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EFFECTS OF GENOTYPE IN CEREAL/PIGEONPEA INTERCROPPING ON THE ALFISOLS OF THE SEMI-ARID TROPICS OF INDIA†

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SUMMARY

In a 2 row cereal:1 row pigeonpea intercropping system, four sorghum and two millet genotypes were examined with four of pigeonpea on a medium-deep Alfisol during 1978 and 1979. The cereals usually produced a large proportion of their sole crop yields. Millets matured relatively early which allowed large yields of later-maturing pigeonpea. A tall millet gave the best total Land Equivalent Ratio (LER) of 1.78 and most monetary returns. Early and/or short sorghums produced large LERs (1.51–1.59) and combinations with an early hybrid also gave good returns. A tall late sorghum gave poor yields of both components, smallest total LER (1.30), and little return. Pigeonpea intercrop yields became larger as the maturity difference between the cereal and pigeonpea increased. A combination of a short, early but large-yielding cereal with a pigeonpea that is as late as possible without incurring undue risk of moisture stress may be ideal.

Cereal/pigeonpea (*Cajanus cajan*) intercropping is practised widely as a rainfed system in those areas of the Indian semi-arid tropics where the annual rainfall lies within the range of 500–1000 mm and the rainy season is about 3–4 months long; typical areas are the Deccan plateau and parts of Central India. Sorghum (*Sorghum bicolor*) is the predominant cereal but gives way to pearl millet (*Pennisetum typhoides*) in the lower rainfall areas with lighter and shallower soils.

The cereal is regarded traditionally as the more important of the two crops and for this component the farmer usually tries to achieve an intercrop yield similar to that of a sole crop. This is possible because the traditional cereal genotypes are tall, late-maturing (4–5 months) and very competitive, and they are sown as a very large proportion of the system. The pigeonpea is later-maturing (5–8 months) and particularly well-adapted to utilizing residual soil moisture after cereal harvest. With this component the objective is usually to produce a 'bonus' pulse yield without jeopardizing the cereal yield. In traditional systems pigeonpea yields are very small but studies have shown that they can be increased substantially, with little or no reduction in cereal yield, if the proportion of pigeonpea sown is increased and both crops are sown at their full sole crop population (Freyman and Venkateswarlu, 1977; Natarajan and Willey, 1980; Rao and Willey, 1980; Shelke, 1977).

Larger yields can also be achieved in these cereal/pigeonpea systems by using

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improved genotypes, even though such genotypes have seldom been developed specifically for intercropping. Improved cereal genotypes with larger yield potentials can substantially increase the cereal yield, and evidence from studies on other crop combinations suggests that shorter stature (Andrews, 1974) and/or earlier maturity (Baker, 1979; IRRI, 1977) could be less competitive on the pigeonpea. Yield increases from improved pigeonpea genotypes are less certain. These mature earlier than the traditional types, which may be beneficial under conditions of limited soil moisture storage, but allow less time after cereal harvest for the pigeonpea to recover from the cereal competition.

Most of the studies reported on cereal/pigeonpea intercropping have used improved genotypes. Many have reported large intercropping advantages, but there is need for a much clearer definition of the plant characters required. The objective of the present study was to explore a range of genotypes of both components to try to quantify the effects of the major characters likely to be important.

MATERIALS AND METHODS

The experiments were conducted for two years during the rainy seasons of 1978 and 1979 on a medium-deep Alfisol, which has an available soil moisture storage capacity of about 100 mm and is generally poor in fertility (57, 10 and 200 ppm of available N, P and K, respectively). Four pigeonpea genotypes of different maturity and growth habit were combined with four sorghum genotypes of different height and maturity and two pearl millet genotypes of different height (Table 1). The experiment was conducted in a strip-plot design

Table 1. *Characteristics of pigeonpea, sorghum and millet genotypes*

		1978–79		1979–80	
Crop species and genotypes	Plant type	Height (cm)	Maturity (days)	Height (cm)	Maturity (days)
Pigeonpeas					
HY-2	Semi-compact	1.73	151	1.67	150
ICP-1-6	Semi-spreading	1.59	174	1.74	152
PM-1	Spreading	1.65	174	1.88	160
PS-41	Spreading	1.64	233	1.73	190
Sorghums					
M-35652		1.31	90	1.40	99
CS-3541		1.40	114	1.25	119
CSH-6		1.80	100	1.70	100
E-35-1		2.00	114	1.90	119
Millets					
IVS-A75		1.70	90	1.67	83
GAM-73 C1 or GAM-73 K77†		1.14	90	1.15	83

†GAM-73 C1 was used in 1978 and GAM-73 K77 in 1979.

(Cochran and Cox, 1964) where strips of sorghum and millet genotypes were randomized across strips of pigeonpea genotypes. A *no cereal* strip was included to provide sole plots of pigeonpea and a *no pigeonpea* strip to provide sole plots of cereals. There were three replicates.

The intercrops were sown as 2 row cereal: 1 row pigeonpea in 45 cm rows. Sole crop cereals were also sown in 45 cm rows but sole crop pigeonpea was sown in 90 cm rows during 1978 and 135 cm rows in 1979. Wider rows were used in 1979 for convenience of machine sowing because it allowed pigeonpea rows to be sown as continuous lines through both sole and intercrop plots. (Earlier studies have shown no loss in yield at this wider spacing; ICRISAT, 1976; AICRPDA, 1976). Full sole crop populations were used for both sole and intercrop treatments (167,000 plants ha^{-1} for sorghum or millet, and 40,000 plants ha^{-1} for pigeonpea) so that total populations were *additive* in the intercrop situation. Harvest areas were 21.6 m^2 in 1978 and 18.9 m^2 in 1979.

The experiments were sown on 14 July 1978 and 11 July 1979. All plots were fertilized with a basal application of 18 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1}. The cereals were top dressed with 62 kg N ha^{-1} three weeks after sowing. Rainfall was high (906 mm) and well distributed during the rainy season in 1978, but low (650 mm) and poorly distributed in 1979. The experiment was rainfed except for a minimal 20 mm irrigation given at 46 days after sowing in 1979, when there was a severe mid-season drought and considerable risk of losing the experiment. Weeds were controlled by two hand weedings but sole crop pigeonpea required an additional weeding. Sorghum plants were protected from shootfly depradations by soil application of 40 kg ha^{-1} of 3% Carbofuron at sowing, and pigeonpeas were sprayed twice with 0.35% Endosulphan to control pod borers. For grain and straw yields the cereal and pigeonpea components were analysed separately but they were combined for analysis of total LER and monetary returns.

RESULTS

Cereal yields

The tall early sorghum CSH-6 produced the largest grain yield in sole cropping in both years, followed by the short early sorghum M-35652 (Tables 2 and 3). The ranking of the other cereals in sole cropping differed between years. In the high rainfall year of 1978 the short late sorghum CS-3541 and the tall millet IVS-A75 gave comparable yields while the tall late sorghum E-35-1 and the short millet GAM-73 gave rather less. In the drier year of 1979 the yield of both millet genotypes was larger than in 1978 but the yield of the tall late sorghum E-35-1 was drastically reduced because of severe end-of-season moisture stress.

In 1978, the maximum yield loss due to intercropping for any cereal genotype was only 13% when averaged over all pigeonpea genotypes, supporting

Table 2. *Seed and straw or stalk yields (kg ha^{-1}) of cereals and pigeonpeas in sole crops and intercrops for 1978*

	Pigeonpea genotypes										
	HY-2		ICP-1-6		PM-1		PS-41		Means		
Cereal genotypes	Cereal	Pigeon-pea	Cereal	Pigeon-pea	Cereal	Pigeon-pea	Cereal	Pigeon-pea	Cereal	Pigeon-pea	Sole cereal
M-35652	2865	666	2886	749	2860	855	2862	965	2868	809	2959
	(3523)†	(2241)	(3760)	(3028)	(3555)	(2805)	(3778)	(3315)	(3654)	(2847)	(4216)
CS-3541	2162	546	2007	567	1985	660	1913	899	2017	668	2332
	(3824)	(2005)	(3278)	(2736)	(3347)	(2430)	(3203)	(3199)	(3413)	(2593)	(3792)
CSH-6	3492	484	3479	537	3525	566	3364	954	3465	635	3605
	(4347)	(1829)	(4349)	(2486)	(4417)	(2204)	(4259)	(3106)	(4343)	(2406)	(4630)
E-35-1	1535	288	1554	248	1649	346	1582	527	1580	352	1685
	(7403)	(1324)	(7755)	(1495)	(8056)	(1570)	(8028)	(2157)	(7810)	(1636)	(8530)
IVS-A75	2228	597	2168	813	2309	690	2250	915	2239	754	2167
	(3472)	(2296)	(3495)	(2958)	(3704)	(2176)	(3273)	(3190)	(3486)	(2655)	(3606)
GAM-73	1275	679	1525	813	1454	789	1630	967	1471	812	1630
	(2139)	(2352)	(2407)	(3106)	(2037)	(2602)	(2722)	(3236)	(2326)	(2824)	(2833)
Mean	2260	543	2270	621	2297	651	2267	871			2396
	(4118)	(2007)	(4174)	(2635)	(4186)	(2298	(4210)	(3017)			(4601)
Sole pigeonpea		1097		1141		1193		1232		1166	
		(3375)		(4486)		(3231)		(4912)		(4001)	

	SE treatment	LSD (0.05) genotype means	
		Cereal	Pigeonpea
Cereal	169	464	–
	(307)	(729)	(391)
Pigeonpea	62	214	90
	(251)	(565)	(399)

† Figures in parentheses are straw/stalk yields.

the indications from other studies that very large proportional yields of cereals can be obtained from these systems. However, in the drier year of 1979 intercropping caused some reductions in the early sorghums (23% for M-35652; 19% for CSH-6) and in the short millet (20% for GAM-73), probably because the pigeonpea, being very well-adapted to low moisture situations, was relatively more competitive in this drier year. There was little difference between pigeonpea genotypes in their effect on cereal yield: the average reduction across all cereals was 5% for PM-1, 9% for HY-2, and 10% for both ICP-1-6 and PS-41.

Straw yield (Table 2) was roughly proportional to genotype height. The tall late sorghum E-35-1 was by far the best yielder, followed by the tall early CSH-6; yield was least for the short millet GAM-73. In intercropping, the effects on straw yields were similar to those on grain yields.

Pigeonpea yields

Sole crop yields were good in both years. In 1978 (Table 2) differences between genotypes were small but there was a slight increase in yield with

Table 3. *Seed and straw or stalk yields (kg ha^{-1}) of cereals and pigeonpeas in sole crops and intercrops for 1979*

	Pigeonpea genotypes										
	HY-2		ICP-1-6		PM-1		PS-41		Means		
Cereal genotypes	Cereal	Pigeonpea	Cereal	Pigeonpea	Cereal	Pigeonpea	Cereal	Pigeonpea	Cereal	Pigeonpea	Sole cereal
M-35652	2286	852	2513	1010	2466	858	2159	740	2356	865	3005
	(2134)†	(1938)	(2110)	(2473)	(2527)	(2096)	(2078)	(2851)	(2212)	(2340)	(3600)
CS-3541	1942	878	1925	1053	2256	1063	1915	885	2009	970	2007
	(3403)	(2265)	(3043)	(2761)	(3619)	(2693)	(3034)	(2799)	(3274)	(2630)	(3568)
CSH-6	3450	720	3620	1058	3809	843	3434	979	3578	900	4392
	(3371)	(1700)	(3338)	(2685)	(3655)	(1984)	(3650)	(2876)	(3503)	(2311)	(4959)
E-35-1	275	417	238	540	291	497	217	624	255	520	265
	(8060)	(1092)	(7798)	(1593)	(8474)	(1587)	(8457)	(1684)	(8197)	(1489)	(8631)
IVS-A75	2995	1042	3042	1344	2910	1107	3063	1212	3003	1176	3132
	(2773)	(1952)	(2872)	(2970)	(2718)	(2427)	(2884)	(3354)	(2812)	(2676)	(3033)
GAM-73	2005	1058	2069	1280	2039	1209	1889	1063	2001	1153	2486
	(1992)	(2060)	(1988)	(2590)	(2131)	(2595)	(1963)	(3190)	(2019)	(2609)	(2176)
Mean	2159	828	2235	1048	2295	930	2113	917			2548
	(3622)	(1835)	(3525)	(2512)	(3854)	(2230)	(3677)	(2792)			(4328)
Sole pigeonpea		1251		1381		1635		1021		1322	
		(3211)		(3519)		(4443)		(3724)		(3724)	

	SE treatment	LSD (0.05) genotype means	
		Cereal	Pigeonpea
Cereal	128	448	242
	(263)	(1012)	(306)
Pigeonpea	101	346	119
	(305)	(988)	(220)

† Figures in parentheses are straw/stalk yields.

change from the earlier semi-compact type (HY-2) to the late spreading one (PS-41). This change in plant type also produced an increase in the proportional yields in intercropping (49% to 71%), so that absolute yields in intercropping increased quite markedly, from 543 to 871 kg ha^{-1}. In 1979 (Table 3), the drier conditions favoured the three earlier pigeonpea genotypes, and their yields were larger than in the previous year, but yield of the late PS-41 decreased because of severe end-of-season moisture stress. Proportional yields in intercropping were larger in this year for all genotypes and, again, they tended to increase from the earlier semi-compact plant type to the late spreading one; absolute yields in intercropping were largest for ICP-1-6 and PS-41, and smallest for HY-2.

The effect of cereal genotype on pigeonpea was similar in both years. Pigeonpea seed yield was reduced less by the millet genotypes than by the sorghums, presumably because the millets matured earlier. There was no difference between the two millets, indicating that at this early maturity height was not important. The early short sorghum M-35652 was similar to the millets in 1978, when its maturity was also similar, but it was more competitive in 1979, when it was rather later to mature. The early tall sorghum CSH-6 was more competitive than the late short CS-3541, suggesting that height was more important in sorghum than in millet, perhaps because of the sorghum's later maturity. The tall late sorghum E-35-1 was by far the most competitive of all the cereal genotypes; averaged over all pigeonpea genotypes, across both years, the proportional pigeonpea yield with this genotype was only 35% compared with 77% for the early short millet GAM-73. Stalk yields of pigeonpea followed a pattern similar to that of seed yields (Tables 2 and 3).

Land Equivalent Ratios

The combined effects on cereal and pigeonpea seed yields are summarized in Fig. 1 as Land Equivalent Ratios (LERs – i.e. intercrop yields expressed relative to sole crop yields). Error variances for this parameter were homogenous across years and so results are presented as means of the two years.

The combinations with the millet genotypes gave the largest total LERs because of the large relative yields of millet and their relatively small competitive effect on the pigeonpea. Averaged across all pigeonpea genotypes, the tall IVS-A75 gave a larger total LER (1.78) than the short GAM-73 (1.64) because the latter did not maintain its own yield quite so well in intercropping. With the sorghum genotypes, total LER was similar for M-35652 (mean 1.56) and CS-3541 (mean 1.59), but was slightly smaller for CSH-6 (mean 1.51); all these genotypes gave large total LERs because they maintained large sorghum yields in intercropping, while also allowing a relatively good pigeonpea contribution. Although the tall late sorghum E-35-1 maintained the best relative yield of sorghum in intercropping (mean 0.95), it gave the smallest total LER (mean 1.30) because its competitive nature resulted in a poor pigeonpea contribution (0.35).

For the mean effect of pigeonpea genotypes, differences in total LER largely reflected the differences in pigeonpea performance described above. Averaged across cereal genotypes, the late spreading PS-41 gave the best total LER of 1.70 (pigeonpea 0.80), compared with 1.56 for the semi-spreading ICP-1-6 (pigeonpea 0.66), 1.51 for the spreading PM-1 (pigeonpea 0.56), and 1.49 for the semi-compact HY-2 (pigeonpea 0.58).

Monetary returns

Monetary returns were calculated from prices prevailing during the experimental period, including values for the cereal straw, which is a valuable fodder (especially the sorghum) and for the pigeonpea stalks, which are used for fencing, basket-making and fuel. Net monetary returns were calculated by deducting the variable costs for seed, fertilizer, plant protection sprays and labour (the last item being estimated from operational-scale plots at ICRISAT Center).

For any of the cereals, intercropping with pigeonpea gave a large increase in

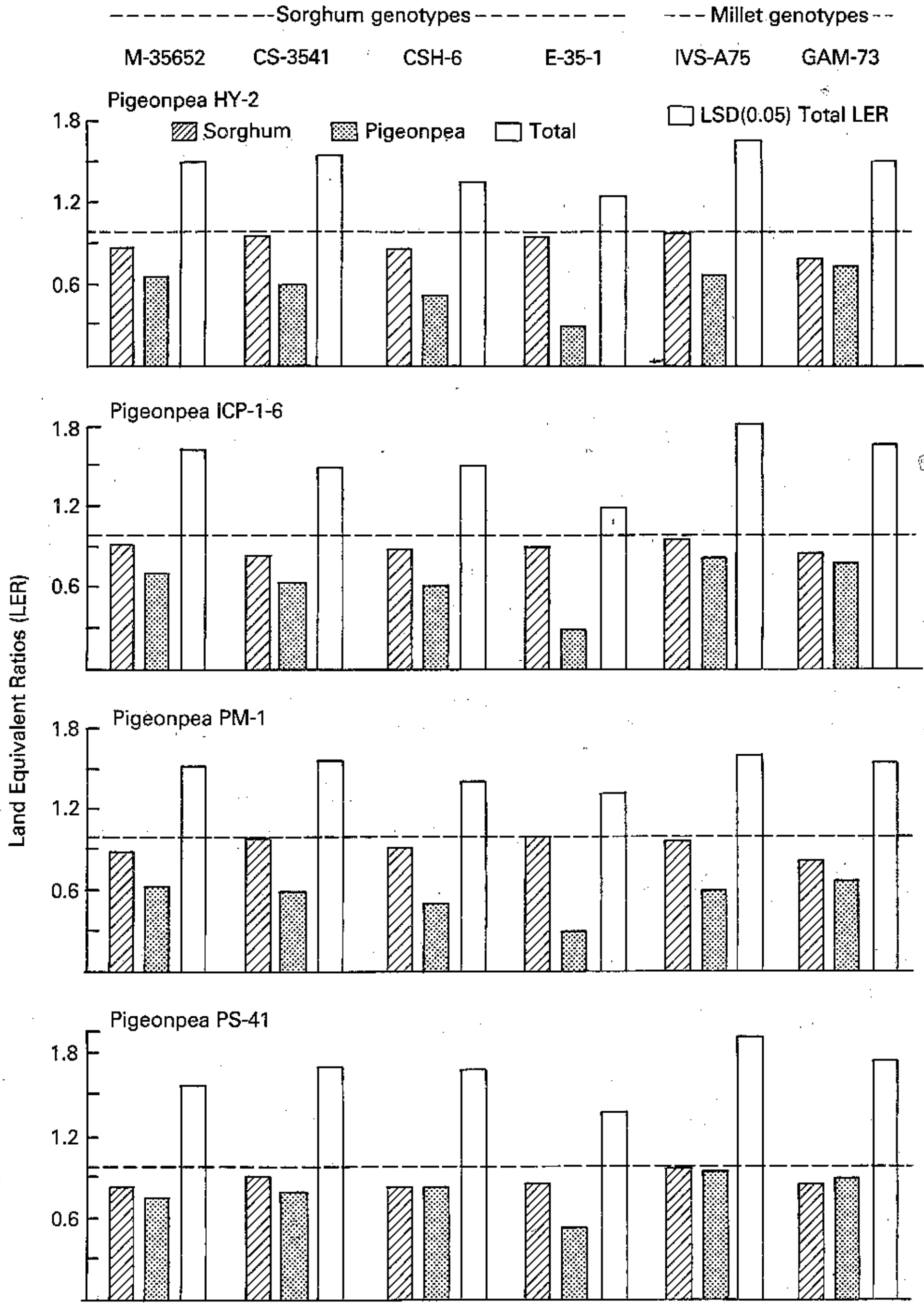

Fig. 1. Land Equivalent Ratios for different genotype combinations in cereal/pigeonpea intercropping.

net monetary returns compared with sole cropping (Fig. 2), emphasizing the widespread usefulness of adding a pigeonpea intercrop to sole cereal systems under semi-arid conditions in India. Conversely, compared with sole pigeonpeas, adding an earlier cereal gave a useful increase in net returns, but adding the short late CS-3541 gave only a small increase and adding the tall late E-35-1 decreased net returns. In farming practice there is increasing interest in sole crop pigeonpea systems because of the current high value of pigeonpea. These results suggest that it is only worth adding a cereal intercrop to such systems if the cereal is relatively large yielding and sufficiently early to avoid severe competition with the pigeonpea.

Considering individual combinations, monetary returns were greatest for those with the millet IVS-A75 because of large total LERs and a large millet yield potential. Returns from the sorghum CSH-6 combinations were only a little smaller, despite a greater suppression of pigeonpea and smaller total LERs, because this genotype had a very large sole crop potential, both in grain and straw. For both these cereals the combinations with PS-41 and ICP-1-6 pigeonpea gave slightly better returns than with the other genotypes because of improved pigeonpea contributions; the large PS-41 contribution was due to a particularly large pigeonpea LER, while the large ICP-1-6 contribution was due to a good sole crop potential as well as a good LER. The sorghum M-35652 and millet GAM-73 combinations also gave good returns and were marginally better with ICP-1-6 pigeonpea than with PS-41. Sorghum CS-3541 combinations gave smaller returns because of the poor yield potential of this genotype. Sorghum E-35-1 combinations gave poor returns because of the small cereal yield potential and severe suppression of pigeonpea yield. (In practice 'local' genotypes, of height and maturity characteristics similar to E-35-1, usually command a price premium of 10–20% because of their preferred grain quality. But even at this improved value, the returns from the E-35-1 combination would still have been poor.)

DISCUSSION

Apart from some evidence of competition from pigeonpea in the drier year of 1979, all the cereals produced intercrop yields almost as good (87% or more) as their sole crop yields. This makes it easy to predict cereal yield in this intercropping system, but at the same time it leaves little scope for manipulating the system to increase the cereal contribution further. However, as seen above, choice of cereal species and genotype does have considerable influence on the performance of pigeonpea. Thus, the cereal required can be defined as one that gives a large yield (preferably of both grain and straw), but has little competitive effect on the pigeonpea.

Considering the sorghums first, the tall late E-35-1 type is poorly suited to the intercropping system: though straw yields may be good, grain yields are poor and competition on the pigeonpea is severe. Furthermore, this genotype

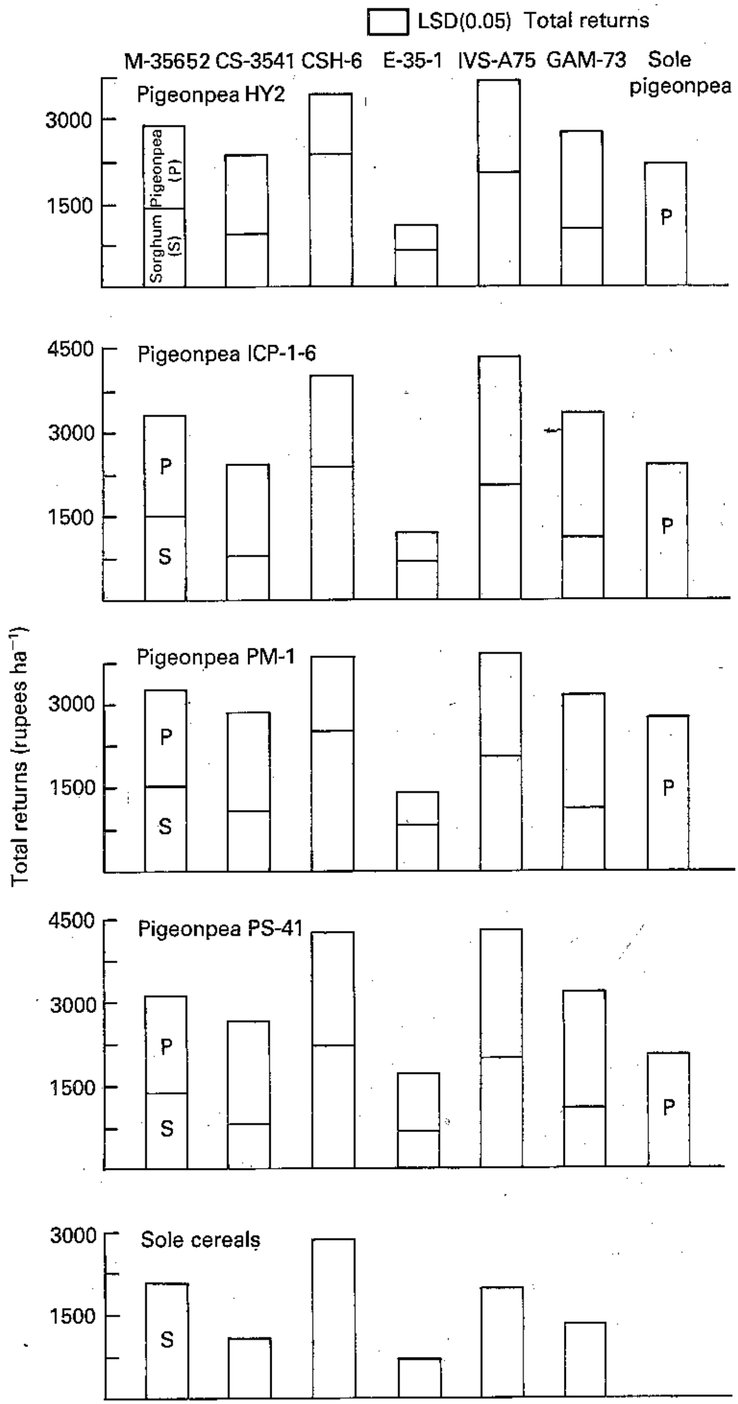

Fig. 2. Monetary returns for different genotype combinations in cereal/pigeonpea intercropping.

may involve considerable risk of end-of-season drought stress; it matures at least two weeks later than the early genotypes examined here and under conditions at ICRISAT Center, the probability of severe drought stress is greater during these two weeks than at any stage earlier in the growing period (Virmani, 1975). Thus, earlier sorghum genotypes in the 90–100 day maturity range seem much more suitable because they achieve much larger grain yields with less competitive effect on the pigeonpea. As typified by CSH-6, a reasonably tall type may be desirable because of the good straw yield, despite a possible small sacrifice in pigeonpea yield. (Within this maturity range, tolerance to grain mould is a generally desirable characteristic of sorghums in case the rains continue for longer than normal.)

The advantage of early cereal maturity is highlighted further in the millets, which proved very compatible with the pigeonpea. Of the two genotypes examined here, the taller IVS-A75 type was preferable because of its larger yield potential and slightly greater ability to maintain this potential in intercropping; at this very early maturity, height did not appear to affect pigeonpea yield. This suitability of millet as an intercrop with pigeonpea emphasizes its possible importance as an alternative to sorghum, in addition to its potential on lighter soils and in the lower rainfall areas. It could prove particularly useful when sowing is delayed because it is better adapted to a shortened growing season and avoids the severe problems of shootfly associated with late-sown sorghum.

The effects of cereal height and maturity were examined in more detail by fitting multiple regressions of pigeonpea LER on the height difference (HD) and maturity difference (MD) between the two crops (maturity difference was defined as the proportion of the pigeonpea growing period that remained after cereal harvest). The fit was better in 1978 (Pigeonpea LER = 0.05 + 0.111 MD + 0.030 HD: $R^2 = 0.83^{**}$) than in 1979 (Pigeonpea LER = 0.043 + 0.015 MD + 0.003 HD: $R^2 = 0.58^{**}$); in both years maturity differences were more important than those in height.

The effect of maturity difference alone is illustrated in Fig. 3, which shows increasing pigeonpea LER with increase in maturity difference. The benefits of increasing maturity difference, by using an earlier cereal, were emphasized above, but the scope for delaying the maturity of the pigeonpea also needs to be considered. The performance of PS-41 illustrates some of the dangers of a late pigeonpea. This gave consistently large LERs, and in the wet year of 1978 the best absolute yields in both sole cropping and intercropping. But in the dry 1979 it suffered from late moisture stress, giving the smallest sole crop yield and an intercrop yield 11% less than the earlier-maturing ICP-1-6. Thus a genotype as late as PS-41 may invite risks in dry years and a somewhat earlier one, say 160–170 days, may be preferred. Put in more general terms, the pigeonpea genotype should be as late as possible to give maximum LER but not so late as to run the risk of end-of-season moisture stress.

Characters other than maturity could also have some influence on inter-

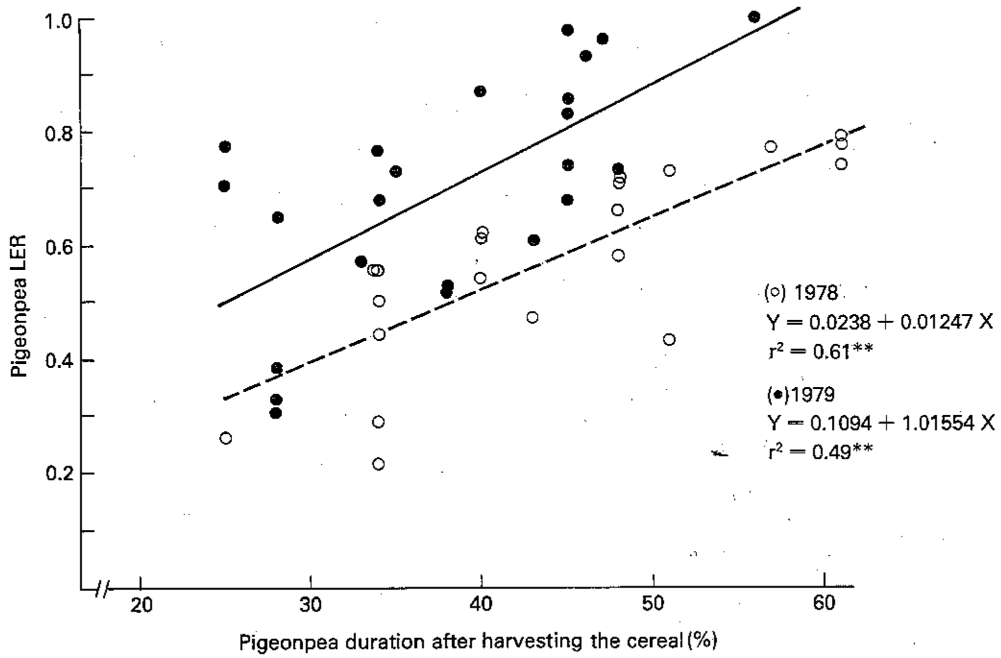

Fig. 3. Relations between pigeonpea LER and the temporal difference between cereals and pigeonpea in intercropping.

cropping performance of pigeonpea. The desirability of a spreading growth habit has been emphasized, though in the genotypes examined here this character was certainly confounded with maturity differences. Rao *et al.* (1981) have further defined this requirement to include a relatively compact growth habit in the early stages, to avoid too much suppression by sorghum, and a spreading habit rather later, about the time of cereal harvest, to make efficient use of resources thereafter. They identified both ICP-1-6 and HY-2 as having these characters to some degree, which could explain why ICP-1-6 had a larger mean LER than PM-1 despite similar maturity, and why HY-2 had a similar mean LER to PM-1 despite earlier maturity. Similarly, characters other than height and maturity could be important in the cereals; for example, the architecture of the canopy could affect competition with the pigeonpea. These more detailed characters are now being studied over a wider range of genotypes in several intercropping combinations.

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