NS	46.9	41.9	1.7	5.10
60 DAS	81.1	78.0	1.8	5.40	83.8	80.4	3.2	NS
No. of branches plant^{-1}								
30 DAS	0	0			1.0	1.0	0.1	NS
60 DAS	3.3	4.5	0.2	0.60	9.8	8.9	0.5	1.50
Leaf area index								
30 DAS	0.30	0.08	0.004	0.01	0.38	0.17	0.02	0.06
60 DAS	1.07	0.49	0.02	0.06	1.89	0.98	0.04	0.12
Total dry matter (g m^{-2})								
30 DAS	30.4	8.1	0.3	0.90	63.3	21.3	1.2	3.60
60 DAS	202.6	82.1	1.0	3.0	285.1	136.3	5.3	15.92
Grain (kg ha^{-1})	1835	1742	35.8	107.52	2349	1975	91.2	273.90
Total DM (kg ha^{-1})	4610	4431	86.1	258.58	7672	8520	379.0	1138.25

The trend is even more apparent in total biomass production of both rice and pigeon pea. A significantly higher (P = 0.05) rice biomass of 29-33% at 30 DAS and 48-55% at harvest was recorded in 1989 over 1988 which in turn led to significantly higher grain (41-54%) and total biomass yields (63-69%). Pigeon pea also produced significantly higher biomass during 1989 and the increase was more pronounced at 30 DAS (108-162%) than at 60 DAS (40-66%). However, the improvement in grain yields was only 13-28% while the total biomass was increased by 66-92%.

Light interception

All three crops had markedly different percentage light interception (*f*) with time (Figure 1). The decline in *f* was earliest and most pronounced in cowpea due to leaf fall after 50 DAS. Pigeon pea cv. ICPL87 showed a 20% decline in *f* from 120 to 140 DAS, reflecting the determinate nature of this cultivar compared to Hy3C (indeterminate) which had a gradual decrease in *f* from 100 to 200 DAS. Maximum *f* was relatively unaffected by intercropping (Figure 2). Pigeon pea cv. ICPL87-rice system showed a large decline in *f* when rice was harvested but there was no comparable decline in Hy3C intercrop because of compensatory growth by Hy3C.

The consequence of intercropping on light interception was analysed by the cumulated amount of radiation intercepted (IR) and the light use efficiency (LUE) during the period 30-100 DAS (Table 6). Generally the total amount of IR was increased by intercropping, ranging from 8 to 40%

with cowpea and 4 to 16% with pigeon pea, when compared to 'expected' values. This is consistent with the observation that both legumes have a higher / than rice (Figure 1), with cowpea as the most appropriate companion crop for the slow-growing rice cv. IET 7564 (IR increase = 28-40%). The LUE of the intercrops was reduced significantly by 14-42% of 'expected' except for pigeon pea cv. Hy 3C-rice IET 7613 treatment. This is not surprising as most of the radiation was intercepted by the legumes. The greatest reduction was recorded for intercrops with cowpea especially in combination with the slower growing rice cv. IET 7564. In general the LUE of rice was 1.5-2 times greater than those of legumes.

Crop performance ratios (CPR)

The relative performance of each plant in mono- and inter-crop was examined by calculating the CPR of rice and legumes for gram and total biomass and total CPR values (Table 7a and b). All legumes yielded high biomass and grain in intercrop in both years (CPR = 1.4-2.9). Thus, although the LAI of pigeon pea indicates that it represented a small fraction of the total LAI in the intercrop it was more competitive than rice. Even a short-duration legume like cowpea produced 2-2.45 times more grain than as a monocrop.

Considering the rice performance in intercrop with legumes, CPR values for grain and total biomass were greater than 1.0 with pigeon pea cv. ICPL87 in both years. In contrast, CPR of the pigeon pea cv. Hy3C-rice system was generally less than 1 except for IET7564 in 1988. Cowpea cv. GC2-rice intercrop produced higher rice CPR than either EC 6216 or cv. Russian giant.

Generally total CPR values are lower than total LER (Tables, 4 and 7). For example, the total LER of cowpea cv. EC 6216-rice system gave an advantage of 19-21% and 40-49% during 1988 and 1989, respectively, whereas total CPR values were always less than 1.0. Similarly the Hy3C-rice system during 1989 also indicated no biological advantage in terms of total CPR, but appears to be quite advantageous in yield (25-54%) when total LER is considered. Nevertheless the most appropriate legume genotype for intercropping (for both total LER and total CPR) was pigeon pea cv. ICPL87, followed by cowpea cv. GC2.

Discussion

The results of this study have shown that intercropping upland rice with grain legumes need not necessarily lead to substantial yield reduction of intercrop rice for a high intercrop advantage (Table 4). Substantial reduction in intercrop rice was observed in treatments involving legumes with rapid canopy formation, *e.g.* cowpeas, or pigeon pea cv. Hy 3C with indeterminate branching habit.

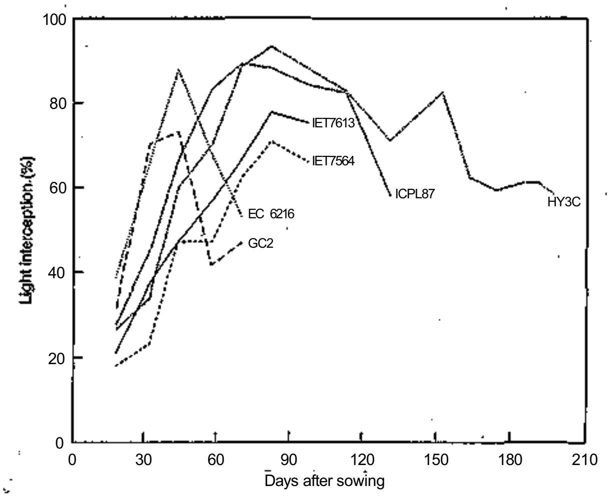

Figure 1 Light interception by monocrops of rice, cowpea, and pigeon pea cultivars at different times after sowing

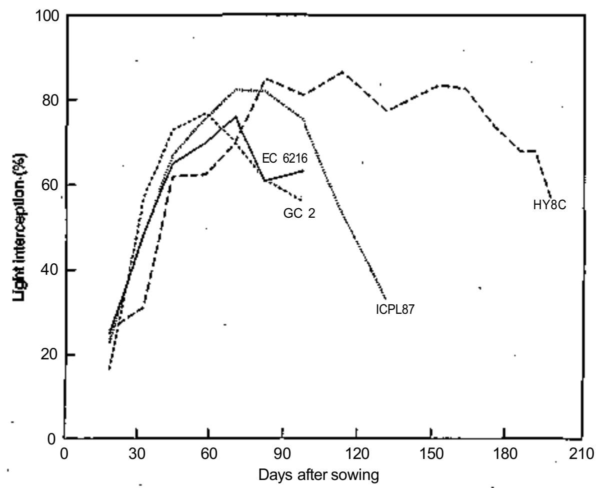

Figure 2 Light interception of cowpea and pigeon pea intercropped with rice cv. IET7613

Table 6 Accumulated intercepted radiation (IR) and light use efficiency (LUE) of mono- and inter-crops from 30 to 100 DAS, 1989

	IR (MJ m^{-2})		LUE (MJ^{-1})	
Crop	IET7613	IET7564	IET7613	IET7564
Rice	776	692	1.44	1.42
Rice-cowpea				
EC 6216	830 (769)	899 (703)	1.20 (1.40)	0.80 (1.37)
GC2	845 (740)	923 (654)	0.90 (1.37)	0.81 (1.34)
Rice-pigeon pea				
ICPL87	928 (895)	906 (809)	0.92 (1.38)	1.05 (1.35)
Hy3C	860 (844)	909 (779)	1.27 (1.26)	1.01 (1.25)
Monocrop cowpea				
EC 6216	492		0.80	
GC2	374		0.68	
Monocrop pigeon pea				
ICPL87	997		0.72	
Hy3C	954		0.96	

Expected values are presented in parentheses

Table 7a Crop performance ratios for grain yields during 1988 and 1989

	Rice		Legume		Total CPR	
Crop	A	B	A	B	A	B
			1988			
Rice - cowpea						
EC 6216	0.78	0.70	2.25	2.45	0.86	0.82
Russian giant	0.57	0.47	2.02	2.09	0.67	0.60
Rice-pigeon pea						
ICPL87	1.03	1.08'	2.25	2.30	1.18	1.28
Hy3C	0.88	1.00	1.65	1.82	1.04	1.22
			1989			
Rice-cowpea						
EC 6216	0.85	0.86	3.18	2.76	0.98	0.98
GC2	1.15	1.16	1.43	1.48	1.16	1.18
Rice-pigeon pea						
ICPL87	1.07	1.05	2.96	2.57	1.29	1.25
Hy3C	0.52	0.63	1.63	2.04	0.72	0.92

A, IET 7613; B, IET 7564

Table 7b Crop performance ratios for total dry. matter as influenced by intercropping during 1988 and 1989

	Rice		Legume		Total CPR	
Crop	A	B	A	B	A	B
			1988			
Rice-cowpea						
EC 6216	0.85	0.77	1.80	2.17	0.93	0.91
Russian giant	0.69	0.60	1.76	1.78	0.81	0.76
Rice-pigeon pea						
ICPL87	1.04	1.08	2.09	2.36	1.22	1.32
Hy3C	0.91	1.06	1.78	1.69	1.15	1.26
			1989			
Rice-cowpea						
EC 6216	0.86	0.93	2.89	2.49	1.06	1.10
GC2	1.05	1.16	1.88	1.67	1.11	1.20
Rice-pigeon pea						
ICPL87	1.04	1.00	2.32	2.31	1.26	1.25
Hy3C	0.60	0.70	1.55	1.88	0.90	1.11

A, IET 7613; B, IET 7564

These results contrast with the reports of Parida *et al.* (1988) and Singh *et a\.* (1988). They showed that intercrop rice is less competitive. A possible explanation may be the drainage properties of the soil types because in their studies the soils were generally sandy loam with low water-holding capacity which would favour the growth of legumes more than that of upland rice. In the present study the Vertisols have a high water-holding capacity so that even with the lower rainfall, growth of rice was less limited by drought than in the sandy loam soils. Another factor is the canopy structure of the legumes used in the various studies which is discussed later.

Although upland rice has a high growth rate, the erect leaf arrangement delays the closure of the canopy compared to legumes such as cowpea (Figure 1). Therefore intercropping with these legumes increased energy interception during the early phase of rice. This exceeded the expected interception because legumes such as cowpea can compensate for the low population in the intercrop (Table 6). The cowpea-rice system is an example of the spatial complementarity intercrop system (Reddy and Willey, 1981) but unlike the groundnut-pearl millet system there was no enhanced conversion of intercepted radiation to dry matter. This is not surprising since the legume canopy was formed at or above the rice canopy and therefore intercepted more of the incident radiation. In the groundnut - pearl millet system the legume canopy represents the understorey of the intercrop canopy.

Pigeon pea-rice systems gave the largest yield advantages among all the systems examined but intercrop with pigeon pea cv. Hy3C was less stable than with cv. ICPL87. Pigeon pea-rice systems also demonstrated some spatial complementarity in that the total intercepted radiation was higher than expected during the period of rice growth but the increases were less than that observed for cowpea-rice systems. As in cowpea-rice systems there was no evidence of an increase in the conversion of intercepted radiation to dry matter. As pigeon pea continued to grow for 50 to 80 days after the harvest of rice, the pigeon pea-rice system can be considered to demonstrate temporal complementarity in resource use as well. Like the sorghum - pigeon pea system described by Natarajan and Willey (1979) more radiation is intercepted by the pigeon pea-rice system, but the rice canopy is less dominant than the sorghum canopy in their respective intercrops with pigeon pea; for example, canopy formation of rice was so slow that it intercepted 80% of the incident radiation at 100 DAS compared to 42 DAS by sorghum in the investigation by Natarajan and Willey (1980). In comparison, the monocrop pigeon pea intercepted 50% of the incident radiation at about 50 DAS in both studies.

The choice of rice cvs. IET 7613 or IET 7564 is less important than the choice of legume cultivars in terms of LER (Table 4) or CPR (Table 7). This is surprising since there were considerable differences in the stature and LAI of the two rice cultivars. Only in intercrops involving Hy3C was there a significant difference in the LER due to rice cultivars, with the taller IET 7564 giving a higher LER or CPR in both years. The higher intercrop advantage of IET 7564 was partly due to a smaller variation in intercrop yield of rice and partly due to a greater compensation by pigeon pea with IET 7564. The limited evidence indicates that with long-duration indeterminate legumes the choice' of rice cultivars may be important for maximizing intercrop advantage.

Canopy structure as determined by the branching habit of the legume appears to be also crucial in determining the competition between the legume arid upland rice; for example, the partial LER of intercrop rice was reduced by the indeterminate cowpea cv. Russian giant to only about half of the expected value compared *to* the determinate cultivars such as EC 6216 and GC2. Similarly, in the second year the partial LER of intercrop rice was reduced by the indeterminate pigeon pea cv. Hy3C to about half of the expected value when conditions were favourable for the growth of legumes. It is therefore not surprising that previous reports of excessive competition of pigeon pea with upland rice consisted of indeterminate pigeon pea cultivars. On the other hand, the determinate pigeon pea cv. ICPL87 was consistently less competitive with intercrop rice in both years. However, further work on a wider range of determinate and indeterminate cultivars is required to determine whether this hypothesis is valid for other situations.

Seasonal effects on the response of both rice and legumes to intercropping were substantial, although irrigation was provided in 1989 to supplement the water deficit during the early and later phases of rice growth. Cowpea cv. EC 6216-rice intercrop gave a higher total LER in 1989 largely due to an increased contribution (more than double of 'expected') from cowpea while maintaining the yield of intercrop rice. A similar observation was reported by Torres *et al.* (1988) who examined 50 cowpea cultivars intercropped with upland rice in the Philippines. A mean LER of 1.37 was observed and intercropped cowpea produced twice its expected yield without competing with upland rice. The higher irradiance in 1989 was favourable to the growth of both legumes and rice as shown by the considerable increase in their biomass. There was no evidence that the legumes performed significantly better in the intercrops except for cowpea cv. EC 6216 in 1989; for example, mean CPR values for intercrop Hy3C was 1.73 in 1988 and 1.72 in 1989. Instead the evidence showed that intercrop rice suffered more in this system which declined from a mean CPR of 0.99 in 1988 to 0.65 in 1989. Although no measurements of water stress was made in the study, it is postulated that the intercrop rice was unable to compete for moisture with pigeon pea because the roots of upland rice are shallow (Gomathinayagam and Soundarapandian, 1987).

This study shows that there is considerable scope to improve the stability and productivity of legume - upland rice intercrop through a selection of appropriate legumes especially with determinate branching, and by the use of rice cultivars with deep roots. However, further work is required to determine the interaction between rice and legumes on soils with low water-holding capacity which is more typical of the areas where upland rice is mostly grown.

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