Field Crops Research, 10 (1985) 333—346
Elsevier Science Publishers B.V., Amsterdam — Printed in The Netherlands

STUDIES ON THE EFFECTS OF CROPPING SYSTEM ON FUSARIUM WILT OF PIGEONPEA

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(Accepted 5 November 1984)

ABSTRACT

Natarajan, M., Kannaiyan, J., Willey, R.W. and Nene, Y.L., 1985. Studies on the effects of cropping system on fusarium wilt of pigeonpea. *Field Crops Res.*, 10: 333—346.

Studies on the effects of crop rotation and intercropping on the soil borne wilt [*Fusarium udum* (Butler)] of pigeonpea were conducted in a wilt-sick plot at ICRISAT Center, India, from 1979 to 1983. The wilt incidence in a continuous sole pigeonpea treatment was 64% in the year 1981 and 80—90% or more in the remaining three years. One-year breaks of sorghum and fallow produced substantial reductions in wilt incidence in the following pigeonpea crop. After two cycles of break crop followed by pigeonpea, wilt incidence was only 16% in the sorghum rotation and 31% in the fallow rotation. Averaged over these two cycles, pigeonpea seed yields were increased from only 93 kg/ha to 340 and 495 kg/ha after the sorghum and fallow breaks, respectively. A break with tobacco caused less reduction in wilt incidence than with other break crops, but pigeonpea yield was increased to 398 kg/ha. A one-year break of cotton or one year of a wilt-resistant line of pigeonpea delayed wilt development, but did not reduce final wilt incidence or significantly affect yield.

Wilt incidence increased again in the second successive pigeonpea crop after a one-year sorghum break, although it was still significantly less than that in the continuous pigeonpea. After a two-year sorghum break, the effects lasted longer, the wilt incidence being only 24% in the second successive pigeonpea crop.

Intercropping with sorghum produced a large reduction in wilt incidence in pigeonpea in the first year (down to 55%) and thereafter it stabilised at about 20—30%. Although intercropped pigeonpea yields were greater than the partial yields normally expected in intercropping, they were no higher than the sole crop yields. The reduced wilt incidence due to a sorghum intercrop was found to be consistent across 14 susceptible pigeonpea genotypes grown in another experiment, but did not occur with maize as the intercop.

INTRODUCTION

Pigeonpea (*Cajanus cajan* (L.) Millsp.) is an important grain legume crop in the semi-arid tropics of Asia, eastern Africa and Central America. In Asia and Africa it is commonly intercropped with a variety of other crops but there is increasing interest in growing it intensively as a high-

0378-4290/85/$03.30

TABLE 1

List of treatments

Treatments	Year 1 (1979)	Year 2 (1980)	Year 3 (1981)	Year 4 (1982)
Experiment 1				
(1) P—P—P—P	Pigeonpea	Pigeonpea	Pigeonpea	Pigeonpea
(2) S—P—S—P	Sorghum	Pigeonpea	Sorghum	Pigeonpea
(3) F—P—F—P	Fallow	Pigeonpea	Fallow	Pigeonpea
(4) T—P—T—P	Tobacco	Pigeonpea	Tobacco	Pigeonpea
(5) P—S—P—P	Pigeonpea	Sorghum	Pigeonpea	Pigeonpea
(6) S—S—P—P	Sorghum	Sorghum	Pigeonpea	Pigeonpea
(7) S—S—S—P	Sorghum	Sorghum	Sorghum	Pigeonpea
(8) SP—SP—SP—SP	Sorghum/pigeonpea	Sorghum/pigeonpea	Sorghum/pigeonpea	Sorghum/pigeonpea
(9) P—P1—P1—P1	Pigeonpea	Pigeonpea (ICP 1)	Pigeonpea (ICP 1)	Pigeonpea (ICP 1)
(10) P—SP1—SP1—SP1	Pigeonpea	Sorghum/pigeonpea (ICP 1)	Sorghum/pigeonpea (ICP 1)	Sorghum/pigeonpea (ICP 1)
Experiment 2				
P1—P1			Pigeonpea (ICP 1)	Pigeonpea (ICP 1)
C—P1			Cotton	Pigeonpea (ICP 1)
RP—P1			Wilt-resistant pigeonpea (ICP 8863)	Pigeonpea (ICP 1)
MP1—MP1			Maize/pigeonpea (ICP 1)	Maize/pigeonpea (ICP 1)

yielding sole crop. A number of diseases have been reported to affect pigeonpea production, among which wilt, caused by *Fusarium udum* (Butler), is one of the most important. It is particularly serious in India and eastern Africa where it is estimated to cause annual yield losses worth US$ 36.3 and 5.2 millions, respectively (Kannaiyan et al., 1981).

The wilt pathogen is soil borne. It enters the plants through the roots, affects the vascular system, and causes wilting within a few days of entry. Pigeonpea plants are prone to this disease throughout their life cycle, but are most susceptible during the reproductive stage. The loss in grain yield due to wilt depends on the stage of the crop at which the disease appears and the loss is total if wilting occurs before pod formation (Kannaiyan and Nene, 1981).

One of the ways in which this disease could be managed is by using resistant cultivars. Intensive efforts are being made, with some success, to develop high-yielding and wilt-resistant cultivars at ICRISAT Center (Nene and Kannaiyan, 1982) and elsewhere. Another important approach by which soil borne diseases such as wilt could be managed, is by the adoption of suitable cultural parctices.

There are reports in the literature that the cropping system can affect wilt incidence. Bose (1938) observed reduced wilt incidence in pigeonpea grown following tobacco. Reductions were also observed when pigeonpea was grown mixed with sorghum (Dey, 1948; Gupta, 1961) or *Crotalaria medicaginea* (Upadhyay and Bharat Rai, 1981). During disease surveys in India, Kannaiyan et al. (1981) observed less wilt in fields of pigeonpea intercropped with sorghum. These reports suggest that pigeonpea wilt might be at least partially controlled by adopting a suitable cropping system. A four-year study was conducted at the ICRISAT center specifically to examine the effects of different 'break' crops, the length of the break period, and the introduction of a cereal intercrop.

MATERIALS AND METHODS

Experiment 1

This was the main experiment, conducted over a four-year period (1979—83) on a deep black soil (Vertisol). The experiment site was a uniformly wilt-sick area developed by incorporating wilted plant material and growing susceptible cultivars for a three-year period preceding the study (Nene and Kannaiyan, 1982). It consisted of ten treatments (Table 1) in four randomised blocks. Treatment 1 was the basic reference treatment, giving the level of wilt incidence in continuous pigeonpea: the experimental period covered the fourth to seventh successive crops. The pigeonpea line was ICP 6997, which is of medium maturity (180—200 days) and wilt-susceptible.

Treatments 2, 3 and 4 examined the effects of introducing a one-year break of sorghum, fallow, or tobacco every other year. The sorghum was an early hybrid, CSH 6, of about 90 days maturity, and the tobacco was a local variety harvested 120 days after transplanting. Originally, treatments 5, 9 and 10 were intended to be the same as above treatments phased one year later to minimise seasonal effects. It was subsequently decided that much more information would be gained by converting these plots to other treatments (see below).

Treatments 6 and 7 allowed examination of longer breaks of two and three years, using sorghum as the break crop. After the first year of the experiment treatment 5 was modified so that, in conjunction with treatment 6, break crop effects could be examined on the first and second successive pigeonpea crops after a one-year and a two-year break.

To examine the effects of intercropping on wilt incidence, treatment 8 was set up as a continuous sorghum/pigeonpea intercop: the sorghum was again the hybrid CSH 6. After the first year it was found that the ICP 6997 pigeonpea was not particularly well adapted to intercropping because it had poor ability to recover from the early sorghum competition. Treatments 9 and 10 were therefore changed to a further sole versus intercropping comparison using the medium-maturity, wilt-susceptible ICP 1 pigeonpea, which in other studies had been found to have quite good intercropping performance (Natarajan and Willey, 1980).

To facilitate drainage the experimental area was laid out in a broad bed and furrow system with 135 cm between furrow bottoms. Each plot was 6.75 m wide (five beds) and 9 m long. Plots were separated by a 1-m border, with provision to divert excess rain water from each plot into a drain to avoid plot to plot contamination. Preparatory tillage on the beds was done in all years with a bullock-drawn tool carrier with its wheels passing along the furrows. The tool carrier was lifted and the equipment was cleaned of soil and crop residues at the end of each plot to prevent contamination between the plots.

Pigeonpeas were grown in one row down the centre of each bed at a recommended optimum population density of 50 000 plants/ha. As a break crop sorghum was grown in three rows per bed at a recommended optimum population density of 180 000 plants/ha; in intercropping, the same overall sorghum population was maintained, but the crop was grown in two rows per bed, each 45 cm from the pigeonpea row on either side. The tobacco was a local variety and was grown in two rows per bed 90 cm apart and at a population density of 18 000 plants/ha. A basal fertiliser dressing of a 48 kg/ha of P_2O_5 was applied to all plots each year and N was top-dressed at 80 kg/ha to sorghum (in sole and intercropping) and to tobacco.

Two or three sprays of endosulfan (700 g active ingredient/ha), depending on the severity of the insect pest problem, were given to sorghum and pigeonpea, mainly against headworm and podborer (*Heliothis* spp). No fungicide was applied to any of the crops.

Grain yield, total dry matter and the number of wilted plants were recorded on an area of 28.35 m^2 per plot (three beds × 7 m). Monthly wilt counts were made starting from 60 days after emergence of pigeonpea up to harvest and percent wilt data were analysed after arcsine transformation. All the crops were cut at ground level and the stubbles were incorporated during the next year's preparatory tillage.

Experiment 2

After the second year of Experiment 1, three further treatments were examined in a small, additional experiment using ICP 1 pigeonpea (Experiment 2, Table 1). The first was a break crop of cotton: this was included because field surveys just completed had indicated that wilt incidence was higher in cropping systems containing cotton than in those containing other crops (Kannaiyan et al., 1981). The second treatment included a break with a wilt-resistant pigeonpea to determine how this affected the survival of the pathogen in the soil. The third treatment was a maize/pigeonpea intercrop to examine whether the effects being observed from the sorghum intercrop were specific to that crop or more generally applicable to cereal intercrops; the maize genotype (Deccan 101) was of roughly similar height to the sorghum but about 15—20 days later in maturing. At this stage in the study these three treatments could not be incorporated into the main experiment. They were thus set up on an immediately adjoining area of the same wilt-sick land, which had been maintained in continuous pigeonpea during the first two years of the main study. Because they then constituted a separate experiment, a further control of continuous pigeonpea was included to provide a valid statistical comparison.

The general management of this experiment was similar to that of Experiment 1. Cotton (Hybrid H4) was grown in two rows per bed at a population density of 50 000 plants/ha; it received 80 kg/ha of N in addition to the basal dressing of 48 kg/ha of P_2O_5 and three sprays of endosulfan. Maize was grown in the same row arrangement as the sorghum, but at a population density of 55 000 plants/ha; it also received a top dressing of 80 kg/ha of N.

Experiment 3

This experiment was conducted on a red soil (Alfisol) to examine the yield performance of 16 genotypes of pigenpea when grown either as sole crops or intercropped with sorghum. However, natural wilt incidence was so high that the experiment was abandoned as a yield trial and final wilt incidence was recorded on all plots.

Because drainage is not a problem on this red soil, the crops were not grown in a bed and furrow system but row spacings, population densities, fertiliser applications, and sorghum genotype were as in Experiment 1.

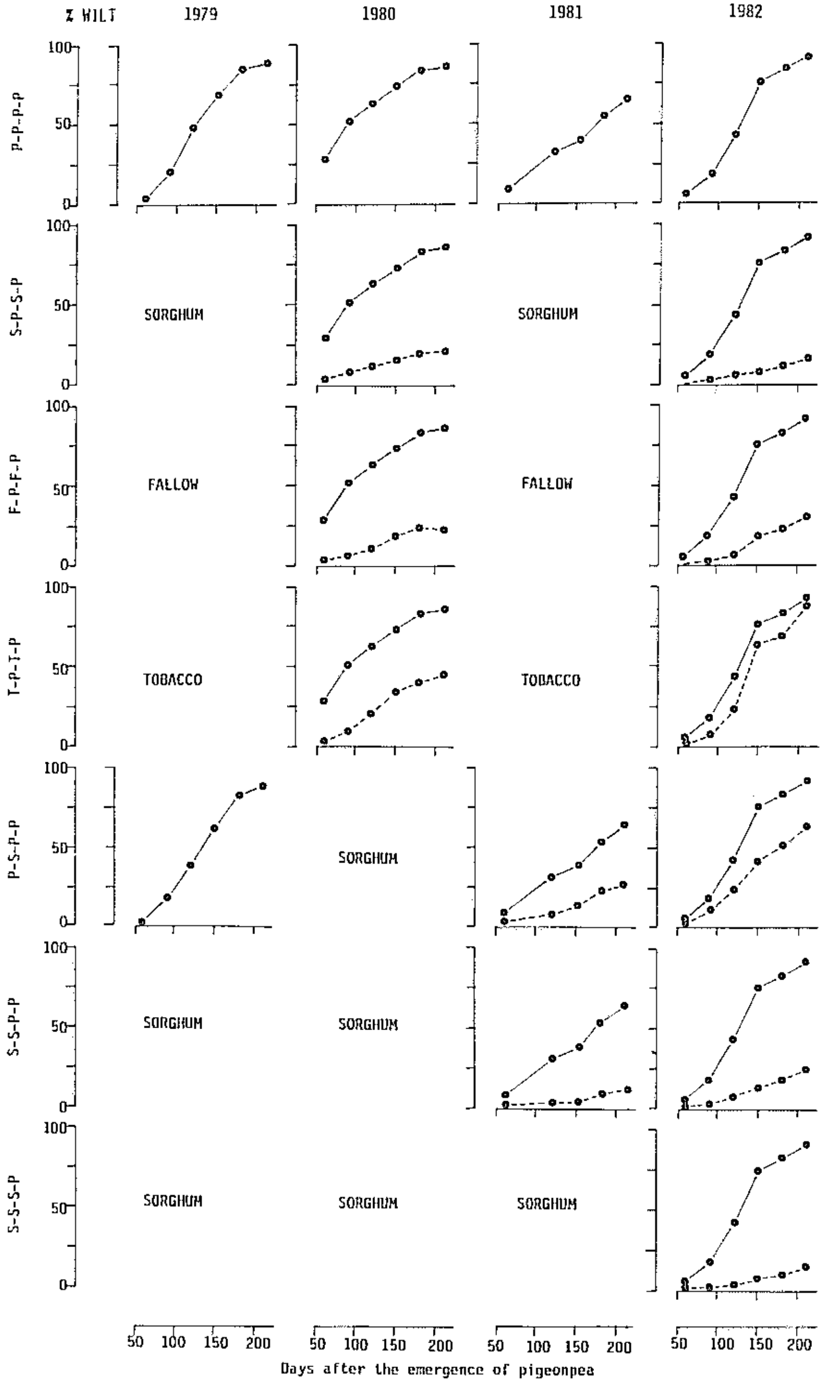

Fig. 1. Effect of different break crops and the length of the break on the patterns of wilt development in pigeonpea (o—o continuous pigeonpea, o---o pigeonpea after break).

Pigeonpea genotypes were arranged in main plots (10.8 m × 9 m) which were split for the sole versus intercrop comparison. Thus, despite the fact that the initial incidence of the wilt pathogen was almost certainly not as uniform as in the wilt-sick area created for Experiments 1 and 2, we considered that the intercropping effect could still be estimated reasonably accurately from the very local sub-plot comparison.

RESULTS AND DISCUSSION

Wilt incidence for all pigeonpea control or 'test' crops in Experiments 1 and 2 is shown as the percentage of plants that became infected during the course of the season (Figs. 1 and 2). In all seasons final incidence in the continuous pigeonpea treatment was high; it was least in 1981 in Experiment 1 at 64%, but in all other situations it was 80—90% or more. In general, the growth of all break crops and intercrops was good.

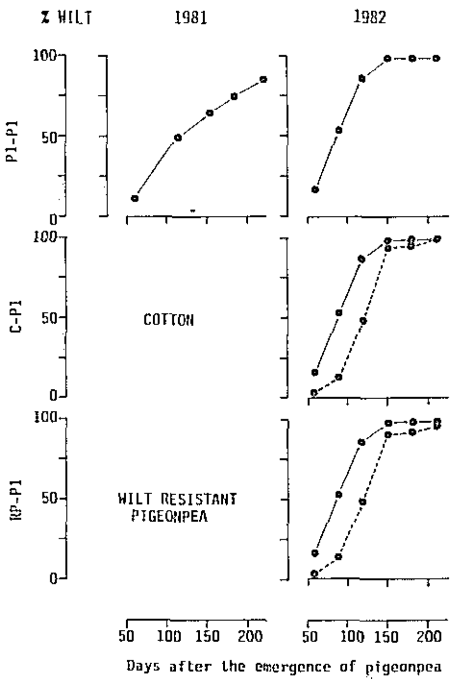

Fig. 2. Effect of break by cotton and a resistant line of pigeonpea on the wilt development in pigeonpea (o—o continuous pigeonpea, o---o pigeonpea after break).

The effects of break crops

In the first two-year period of Experiment 1, the one-year breaks of sorghum, fallow, and tobacco all produced substantial reductions in wilt in-

TABLE 2

Grain yield, total dry matter (TDM), harvest index (HI) and wilt at the time of harvest, in pigeonpea as influenced by different break crops and intercrops

Treatment	Year 1 (1979)				Year 2 (1980)				Year 3 (1981)				Year 4 (1982)			
	Grain (kg/ha)	TDM (kg/ha)	HI %	Wilt (%)	Grain (kg/ha)	TDM (kg/ha)	HI %	Wilt (%)	Grain (kg/ha)	TDM (kg/ha)	HI %	Wilt (%)	Grain (kg/ha)	TDM (kg/ha)	HI %	Wilt (%)
Break crops																
P—P—P—P	433	2266	19	86a	102	622	16	85c	113	800	14	64b	84	1113	7	91c
S—P—S—P	—	—	—	—	333	1425	23	20a	—	—	—	—	348	1485	23	16a
F—P—F—P	—	—	—	—	349	1493	24	22a	—	—	—	—	641	2725	24	31a
T—P—T—P	—	—	—	—	533	2541	21	44b	—	—	—	—	262	2236	12	87c
P—S—P—P	—	—	—	—	—	—	—	—	187	963	19	27a	198	1010	21	62b
S—S—P—P	—	—	—	—	—	—	—	—	336	1456	22	11a	351	1619	22	24a
S—S—S—P	—	—	—	—	—	—	—	—	—	—	—	—	611	2628	24	15a
P1—P1	—	—	—	—	—	—	—	—	355	1708	15	85A	113	1236	9	98A
C—P1	—	—	—	—	—	—	—	—	—	—	—	—	63	2042	3	98A
RP—P1	—	—	—	—	—	—	—	—	—	—	—	—	223	2494	9	95A
Intercropping																
SP—SP—SP—SP	184	695	26	55b	113	400	29	18a	84	361	22	21a	96	371	24	28a
P1—P1—P1—P1	—	—	—	—	232	1225	18	90c	179	1400	13	79b	67	969	6	98c
SP1—SP1—SP1—SP1	—	—	—	—	179	672	29	54b	116	518	22	29a	93	375	26	20a
MP1—MP1	—	—	—	—	—	—	—	—	180	770	24	70A	218	1244	16	80A
LSD (0.05) Experiment 1	—	—	—	—	143	598	6	—	171	558	6	—	130	484	7	—
CV%	30	20	14	7	39	37	16	20	56	40	18	21	32	23	26	18
LSD (0.05) Experiment 2	—	—	—	—	—	—	—	—	156	1291	7	—	198	630	11	—
CV%	—	—	—	—	—	—	—	—	7	17	13	9	46	18	36	12

Wilt % data are analysed after transformation; numbers not followed by the same letter are statistically different. For experiment 1 the letters are in lower case and for experiment 2 in capitals.

cidence in the following pigeonpea crop (in 1980) compared with the continuous pigeonpea treatment (Fig. 1). Final incidence was significantly less after sorghum and fallow than after tobacco, but even after tobacco the final incidence was significantly less than in continuous pigeonpea (Table 2). In the second two-year period of these treatments, sorghum and fallow again produced very substantial, and significant, reductions in wilt incidence in the following pigeonpea crop (in 1982) but effects following tobacco were not significant.

The growth of pigeonpea was observably better in the field after all one-year breaks and this was borne out by higher yields (Table 2). The yield increases from individual treatments were not very consistent between 1980 and 1982 and did not accord particularly well with the reductions in wilt incidence, perhaps because of the high degree of variability associated with the low yield levels. Nevertheless, all one-year breaks raised the very poor yield of the continuous pigeonpea treatment to at least a reasonable level.

The inability of *Fusarium udum* to survive very long in the soil without a living host was shown many years ago (Sadasivan and Subramanian, 1954; Subramanian, 1955), and explains the reduction in wilt incidence after the fallow break. Similarly, host specificity of the pathogen (J. Kannaiyan and Y.L. Nene, unpublished data) can explain why the sorghum break had effects similar to a fallow. The effect of the tobacco break is less straightforward, however, because this had less effect on wilt incidence, but it still produced quite large yield increases. A possible explanation is that, although wilt was logically the major cause of yield reduction in the experiment, other factors may have been involved; for example, it was seen that the wilt-sick area also had increased parasitic nematode populations which might have been decreased by tobacco.

The limited investigation of a one-year break of cotton and of a crop of wilt-resistant pigeonpea in Experiment 2 was of considerable interest, though results are necessarily more tentative. Both these treatments slightly delayed the wilt buildup in the following pigeonpea, but final incidence was just as high as in continuous pigeonpea. One possible explanation is that although neither break crop displayed symptoms, they might both have harboured the pathogen; examination of their root systems did not show this, however. An other possibility could be that cotton and wilt-resistant pigeonpea did not encourage rhizosphere microflora that is inhibitory to *Fusarium udum*. In view of these findings with the cotton break it is of interest that disease surveys have shown higher wilt incidence in the Maharashtra state of India, where pigeonpea is traditionally intercropped with cotton (Kannaiyan et al., 1981).

The length of break comparison showed that the effect of a two-year break (S—S—P—P) on wilt incidence was not significantly different from that of a one-year break (P—S—P—P) but it had significantly higher total dry matter and grain yield (Table 2). Yield of pigeonpea after the three-year break was very good, but wilt incidence appeared no lower than after a two-year break; these effects could not be compared statistically because the comparison involved different years.

A measure of the duration of effect of a break on wilt incidence was provided by the second successive pigeonpea crops after a break. After a one-year sorghum break, the level of wilt incidence in the second pigeonpea crop rose again quite markedly compared with a first crop, but it was still significantly less than in the continuous pigeonpea; grain yield was also higher than in the continuous pigeonpea but the difference was not significant. After a two-year sorghum break there was evidence of a much bigger carry-over effect into the second year : wilt incidence in the second pigeonpea crop was still very low and not significantly different from that in a first crop after a one-year break; and both total dry matter and grain yield were as good as in the first crop after a one-year break. On the basis of these results, a rotation consisting of two years of sorghum followed by two years of pigeonpea might be better than alternate years of sorghum and pigeonpea to maximise pigeonpea production; but this suggestion can only be confirmed by a much longer period of experimentation.

Intercropping

The effects of the intercropping treatments in Experiments 1 and 2 are shown in Fig. 3. Introducing a sorghum intercrop with the original wilt-susceptible pigeonpea ICP 6997 produced a significant reduction in wilt incidence in the first year (1979) itself and a yet further reduction in the second year (1980). Thereafter for the duration of the experiment the incidence stabilised at a low level of 20—30% of the incidence in the continuous sole pigeonpea. Yield response to this decreased wilt incidence was not commensurate, however. During the final three years, when intercropping had its greatest effect on wilt incidence, the average intercrop yield (97 kg/ha) was virtually identical to the continuous sole crop yield (100 kg/ha). This effectively represents a yield response because pigeonpea yield in intercropping is normally only some fraction of the sole crop yield; but the yield level was very low.

As stated earlier, these poor intercropping yields were at first thought to be due to the inability of ICP 6997 to withstand the sorghum competition. Rather surprisingly, however, a similar pattern of a marked reduction in wilt incidence but a very poor yield response also occurred with the ICP 1 pigeonpea which is known to perform quite well in intercropping : for example in another three-year Vertisol experiment in which wilt did not occur, yields of ICP 1 averaged 1312 kg/ha in the sole crop and 945 kg/ha in a sorghum/pigeonpea intercrop (Willey et al., 1983). In a similar Vertisol experiment in which wilt did unexpectedly appear, ICP 1 developed 81% wilt in the sole crop with a yield of only 129 kg/ha, but only 20% wilt in the intercrop with a much higher yield of 516 kg/ha; this is the kind of yield response that might reasonably have been expected in the present experiment. It must therefore be assumed that the wilt-sick area was harbouring yield-limiting factors other than wilt.

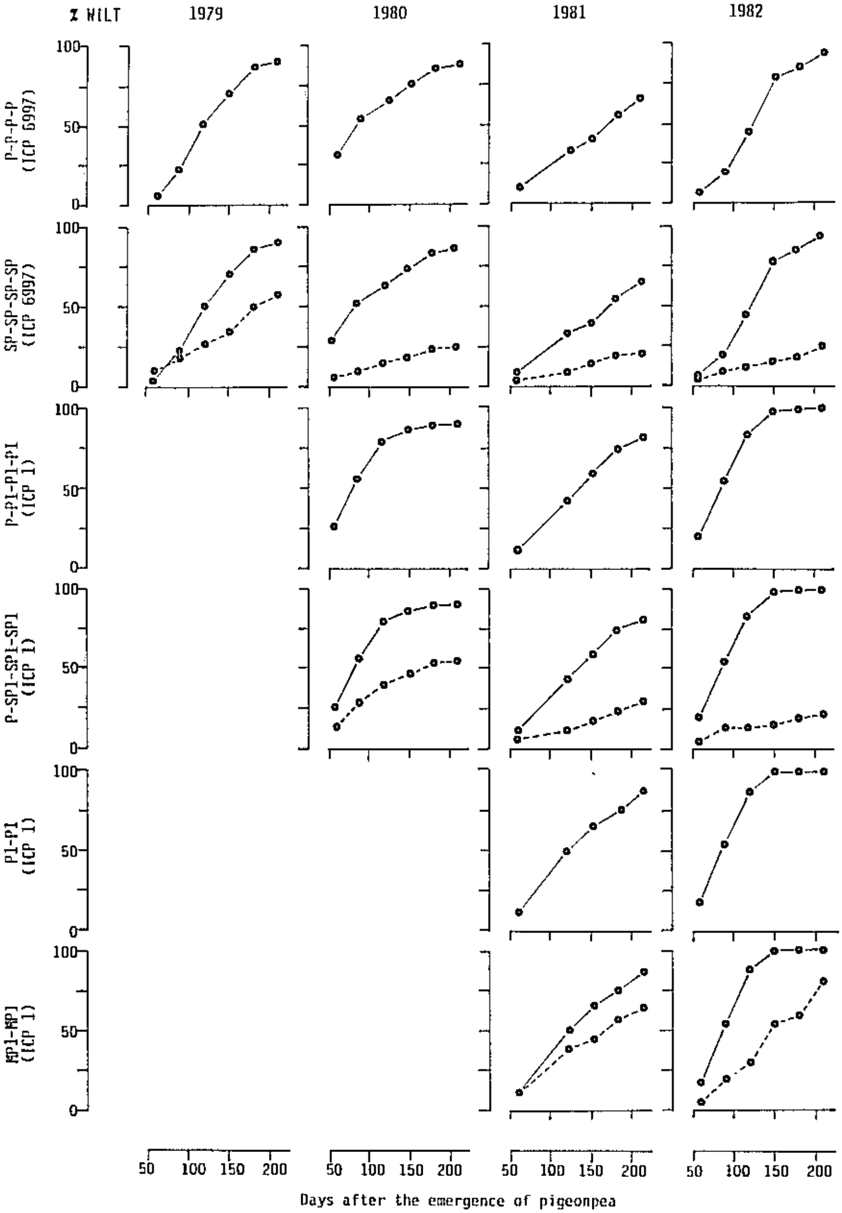

Fig. 3. Effect of intercropping with sorghum and maize on the wilt development in pigeonpea (o—o sole pigeonpea, o---o intercropped pigeonpea).

Despite the lack of yield response, however, the results of Experiment 1 show clearly that a sorghum intercrop can decrease wilt incidence. This is further substantiated by the results of Experiment 3 which showed that 15 of the 16 diverse pigeonpea genotypes had less wilt when grown with a sorghum intercrop than when grown as a sole crop (in the remaining genotype incidence was extremely low in both sole and intercrops) and the reduction in wilt incidence was statistically significant in 14 of these genotypes (Table 3). An even more surprising feature of these intercropping effects is that in Experiment 2 the maize intercrop produced only very moderate reductions in wilt incidence, which were not significant in either year. This difference between sorghum and maize has also been observed in other experiments at ICRISAT; in some large, long-term operational plots, a rotation involving quite a high proportion of a maize/pigeonpea intercrop sustained a higher level of wilt than a rotation involving a similar proportion of a sorghum/pigeonpea intercrop.

TABLE 3

Effect of sorghum intercrop on the fusarium wilt in 16 pigeonpea genotypes

Pigeonpea genotype	Wilt %	
	Sole crop	Intercropped with sorghum
ICP 1-6	0.5	1.7*
HY 3C	9.3	5.7*
BDN 1	12.6	5.3
C 11	19.9	11.8
HY 4	21.1	7.6
ICPL 304	23.4	5.8
ICPL 234	31.0	5.2
ICPL 296	36.1	13.1
IGDT 1	38.0	7.4
ICP 185-9	42.1	20.6
LRG 30	42.2	20.5
75559 F4B 1B	43.2	21.6
ICP 1	51.4	20.5
ICPL 297	61.0	16.3
ICPH 2	65.3	16.7
GS 1	73.2	23.6

Data are analysed after arcsine transformation. The difference in wilt incidence between sole and intercrop systems is significant for all genotypes except the two marked with*.

These comparisons of sorghum and maize suggest that the reduction in wilt by intercropping might be specific to sorghum as an intercrop. There are reports in the literature that sorghum roots can secrete fungitoxic exudates, which may explain this specific effect. Rangaswami and Balasubramanian (1963) reported that sorghum roots secreted hydrocyanic acid, the concentration of the acid varying with the age of the plant and the sorghum strain; when the spores of *Fusarium moniliforme* (Scheld) were treated with sorghum root exudate their germination was delayed. They found that in the early stages of plant growth this fungus was not capable of establishing in the rhizosphere of the two sorghum strains which they tested. Odunfa (1978) also suspected the presence of anti-fungal substances in sorghum root exudates when he obtained scanty mycelial growth of four species of *Fusarium* when treated with these exudates. An experiment conducted at ICRISAT in the greenhouse showed that extracts from soil in which sorghum seedlings were growing reduced the germination of *Fusarium udum* spores more than extracts from uncropped soil. The reductions in spore germination were 59, 68 and 36% with soil extracts collected at 10, 20 and 30 days after sorghum emergence. However, the extracts collected after more than 30 days had very little effect on the spore germination (J. Kannaiyan and V. Subramanian, unpublished). It is also possible that sorghum roots encourage rhizosphere microflora that is inhibitory to *Fusarium udum*. This aspect needs to be investigated.

The general implication of these results lies in the fact that, at least in India, sorghum/pigeonpea is one of the commonest of all intercropping systems. Traditionally the proportion of pigeonpea is low, but the present results show that even with much higher proportions, a sorghum intercrop may provide a means of increasing the frequency of pigeonpea crops while still providing good control of wilt. After the first year, the incidence in the continuous intercrop was as low as that after a one-year break. Yields of intercropped pigeonpea were particularly disappointing in the present experiments and remain unexplained. However, if yields comparable with those more generally experienced (e.g. Rao and Willey, 1983; Willey et al., 1983) were achieved, then a sequence of intercrops would provide more pigeonpea yield than systems of alternate sole crops suggested above. The long-term feasibility of this intercrop system would of course depend on other factors, such as nematodes, that might build up in the continuous pigeonpea intercrop (or indeed in the continuous sorghum intercrop) and also on how these in turn might be affected by intercropping.

ACKNOWLEDGEMENTS

The authors thank Messrs. T.N. Raju, B.N. Reddy and K.K. Rao and Ms. V.K. Sheila for their help in the field and laboratory work. The help of Mr. B. Uday Kumar in preparing the diagrams and Mr. Y.M. Prasada Lingam in typing the manuscript is also acknowledged.

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