

***Management***

## Chapter 5

### *Opening comments*

The next chapter deals with cultural practices devised for managing the peanut clump disease. Data generated during epidemiological studies have led to formulation of hypothesis on possible ways for controlling peanut clump disease through cultural practices. These measures of control were tested under field conditions in both research stations and farmers' fields. Various trials have been successfully conducted to show that the following practices are effective in reducing the peanut clump disease spread and incidence.

- **Rotation** with cereal crops should be avoided and cropping with dicotyledonous hosts can reduce the disease incidence (5-1)
- **Trap cropping** with pearl millet is an environmentally friendly method to reduce inoculum potential and consequently disease incidence (5-2)
- **Early sowing** before the onset of monsoon rains and application of judicious irrigation was shown to be very efficient in controlling the disease (5-3)

## 5-1. Reduction of Indian peanut clump virus (IPCV) incidence in groundnut and pigeonpea rotated with non-cereal crops.<sup>9</sup>

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### Abstract

The influence of growing various monocots and dicots, and fallowing during the post-rainy season on peanut clump disease incidence in rainy season crops of groundnut and pigeonpea was studied. Soil samples were collected prior to adopting the various cropping systems and prior to sowing the rainy season crops. All the post-rainy season crops tested, including groundnut, maize, marigold, mustard, pigeonpea, sorghum and wheat, hosted IPCV-Hyderabad isolate (IPCV-H). Growing maize and sorghum in post-rainy season was shown to perpetuate *P. graminis* and virus inoculum in the soil. In plots where maize was grown, disease incidence in the ensuing groundnut and pigeonpea crops was higher than in plots where the other cropping systems were tested. The effect persisted up to the second rainy season. High incidence in plots used for growing maize was correlated with low yield in rainy season groundnut crops, and *P. graminis* inoculum potential was also found to be highest in such plots. The lowest incidence was observed in plots where mustard was grown. These plots also showed the highest groundnut and pigeonpea yield.

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<sup>9</sup> To be submitted for publication

## Introduction

A previous report (Reddy *et al.*, 1988) suggested that because of the extremely wide host range of IPCV and *P. graminis* in India, including wild and cultivated species in both mono- and dicotyledons, crop rotation was not expected to reduce disease incidence. However, more recent studies on the epidemiology of the vector *P. graminis* (Ratna *et al.*, 1991, Delfosse *et al.*, 1996; Legrève, 1999) have shown that even if this parasite infects and transmits IPCV to dicotyledonous crops such as groundnut, it does not multiply intensively in roots of these plants. On the contrary, monocots such as maize (*Zea mays* L.), pearl millet (*Pennisetum glaucum* [L.] R. Br.) and sorghum (*Sorghum bicolor* [L.] Moench) were found to be excellent hosts supporting parasite multiplication (Ratna *et al.*, 1991; Delfosse *et al.*, 1996, Legrève, 1999). They also host the virus. Therefore, monocotyledonous hosts supporting good multiplication were considered as preferred hosts of *P. graminis* whereas dicotyledonous hosts were qualified as fortuitous hosts. In West Africa where the disease is caused by peanut clump virus (PCV), Dollet, Fauquet and Thouvenel, (1976) and Thouvenel and Fauquet, (1981), observed a positive correlation between virus incidence and rotation of groundnut with the monocot, *Sorghum arundinaceum* (Desv.), a natural host for both PCV and its vector. The authors suggested that a crop rotation system with a non-host of both the vector and the virus would help to reduce disease incidence. Based on results obtained during epidemiological studies conducted on *P. graminis* and IPCV in India, a strategy using crop rotation systems, which avoids preferred hosts of *P. graminis*, was evaluated to reduce IPCV incidence. This paper focuses on identification of cropping systems applicable to Indian conditions which can possibly reduce the disease incidence through growing crops which do not support *P. graminis* multiplication in the post-rainy season prior to rainy season crops.

Recent experiments have shown that pigeonpea is a susceptible host for IPCV (Delfosse *et al.*, 1996). Pigeonpea was therefore included as an indicator host, along with groundnut, in the present experiment aimed at assessing the influence of the crop rotation on IPCV incidence.

Isolation of *P. graminis* from Indian and African soils infested with clump disease has proved difficult (Legrève, 1999). Measurement of inoculum potential of *P. graminis* and IPCV in tropical soils have so far been unsuccessful. In this paper we described a new technology developed to favour infection and multiplication of the vector under environmentally

controlled conditions that allowed assessment of the number of infective units of the virus and its vector per litre of soil.

## Materials and Methods

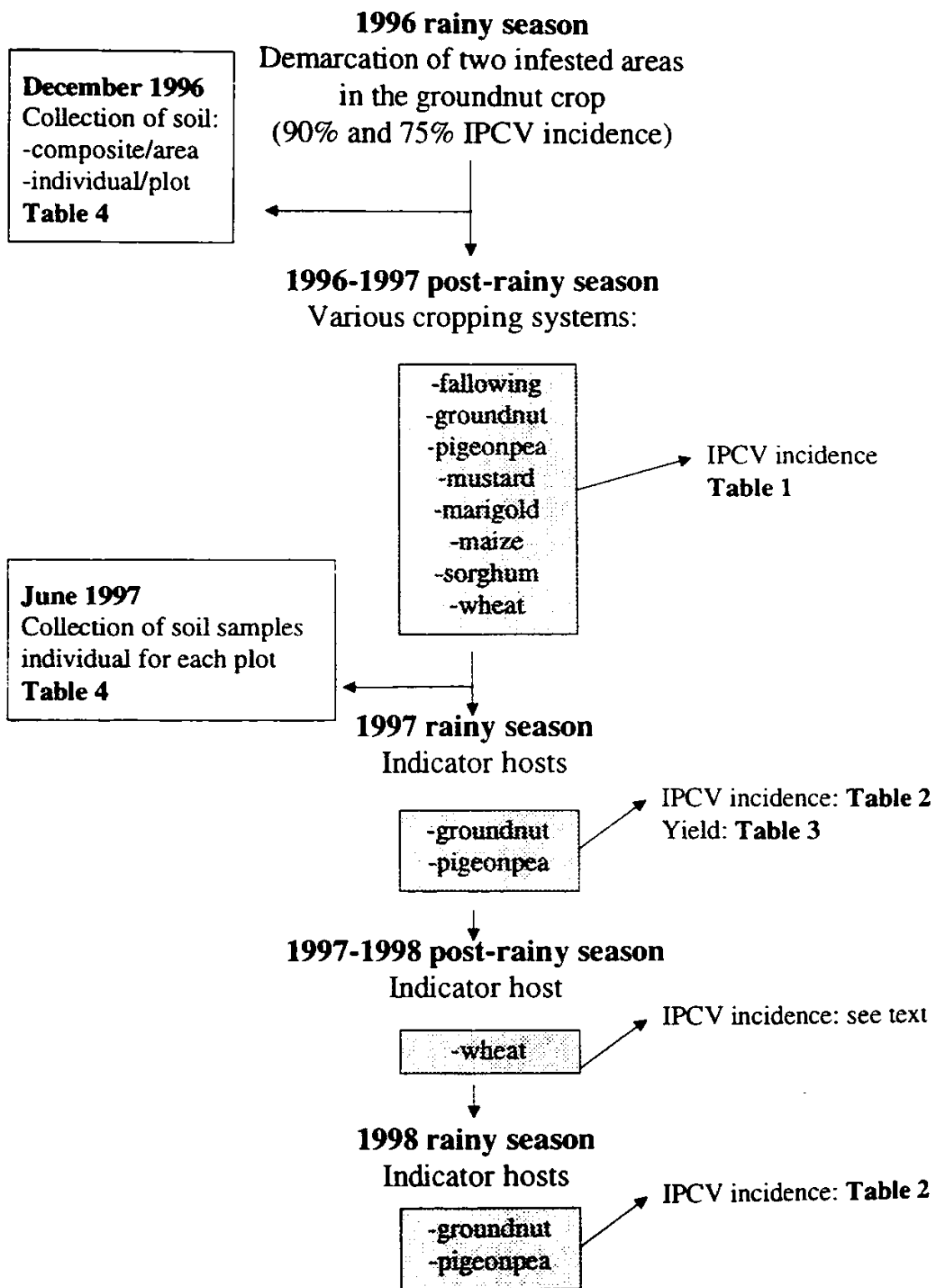
### *The 1993-1994 experiment*

Four uniformly clump infested patches (replicates) of approximately 2 m<sup>2</sup> were demarcated on the ICRISAT farm in a field infested with the Hyderabad isolate of IPCV (IPCV-H) (Nolt *et al.*, 1988). The virus incidence, recorded on the basis of visual symptoms, ranged from 60 to 80% in the groundnut (cv. NCAc 17090) crop raised during the 1993 rainy season (June to October). During the 1993-1994 post-rainy season (December to April) half of each patch was sown on 8 December 1993 with sorghum (ICSV 88036) while the other half was sown with groundnut (cv. NCAc 17090). The crops were irrigated three times a week and monitored at regular intervals for virus infection by double antibody sandwich ELISA tests performed on leaves described by Reddy *et al.*, (1998). Three months after sowing the irrigation was stopped to favour maturation of *P. graminis* resting spores. In April 1994, the four blocks were watered to facilitate sampling of sorghum roots and for harvesting groundnut. Sorghum roots were further analysed for the presence of *P. graminis* after staining in lacto-phenol cotton blue and observed under a compound microscope (Maraite, Goffart, and Bastin, 1988). Leaves and roots of groundnut and sorghum were assayed for virus presence by ELISA. During the 1994 rainy season, groundnut was sown as a sole crop in the four blocks on 1 July to serve as indicator host for estimation of virus inoculum potential. The groundnut crop was scored at 2 week intervals for IPCV symptoms. The plots were harvested during the first week of November, pods were dried in the sun and the dry pod yield measured.

### *The 1996-1998 experiments*

The effect of growing various crops or fallowing during the post rainy season on IPCV incidence in ensuing rainy season crops was assessed by using groundnut and pigeonpea as indicator hosts (Fig. 1). On the other hand, virus and *P. graminis* inoculum were measured in soil sampled from the plots where the different crop rotation and fallowing were practised.

# 1996-1998 Experiment



**Figure 1:** Time table for the 1996-1998 experiment

*Cropping systems practised.* During the 1996 rainy season two large infested areas (6 x 20m) were demarcated in the groundnut crop. In the first infested area the virus incidence was estimated to be 90% while in the other area it was 75%. In the 1996-1997 post-rainy season various cropping systems were applied including fallowing to analyse the effect of natural weeds, and crop rotation with seven different crops which included dicots such as groundnut (NCAc 17090), pigeonpea (*Cajanus cajan* (L.) Millsp., cv. ICPL-87), mustard (*Brassica juncea* (L.) Czerniak.), marigold (*Tagetes patula* L., cv. African ball) and monocots such as maize (*Zea mays* L., cv. DHM 103), sorghum (cv. ICSV 88036) and wheat (*Triticum aestivum* L., cv. RR-21). The crops were sown in 1 m broadbeds (4 lines per bed) on 10 December 1996. The plots were 1x2 m size with a distance between plots of 0.5m. The experiment was conducted as a randomised complete block design with four replicates in each level of infestation. The various crops were grown under irrigation and all the plants were scored for virus presence by testing their leaves by ELISA two months after sowing. Additionally 5 plants were collected in each plot and their leaves and roots tested by ELISA for virus presence 4 months after sowing.

*Effect of the cropping systems on IPCV-H incidence in the ensuing 1997 and 1998 rainy seasons.* After harvesting the various post-rainy season crops, the soil was prepared manually to avoid movement from one plot to another, and indicator hosts, groundnut (NCAc 17090) and pigeonpea (ICPL-87), were sown on 24 June 1997. Sowing was done in broadbeds as above, alternating groundnut and pigeonpea seeds (100 seeds each/plot). Three months after sowing, peanut clump disease incidence was recorded in groundnut on the basis of visual symptoms. In pigeonpea, the incidence was assessed on the basis of ELISA tests performed on leaves. In the 1998 rainy season, on 25 June, groundnut and pigeonpea were sown at the rate of 50 seeds /plot to assess if the cropping systems had a long term effect on the level of infestation by IPCV-H.

*Effect of the cropping systems on IPCV-H incidence in the 1997-1998 wheat crop.* In the 1997-1998 post-rainy season the plots were sown with wheat (cv. RR-21) and IPCV incidence was monitored by testing all wheat plants for virus presence in leaves by ELISA, 3 months after sowing.

*Effect of the crop rotation on P. graminis and IPCV-H inoculum potential in soil samples.* A new technology was developed to favour *P. graminis* infection and multiplication by alternate dry and wet conditions at the root level using an automatic immersion system (AIS) with individual watering for each plant (Fig. 1). The system is an adaptation of those described by

Adams *et al.* (1986) and Legrève *et al.* (1998) with the advantage that plants were watered individually, excluding the possibility of cross-infection between plants. The system allowed assessment of *P. graminis* and IPCV inoculum potential in soil by means of the most probable number (MPN) (Cochran, 1950, Goffart *et al.*, 1987, Adams and Welham, 1995) as described hereafter. Individual soil samples (10 cores per plot representing about 5 kg) were collected from the layer 0-20 cm below surface in each of the 32 plots from both levels of infestation (based on 90% and 75% incidence in 1996). Sampling was done in December 1996, prior to adoption of various cropping systems, and prior to sowing groundnut and pigeonpea in June 1997 (Fig. 1). The soil samples collected could not be analysed individually for all the 32 plots present in each block because of the limited number of AIS units available. Therefore, for the soil collected during the 1996 post-rainy season, a composite sample was made for each level of infestation by mixing 100 g aliquots from the 32 plots. In the case of the soil collected in June 1997, soil samples from the plots where maize was grown in post-rainy season were analysed individually while for the other cropping systems, soil aliquots from the 4 replication plots were thoroughly mixed prior to the analysis (Table 4). The soil was air dried at room temperature (22 to 28°C) for approximately 3 and 4 months for the 1996 and 1997 samples respectively. Soil was crushed in a commercial blender and sieved to remove soil particles exceeding 2mm in size. Serial soil dilutions were prepared in sterile sand with a particle size ranging from 1 to 2 mm to obtain dilutions 1:2, 1:4, 1:8, 1:16 and 1:32. Seeds were pre-germinated for two days before being transplanted in individual receptacles filled with 60 ml of soil/sand mixture (Fig. 1). For each dilution 14 plants were grown.

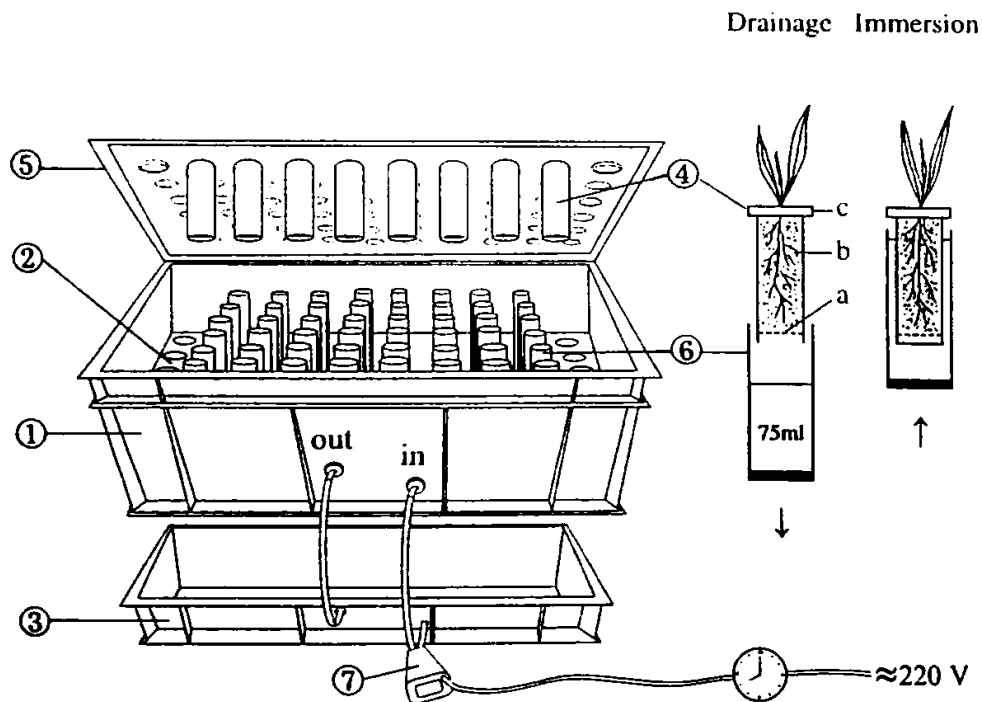
In the AIS, the position of the nutrient solution containers coincided with that of the plant receptacles held in the lid in such a way that when the floating board was lifted hydraulically, each receptacle was supplied with its own nutrient solution (modified Hoagland solution, Adams *et al.* (1996)) The bottom tank placed under the first tank served as a water reservoir for the hydraulic system. A small magnetically-driven centrifugal pump supplied the water to the upper tank through rubber hoses and brass inlets and outlets fixed to the sides of the tanks. When the pump was running the water entered the upper tank, and when the level of water reached the outlet the water overflowed and returned to the bottom tank. When water is at its highest level, the floating board is at its highest position permitting complete immersion of roots (immersion phase). The floating board with the nutrient solution containers reached the highest level in approximately 5 minutes, allowing a gentle and progressive immersion of the roots. When the pump stopped, the water receded to the

bottom tank by counterflowing through the pump and the floating board reached its lowest position. The plant receptacles were no longer in contact with the nutrient solution (drainage phase) (Fig. 2). The pump was switched on and off by an electrical clock that programmed the alternate cycles of immersion and drainage. In order to allow vigorous plant growth, roots were immersed 1 h every 6 h during the first week, then the daily immersion and drainage cycles were as follows: immersion for 3 h (starting daily at 8.00 am), drainage for 15 min, immersion for 15 min, drainage for 4 h, immersion for 3 h, drainage for 13.5 h (overnight). The level of nutrient solution was adjusted every two days to its maximum by gently pouring the liquid in plant receptacles during the immersion phase.

The plants were grown for 2 months in AIS in a glasshouse at 25-30°C. Plants were harvested by carefully washing their roots free of soil/sand mixture. The roots were divided longitudinally and half of each was analysed for the presence of *P. graminis* as above. The other half was dried at room temperature and kept as potential source of *P. graminis* inoculum for further work. For the soil collected in December 1996, the experiment was done simultaneously with sorghum (cv. ICSV 88036), groundnut (cv. NCAc 17090), and wheat (cv. RR-21) as bait plants. To assess the virus inoculum potential, the plants were tested for virus presence in leaves and roots by ELISA. *P. graminis* inoculum from soil collected in June 1997 was baited only with sorghum plants.

#### *Data analysis*

The effect of crop rotation systems on IPCV-H incidence was analysed by the general linear model (SPSS-software) after logit transformation [ $\text{logit} = 0.5\ln(\%/100 - \%)$ ] for the 1993-1994 experiment and by ANOVA with angular transformation [ $\theta = \arcsin\sqrt{\%}$ ] for the 1996-1998 experiment. Yield data were analysed without transformation. Replicates (blocks) were considered as random factors both in 1993-1994 and 1996 to 1998 experiments.

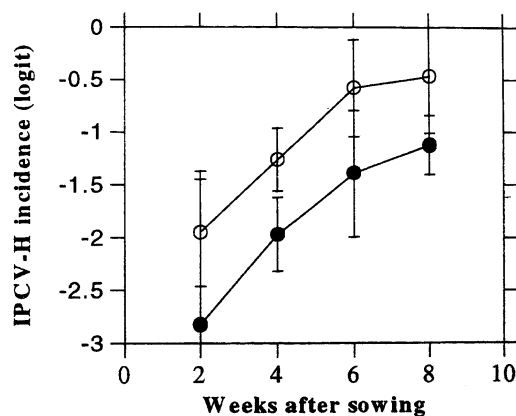


**Figure 2.** Automatic immersion system with individual watering for each plant for the assessment of *P. graminis* and IPCV inoculum potential in soil samples. The system uses high density polyethylene crates (60 cm long, 40 cm wide) produced by Nikamal Crates & Containers, Mumbai, India. (1) Upper tank, (22 cm high, model CC 64220) in which a floating board (2) made of waterproof polystyrene foam (5 cm thick) can be lifted hydraulically. (3) Bottom tank (12 cm high, model CC 64120) placed under the upper tank, and filled with 25 l of water for the hydraulic lifting system. (4) 70 plant culture receptacles made of 32 mm rigid polyvinyl-chloride (PVC) tubing (10.5 cm high) closed at the bottom with a nylon mesh of pore size 500 $\mu$  (a), filled with 60 ml of crushed soil/sand mixture (b) and suspended with the help of shoulder ring (c) in an opaque and removable lid (5) (model 64000) in which 70 holes (diameter 34 mm) have been drilled (6) 70 nutrient solution containers made of 40 mm rigid PVC tubing (11 cm high), sealed with a PVC lid glued to the bottom, and filled with 75 ml nutrient solution. (7) Small magnetically driven centrifugal pump (Rena, Annecy, France, model C20, 200 liters/h). For operation see the text.

## Results

### *The 1993-1994 experiment*

From Fig. 2, it is evident that IPCV-H incidence on groundnut increased over time during the growth of the crop. Two weeks after sowing IPCV-H incidence was low and no significant effect of the previous crop on incidence was observed ( $P=0.187$ ). At the second scoring, 4 weeks after sowing the indicator groundnut crop, a higher IPCV-H incidence was observed in the plots where sorghum was grown as a post-rainy season crop (8.2%) compared to the plots where groundnut was grown (2.3%) ( $P=0.05$ ). Eight weeks after sowing, the effect of the previous crop was even more pronounced. Mean virus incidence was 30.9% in plots cultivated with sorghum and 10.3% in plots used for growing groundnut ( $P=0.035$ ). The increase in incidence was significant between the scorings done 2 or 4 weeks after sowing and the scorings done after 6 or 8 weeks ( $P<0.05$ ). At harvest, about 4 months after sowing, virus incidence remained at the level observed 8 weeks after sowing. Plots where groundnut was grown in post-rainy season showed similar dry pod yield (602 kg/ha) as compared to plots where sorghum was used in the crop rotation (476 kg/ha) ( $P=0.105$ ).



**Figure 3.** Progress of IPCV-H incidence (logit transformation) in the 1994 rainy season groundnut crop in plots where either groundnut (●) or sorghum (○) were grown during the post-rainy season 1993-1994. The intervals indicate the standard deviation. The plant population was  $474 \pm 44$  per plot. Virus incidence was higher in plots where sorghum was grown than in plots where groundnut was grown ( $P=0.037$ ); the effect “week after sowing” was significant ( $P \leq 0.001$ ); there was no interaction between “previous crop” and “week” ( $P=0.930$ ). The intercept of the sorghum regression was significantly different from that of groundnut ( $P=0.011$ ) (General linear model).

*The 1996-1998 experiments*

*Virus incidence in the 1996-1997 post-rainy season crops.* All the crops grown during the post-rainy season were found to host the virus (Table 1). Wheat showed the highest incidence and the virus was detected in both leaves and roots. Pigeonpea showed a relatively high virus incidence in roots. Marigold and mustard were found to be infected only in roots. In sorghum leaves, the virus was detected in only three plants out of nearly 1000 plant tested. In maize the virus was detected in both leaves and roots. Three groundnut plants were found to be infected by the virus when tested two months after sowing. These plants showed typical clump disease symptoms identical to those observed during the rainy season. Wheat was also symptomatic (Delfosse *et al.*, 1999). The other host plants did not exhibit overt symptoms of virus infection during the post rainy season.

*Virus incidence in groundnut and pigeonpea indicator crops during the 1997 and 1998 rainy seasons.* A great variability was observed in IPCV-H incidence according to the cropping system practised in the 1996-1997 post-rainy season (Table 2). It was clear that in the plots where maize was grown during the 1996-1997 post-rainy season, IPCV-H incidence in the ensuing 1997 groundnut and pigeonpea crops was higher compared to fallowing and rotation with other crops. The effect of growing maize in 1996-1997 post-rainy season on IPCV-H incidence was still apparent in the 1998 rainy season indicator crops, after growing wheat in the 1997-1998 post-rainy season. The lowest level of incidence was observed in plots where mustard was grown. This was true in both levels of infestation, for both 1997 and 1998 indicator crops. The other cropping system, including fallowing, showed statistically similar level of incidence.

Compared to the 1996 rainy season, a lower virus incidence was observed in the 1997 rainy season crop of groundnut. In 1997, IPCV-H incidence was 23.4% and 5.4% in comparison to previously 90% and 75% respectively in the 1996 rainy season. The incidence further decreased in the 1998 groundnut crop to reach 10.3% and 2.9% in the respective areas. A similar situation happened when using pigeonpea as an indicator host (Table 2).

In the 1997 rainy season, groundnut and pigeonpea yield was the highest where mustard was grown. These plots also showed the lowest virus incidence in both the 1997 and 1998 rainy seasons (Table 2 and 3). Plots where maize was grown showed the lowest yield. The percentage yield loss between “maize” and “mustard” plots was measured to be 47%, equivalent to a difference in dry yield of 634 g/plot.

**Table 1.** IPCV-H incidence in various crops grown during the 1996-1997 post-rainy season in two blocks that showed high (90%) and moderate (75%) disease incidence in the 1996 rainy season crop of groundnut.

Crops grown in the 1996-1997 post-rainy season	Area with 90% clump disease incidence in 1996		Area with 75% clump disease incidence in 1996	
	ni/N <sup>1</sup>	% <sup>2</sup>	ni/N <sup>1</sup>	% <sup>2</sup>
<i>All plants tested two months after sowing</i>				
Pigeonpea	5/395	1.26	1/365	0.27
Maize	0/415	0.00	1/395	0.25
Wheat	135/425	31.76	21/370	5.67
Sorghum	3/505	0.59	0/485	0.00
Groundnut	0/270	0.00	3/280	1.07
Mustard	0/520	0.00	0/595	0.00
Marigold	0/440	0.00	0/360	0.00
<i>20 plants tested four months after sowing</i>	leaves <sup>3</sup>	roots <sup>4</sup>	leaves <sup>3</sup>	roots <sup>4</sup>
Pigeonpea	5	80	0	45
Maize	0	5	10	5
Wheat	70	75	60	60
Sorghum	0	5	0	0
Groundnut	0	0	0	0
Mustard	0	0	0	10
Marigold	0	20	0	15

<sup>1</sup> Number of infected plants / number of plant tested by ELISA on leaf extracts.

<sup>2</sup> Mean incidence calculated for four replication in block with 90 and 75% incidence.

<sup>3</sup> IPCV-H incidence in leaves on the basis of ELISA test.

<sup>4</sup> IPCV-H incidence in roots on the basis of ELISA test.

While pigeonpea grown in post-rainy season did not exhibit clear symptoms, pigeonpea grown during the rainy season, if infected by IPCV-H, showed severe stunting, dark green leaves and mosaic symptoms on young leaves. The virus was readily detected in leaves of such plants by ELISA. Infected plants produced pods of smaller size compared to healthy one. Grow out tests in sterile sand and under glass house conditions were unsuccessful in showing seed transmission in seed from infected pigeonpea plants. Out of 854 seeds kept for germination, 539 germinated and all gave rise to healthy plants as assessed by ELISA tests on leaves.

*Virus incidence in wheat during the 1997-1998 post-rainy season.* About 100 wheat plants were tested by ELISA in each replication plot. In both areas with low and high levels of infestation (based on incidence in the 1996 rainy season), virus incidence in wheat was almost nil for most of the cropping systems studied. None of the wheat plants were found to be infected by IPCV-H in the plots where pigeon pea, marigold, sorghum, mustard and maize were grown in the 1996-1997 post-rainy season. However a very high incidence occurred in wheat plants in plots where wheat was grown during the 1996-1997 post-rainy season. The incidence was  $69.3 \pm 15.1$  % (mean  $\pm$  stdev) in the block infested at a high level and

51.9 ± 13.4% in the block with a low level of infestation. In the plots where groundnut was grown in the 1996-1997 post-rainy season one wheat plant was found to be infected in each level of infestation (2/680).

**Table 2.** Effect of various cropping systems practised during the 1996-1997 post-rainy season on IPCV-H incidence (angular transformation) in the ensuing 1997 and 1998 rainy season crops of groundnut and pigeonpea. Incidence recorded by ELISA 2 months after sowing.

Effect analysed	Mean IPCV-H incidence in groundnut and pigeonpea in 1997 and 1998 <sup>1</sup>							
	Area with 90% clump disease incidence in 1996				Area with 75% clump disease incidence in 1996			
	1997		1998		1997		1998	
	(θ)	%	(θ)	%	(θ)	%	(θ)	%
<b>Cropping system in the 1996-1997 post-rainy season<sup>2</sup></b>								
Pigeonpea	(32.1)	31.8 <sup>ab</sup>	(21.7)	18.2 <sup>ab</sup>	(8.0)	3.6 <sup>b</sup>	(11.2)	6.1 <sup>a</sup>
Maize	(44.1)	51.0 <sup>a</sup>	(28.7)	24.3 <sup>a</sup>	(27.1)	22.2 <sup>a</sup>	(5.5)	2.2 <sup>a</sup>
Wheat	(26.5)	23.1 <sup>bc</sup>	(12.7)	8.0 <sup>ab</sup>	(5.9)	1.7 <sup>b</sup>	(5.3)	2.2 <sup>a</sup>
Sorghum	(22.8)	16.6 <sup>bc</sup>	(14.8)	9.1 <sup>ab</sup>	(6.4)	1.9 <sup>b</sup>	(3.0)	0.8 <sup>a</sup>
Groundnut	(14.2)	8.4 <sup>bc</sup>	(15.1)	10.8 <sup>ab</sup>	(8.0)	2.6 <sup>b</sup>	(4.4)	1.4 <sup>a</sup>
Mustard	(7.8)	2.4 <sup>c</sup>	(4.6)	2.2 <sup>b</sup>	(2.7)	0.8 <sup>b</sup>	(1.9)	0.5 <sup>a</sup>
Marigold	(13.7)	7.3 <sup>bc</sup>	(5.5)	3.4 <sup>b</sup>	(7.9)	3.1 <sup>b</sup>	(4.4)	2.1 <sup>a</sup>
Fallow	(16.8)	12.8 <sup>bc</sup>	(7.5)	5.9 <sup>b</sup>	(4.7)	1.3 <sup>b</sup>	(2.5)	1.0 <sup>a</sup>
Angular SED <sub>previous crop</sub>	(6.7) <sup>***</sup>		(7.5) <sup>*</sup>		(3.7) <sup>***</sup>		(4.6) <sup>ns</sup>	
<b>Effect of the indicator host<sup>3</sup></b>								
Pigeonpea	(17.9)	15.0 <sup>a</sup>	(13.6)	10.2 <sup>a</sup>	(7.3)	3.9 <sup>a</sup>	(3.8)	1.2 <sup>a</sup>
Groundnut	(26.6)	23.4 <sup>b</sup>	(14.1)	10.3 <sup>a</sup>	(10.4)	5.4 <sup>a</sup>	(5.7)	2.9 <sup>a</sup>
Angular SED <sub>indicator host</sub>	(1.6) <sup>*</sup>		(2.1) <sup>ns</sup>		(1.7) <sup>ns</sup>		(1.0) <sup>ns</sup>	

<sup>1</sup> Mean IPCV-H incidence calculated on the basis of 4 replications. Means (θ=angular transformed %) in a column, for one season and one effect, followed by the same letter do not differ at  $P \leq 0.05$ .

<sup>2</sup> Means IPCV-H incidence combined for groundnut and pigeonpea.

<sup>3</sup> Means IPCV-H incidence combined for the various cropping systems.

The population density per plot was (mean±stdev): 53±7 for pigeonpea and 82±5 for groundnut in 1997, and in 1998, 30±4 for pigeonpea and 37±5 for groundnut. Between 1997 and 1998, wheat was grown in all plots in the 1997-1998 post-rainy season.

Treatments were: <sup>ns</sup> not significant, <sup>\*</sup> significant at 5% level, <sup>\*\*\*</sup> significant at 0.1 level

**Assessment of *P. graminis* and IPCV-H inoculum potential in soil samples.**  
 The composite sample of soil collected in December 1996, was tested with groundnut, sorghum and wheat plants. *Polymyxa* sp. was detected in roots of sorghum plants but not in groundnut and wheat roots while IPCV-H was detected in leaves and roots of wheat plants but not in sorghum and groundnut. Therefore in Table 4 we presented *P. graminis* incidence on sorghum and IPCV-H incidence on wheat. The soil collected from the area infested at a high level (90%), showed a higher inoculum potential (38.0 infective units per litre of soil, IU/l) of *P. graminis* compared to the soil from the area infested at lower level (75%) (1.24 IU/l). The estimation of IPCV-H inoculum potential per litre of homogenised soil was similar for the two areas (1.2 IU/l). The ratio of virus and *P. graminis* inoculum

potentials gave an indication of the proportion of infective *P. graminis* resting spores that are carrying the virus (Tuitert, 1994). The proportion was calculated to be 7% for the area showing a high level of IPCV-H infestation.

**Table 3.** Effect of various crop rotations and fallowing during the 1996-1997 post-rainy season on dry yield (haulms and pods) of the ensuing 1997 rainy season groundnut and pigeonpea crops.

Effect analysed	Dry yield in the 1997 groundnut and pigeonpea crops (g) <sup>1</sup>	
	Area with 90% clump disease incidence in 1996	Area with 75% clump disease incidence in 1996
<i>Cropping system practised in the 1996-1997 post-rainy season</i> <sup>2</sup>		
Pigeonpea	584 <sup>b</sup>	1004 <sup>ab</sup>
Maize	607 <sup>b</sup>	793 <sup>b</sup>
Wheat	667 <sup>b</sup>	1247 <sup>a</sup>
Sorghum	820 <sup>ab</sup>	1189 <sup>ab</sup>
Groundnut	936 <sup>ab</sup>	1109 <sup>ab</sup>
Mustard	1283 <sup>a</sup>	1386 <sup>a</sup>
Marigold	999 <sup>ab</sup>	1044 <sup>ab</sup>
Fallow	1029 <sup>ab</sup>	1239 <sup>a</sup>
SED <sub>cropping system</sub>	134 <sup>***</sup>	102 <sup>***</sup>
<i>Indicator hosts grown in the 1997 rainy season</i> <sup>3</sup>		
Pigeonpea	804 <sup>a</sup>	1300 <sup>a</sup>
Groundnut	928 <sup>a</sup>	953 <sup>b</sup>
SED <sub>indicator host</sub>	146 <sup>ns</sup>	115 <sup>*</sup>

<sup>1</sup> Mean dry yield (stems and pods) calculated on the basis of 4 replications. Means in a column, for one effect, followed by the same letter do not differ at  $P=0.05$ .

<sup>2</sup> Means combined for groundnut and pigeonpea.

<sup>3</sup> Means combined for the various cropping systems.

The population density per plot was (mean±stdev): 53±7 for pigeonpea and 82±5 for groundnut.

Treatments were: <sup>ns</sup> not significant, <sup>\*</sup> significant at 5% level, <sup>\*\*\*</sup> significant at 0.1 level

Prior to adoption of any of the cropping systems, a great variability in *P. graminis* inoculum potential was observed even between plots from a same level of IPCV-H infestation. The inoculum potential in soil sampled in December 1996 in the area infested with IPCV-H at a high level, varied from 0 to 33 IU of *P. graminis* per litre of soil (Table 4). The plots that showed the highest *P. graminis* inoculum potential were the plots where wheat and groundnut were intended to be sown.

**Table 4.** Effect of various crop rotations and fallowing during the 1996-1997 post-rainy season on *P. graminis* and IPCV-H inoculum potential in soil. Comparison between areas where 90% and 75% virus incidence was recorded in the 1996 groundnut crop, and between soil sampled before (December 1996) and after (June 1997) adoption of the various cropping systems in the 1996-1997 post-rainy season.

	Percentage of infected plants at dilutions <sup>1</sup>					Inoculum potential	
	1:2	1:4	1:8	1:16	1:32	IU/l <sup>2</sup>	95% confidence interval
<b>Soil collected in December 1996 prior to adoption of the cropping systems</b>							
<i>Area showing 75% incidence in 1996</i>							
IPCV-H on wheat <sup>3</sup>	7	0	0	0	0	1.25	0.07-5.51
<i>P. graminis</i> on sorghum <sup>3</sup>	0	7	0	0	0	1.24	0.07-5.46
<i>Area showing 90% incidence in 1996</i>							
IPCV-H on wheat <sup>3</sup>	14	0	0	0	0	2.55	0.43-7.89
<i>P. graminis</i> on sorghum <sup>3</sup>	50	57	14	36	7	38.00	24.3-56.3
<i>P. graminis</i> on sorghum							
Maize replication 1	7	14	7	0	0	5.13	1.59-11.9
Maize replication 2	43	14	7	0	7	14.30	7.17-25.3
Maize replication 3	7	21	21	14	7	12.7 <sup>†</sup>	6.11-23.0
Maize replication 4	21	14	7	14	0	10.8	4.91-20.1
Fallow <sup>4</sup>	0	0	0	0	0	*	*
Groundnut <sup>4</sup>	36	29	14	7	7	18.8	10.4-31.2
Mustard <sup>4</sup>	14	14	0	0	7	6.52	2.34-14.0
Pigeonpea <sup>4</sup>	0	0	0	0	0	*	*
Sorghum <sup>4</sup>	29	7	21	7	0	12.3	5.92-22.3
Wheat <sup>4</sup>	57	43	14	21	7	32.7	20.2-49.7
Combined	21	16	9	6	4	10.4	8.2-12.9
<b>Soil collected in June 1997 after adoption of the cropping systems</b>							
<i>Block showing 90% incidence</i>							
<i>P. graminis</i> on sorghum							
Maize replication 1	86	64	86	64	50	72.5 <sup>‡</sup>	47.3-107.1
Maize replication 2	93	100	86	86	86	*	*
Maize replication 3	100	93	71	79	50	245.1	169.8-347.4
Maize replication 4	71	100	93	93	64	258.7 <sup>†</sup>	170.2-388.4
Fallow <sup>4</sup>	14	36	21	0	0	13.7	6.84-24.0
Groundnut <sup>4</sup>	100	71	64	71	50	*	*
Mustard <sup>4</sup>	21	36	14	7	0	15.3	7.95-26.3
Pigeonpea <sup>4</sup>	50	50	43	43	29	39.6	25.3-58.6
Sorghum <sup>4</sup>	43	50	29	14	0	29.8	18.3-45.8
Wheat <sup>4</sup>	14	14	0	0	0	5.2	1.62-12.1
Combined	59	61	51	46	33	66.0	59.0-73.6

<sup>1</sup> For each soil/sand dilution 14 plants were analysed.

<sup>2</sup> Infective unit (IU) of *P. graminis* or IPCV-H per litre of homogenised soil estimated by means of the most probable number (data fit the Poisson distribution,  $P > 0.05$ ,  $\chi^2$  with 4df), <sup>†</sup> ignoring the 1:2 dilution ( $P > 0.05$ ,  $\chi^2$  with 3 df), <sup>‡</sup> ignoring the 1:2 and 1:4 dilution to fit the Poisson distribution ( $P > 0.05$ ,  $\chi^2$  with 2df), and \* not possible to do a valid estimation.

<sup>3</sup> Composite samples made of aliquots of equal weight from 32 plots.

<sup>4</sup> Composite samples made of aliquots of equal weight from 4 replication plots except for the plots where maize was grown for which samples were analysed individually.

In June 1997, after adoption of the various cropping systems, *P. graminis* inoculum potential between plots varied in a even higher range than that observed for the soil collected in December 1996. The highest *P. graminis* inoculum potential was 324 IU/l in a plot where maize was grown and the

lowest one was observed for the composite samples from the “wheat” plots (5.21 IU/l). In the area infested at a high level (90%) the number of infective units calculated for all the plots combined was higher for the samples collected in June 1997 (66.0 IU/l) than for the samples collected in December 1996 (10.4 IU/l) (IU/l calculated on the total number of plants analysed for each year, Table 4). Higher inoculum potential of *P. graminis* for the soil sampled in June 1997 compared to the soil sampled in December 1996 is mostly observed in plots where maize was grown in the post-rainy season. Surprisingly, the plots used for growing wheat showed the highest number of IU in December 1996 (33 IU/l) and the lowest in June 1997 (5.2 IU/l). These are the only plots which showed a reduction in inoculum potential of *P. graminis*.

## Discussion

A great variability in inoculum potential of *P. graminis* was observed between plots from an area that appeared homogeneously infested based on disease incidence (visual symptoms) in groundnut (Table 4). The heterogeneity was further amplified by the fact that only a small proportion of *P. graminis* propagules (about 7%) carry the virus. This observation is of great importance for the planning of experiments on peanut clump disease. Experiments conducted on large area will lead to high variability because of the heterogeneity of the inoculum potential in the soil. The 1993-1994 experiment using infested patches of small size, about 2 square meters, was more accurate than the 1996-1998 experiment where a great variability in initial inoculum potential to some extent hampered proper analysis of the effect of the various crop rotations. These observation suggest that experiment on peanut clump should be conducted preferentially on high number of small plots to minimise the variability due to difference in the level of infestation even in field area where homogeneous incidence occurs in groundnut.

Though it was difficult to analyse the effect of the cropping system on *P. graminis* inoculum potential, the experiments conducted in 1993-1994 and 1996-1998 showed that the cropping system used in the post-rainy season can influence IPCV incidence in rainy season crops of groundnut and pigeonpea and in wheat crops grown in the post-rainy season. Growing monocots such as maize (Table 2) and sorghum (Fig. 2), which are known to be among the preferred hosts for *P. graminis* and which also host IPCV (Ratna *et al.*, 1991, Legrève, 1999, Delfosse *et al.*, 1996), resulted in higher disease incidence in groundnut and pigeonpea crops compared to the other cropping systems studied. Maize usually shows a systemic virus

infection and the virus is transmitted through maize seed at a rate close to 1% (Delfosse *et al.*, 1996, Delfosse *et al.*, 1999). Sorghum is also an excellent host for *P. graminis*. However the genotype ICSV 88036 used in this experiment rarely showed systemic infection, the virus being mostly restricted to the roots. Maize (6 M ha in 1998) and sorghum (10.2 M ha in 1998) are two important crops in India where they are mostly grown during the rainy season, a favourable period for *P. graminis* multiplication. Therefore Maize and sorghum can be suspected to play an important role in the spread and survival of peanut clump disease.

While growing maize or sorghum favours the perpetuation of IPCV-H, growing mustard and marigold, dicotyledonous hosts, in post rainy season resulted in significantly lower IPCV-H incidence in both groundnut and pigeonpea crops (Table 2). In this paper mustard and marigold hosted IPCV-H in roots but *P. graminis* from IPCV-H infested soil did not infect mustard under controlled environmental conditions (Legrève, 1999). Ratna *et al.* (1991) reported infection of *P. graminis* on *Brassica nigra* [L.] Koch and *B. oleracea* L. grown on soil infested with the Bapatla isolate of IPCV (sea shore area of Andhra Pradesh) but the infection was limited to rare resting spores. Mustard and marigold, two important cash crops, could beneficially replace wheat and barley as post-rainy season crops in the cereal-groundnut rotation practised in Rajasthan and can lead to reduction of peanut clump disease in these areas. It may be difficult to change the cultural practice of rotating groundnut with cereals especially when it is a traditional practice recommended by agronomists. However, higher income provided by these two crops compared to wheat and barley, should add to the incentive for the farmers to follow this advise for clump infested fields.

The other dicotyledonous crops, groundnut, and pigeonpea, are also suspected not to support *P. graminis* multiplication (Ratna *et al.*, 1991, Legrève, 1999, Delfosse *et al.*, 1996). Indeed, they are also considered as fortuitous host for *P. graminis*. Surprisingly, in crop rotation experiments utilising pigeonpea, it was interesting to note a relatively high virus incidence in the indicator hosts (groundnut and pigeonpea grown in 1997 rainy season) only in the block infested at a high level (90%) (Table 2). This was unexpected since *P. graminis* was never observed in 25 pigeonpea roots tested and because the other dicots did not contribute to build up of the virus inoculum. We don't know if these results can be attributed to a heterogeneous distribution of virus inoculum in the soil or inoculum movement from plots where maize was grown during root growth or during soil preparation as it has been reported for *P. betae* (Tuitert, 1993). Indeed the four replication plots for pigeonpea were

located in the same area of the highly infested soil and were all adjacent to a maize plot.

Wheat is the host showing the highest clump incidence among both monocots and dicots studied to date (Delfosse *et al.*, 1996, Delfosse *et al.*, 1999). It supported systemic virus infection including transmission through seed at a rate of approximately 1% (Delfosse *et al.*, 1999). However, it did not support good multiplication of the *P. graminis* isolated from the experimental field of the ICRISAT farm (Legrève *et al.*, 1999, Delfosse *et al.*, 1999). Wheat is not an important crop in Andhra Pradesh where relatively high temperatures do not favour high yield. On the contrary, in Rajasthan where wheat is a major post-rainy season crop, *P. graminis* isolates multiply well on this host (Legrève *et al.*, 1999). High incidence was observed in the wheat crop grown in the 1997-1998 post-rainy season in plots where wheat was grown in 1996-1997 whereas plots used for different cropping systems showed nil to negligible incidence. Did wheat trap the viruliferous inoculum? Plots that were used for growing wheat were the only one showing reduction of inoculum potential of *P. graminis* after adoption of the various cropping systems. These plots showed the highest initial inoculum in December 1996 and the lowest one in June 1997 (Table 4). Wheat has been grown every post-rainy season since 1994 in this field. Did *P. graminis* adapted to wheat and was thus rendered less prone to infect sorghum bait plants used in the bioassay? Are there populations of *P. graminis*, that preferentially infect wheat or sorghum? Comparison of the host range of *P. graminis* isolates from this field prior to growing wheat and after several seasons of wheat cultivation are required to confirm this hypothesis. This was well beyond the scope of this investigation. Also the variation of *P. graminis* inoculum observed in IPCV infested soil did not allow a conclusive statement.

This paper mostly focused on the effect of cultivating post-rainy season crops on the incidence of peanut clump disease in the ensuing rainy season crops. However, studies on the influence of the cropping system practised during the rainy season are likely to yield valuable clues for a better understanding of the variation in IPCV incidence in rainy season crops of groundnut. The ability of monocotyledonous crops to build up virus inoculum potential can be expected to be high if they are raised during the rainy season, characterised by conducive temperatures and rainfalls for the multiplication of *Polymyxa* sp. (Legrève, 1999, Delfosse *et al.*, 1996), as compared to the post-rainy season. Recent experiments in the IPCV-H infested field during the rainy season indicated that growing various sorghum and pearl millet accessions or maize, resulted in very high disease incidence in the ensuing rainy season crops of groundnut (Delfosse *et al.*,

unpublished). These confirmed the reports of Dollet *et al.* (1976) and Thouvenel and Fauquet (1981) who observed high peanut clump incidence in groundnut crops rotated with *Sorghum arundinaceum* in West Africa. These aspects should be given high priority in future studies on the epidemiology of peanut clump disease in India and Africa. On the other hand, as demonstrated in Table 2, continuous cultivation with dicots such as groundnut and pigeonpea can contribute to severe reduction in disease incidence.

This is the first time that the inoculum potential of *P. graminis* and IPCV-H in tropical soil samples has been estimated by means of serial soil dilutions and the most probable number (MPN). Methods used prior to this did not facilitate optimum conditions for *P. graminis* infection and multiplication. The AIS with individual watering was developed to meet these conditions. Most of the sorghum plants grown on serial soil/sand dilutions that showed the presence of the vector also contained a large number of resting spores. Nevertheless, for some of the soil samples, the inoculum did not dilute as expected for a Poisson distribution (Adam and Welham, 1995). Therefore the estimation of the MPN was not possible or in some case the most concentrated soil/sand mixtures were ignored to fit the Poisson distribution (Table 4) Reasons for this are still unclear. It is possible that factors such as antagonism by other soil organisms or low porosity at the 1:2 and 1:4 soil/sand mixture were not favourable to *P. graminis* infection. Another explanation could be that *P. Graminis* inoculum is aggregated into root fragments and resting spores are released from such aggregates during soil/sand mixing process in a bi-cone mixer.

The inoculum potential of *P. graminis* in Indian soil was found to be much lower (0.9 to 200 IU/kg of soil, soil density = 1.3 kg/l) than in the case of *P. graminis* (4 to 5 600 IU/kg of soil, Bastin *et al.*, 1989) and *P. betae* (120 to 13 600 IU/kg of soil, Goffart, 1992) in soils from temperate areas. In the Indian soil collected from a block showing 90% incidence in a rainy season crop of groundnut, the percentage of viruliferous *P. graminis* among the total population was estimated to be close to 7%. This is similar to the low proportion of viruliferous propagules observed in the case of barley yellow mosaic virus (BaYMV) (Adams *et al.* 1988) and barley mild mosaic virus (BaMMV) transmitted by *P. graminis* (Chen *et al.*, 1991), and beet necrotic yellow vein virus (BNYVV) transmitted by *P. betae* (Tuitert and Homeester, 1992; Tuitert, 1994). It is interesting to note that even though the inoculum potential of viruliferous *P. graminis* in Indian soil is very low compared to soils from temperate areas, this inoculum is sufficient to induce clump disease at high incidence. In this experiment, wheat was used as a bait plant to assess the virus inoculum potential.

Recently we identified a sorghum genotype (IS 18519 from Uganda, ICRISAT germplasm) which is a host for *P. graminis* and unlike ICSV 88036, showed systemic infection by IPCV-H under field conditions. This genotype could be beneficially utilised in further tests to simplify the assessment of both fungus and virus inoculum potential by using only one bait crop.

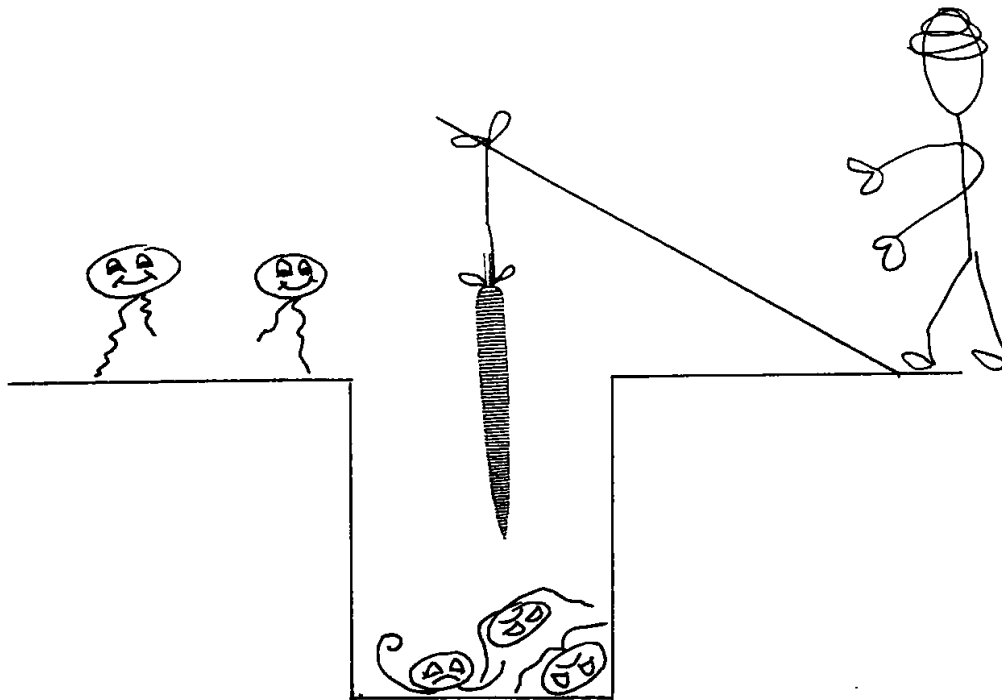
Expression of *P. graminis* inoculum potential apparently showed seasonal variation (compare MPNs of IU for the December 1996 samples to the June 1997 ones, Table 4). However, analysis of the inoculum potential of IPCV and *P. graminis* in soil samples over a longer period of time and sampling soil at different time during the year is required to accurately discriminate between the respective effects of the season and the cropping system on peanut clump disease incidence. The AIS with individual watering is a valuable tool to help to resolve this complex problem.

This paper described for the first time that pigeonpea can be infected by IPCV-H during the rainy season. In post-rainy season there was no overt symptoms on pigeonpea and the virus was mostly localised in roots. In the rainy season, symptoms were severe and the virus was detected in both leaves and roots. Symptoms were similar to those caused by IPCV in the other susceptible species such as groundnut, wheat and barley (Reddy *et al.*, 1988, Delfosse *et al.*, 1999). It suggests that IPCV may cause stunting by acting on phyto-hormones involved in plant growth.

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Trap cropping with  
Pearl millet



Pearl millet is a tropical crop, well-adapted to dry and hot climates. It emerges and establishes rapidly allowing exploration of a large volume of soil in a short time. Pearl millet is an excellent host for *Polymyxa graminis*, the vector of the Indian peanut clump virus. Planting with preferred hosts such as maize, pearl millet and sorghum is expected to result in large scale infection by the vector and it was expected that using these as trap crops prior to sowing groundnut will lead to reduction of inoculum potential in the soil if the trap crop was maintained for a short time interval, sufficient to stimulate germination of resting spores, but restricting *P. graminis* multiplication in roots. The small seed size (3-12 g/1000 grains) permits a dense sowing without prohibitive costs.

## 5-2. Reduction of Indian peanut clump (IPCV) incidence by trap cropping with pearl millet<sup>10</sup>

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### Abstract

Trials on the effect of trap cropping with pearl millet to reduce Indian peanut clump virus (IPCV) incidence were conducted at two locations in Andhra Pradesh (on the ICRISAT farm, during the rainy season and on a farmer's field in Guntur district during the post rainy season). In Rajasthan, trap cropping was done during the rainy season at Bobas and Rampura in Jaipur district. Pearl millet was sown in clump infested soil at high seed rates and allowed to grow for two weeks prior to incorporation in to soil and followed by sowing with groundnut. When pearl millet was sown at 100kg/ha, its root density reached 0.75 cm/cm<sup>3</sup> of soil and trap cropping reduced IPCV incidence by 20 to 78%. The method was effective at all the locations and in soils infested with two distinct IPCV serotypes. If pearl millet was sown at 20kg/ha there was no significant effect on disease incidence in groundnut. Pearl millet used solely as a source of organic matter also reduced virus incidence but to a lesser degree than that achieved with trap cropping. Various factors which contributed to reduction in disease incidence are discussed.

**Key words:** Indian peanut clump virus, pecluvirus, *Polymyxa graminis*, management, pearl millet, trap cropping.

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<sup>10</sup> The results were partially published as: Delfosse P, Reddy AS, Devi KT, Devi PS, Reddy DVR. 1997. Pearl millet as a bait crop for the management of Indian peanut clump virus. *Indian Journal of Plant Protection* **25**: 70-72.

## Introduction

Studies on the epidemiology of *P. graminis* (Reddy *et al.*, 1988; Delfosse *et al.*, 1996; Legrève, Vanpee, Delfosse & Maraite, 1999) have shown that this vector infects and transmits IPCV to groundnut crops mainly during the early part of the rainy season (June-October), coinciding with the onset of monsoon rains that follow the dry hot summer. Drought and heat prevailing during April to June are conducive for the breakdown of dormancy of *P. graminis* resting spores (Legrève *et al.*, 1999). Therefore, heavy monsoon rains, which occur when the groundnut crops are young, contribute to high disease incidence and severe damage to the crop (Delfosse *et al.*, 1996). Although *P. graminis* infects dicots, evidence for intense multiplication in these hosts is lacking (Ratna *et al.*, 1991; Delfosse *et al.*, 1996; Legrève *et al.*, 1999). On the contrary, monocots such as maize (*Zea mays* L.), pearl millet (*Pennisetum glaucum* [L.] R. Br.) and sorghum (*Sorghum bicolor* [L.] Moench) were found to be the preferred hosts, on the basis of relatively high incidence and multiplication as measured by the number of sporosori present in the roots (Ratna *et al.*, 1991; Delfosse *et al.*, 1996; Legrève *et al.*, 1999). They also host the virus. While groundnut shows high disease incidence mostly during the rainy season, monocots can be infected by the virus with relatively high incidence throughout the year (Delfosse *et al.*, 1996; Delfosse *et al.*, 1999). Based on results obtained during these epidemiological studies, various strategies such as early sowing of groundnut crops prior to the onset of monsoon rains, crop rotation which avoids cereal hosts supporting *P. graminis* multiplication, and trap cropping, were evaluated for the management of IPCV. This paper focuses on the trap cropping strategy which is detailed below.

Planting with preferred hosts such as maize, pearl millet and sorghum is expected to result in large scale infection by the vector and it was expected that using these as trap crops prior to sowing groundnut will lead to reduction of inoculum potential in the soil if the trap crop was maintained for a short time interval, sufficient to stimulate germination of resting spores, but restricting *P. graminis* multiplication in roots. Pearl millet was selected because it is a tropical crop, well-adapted to dry and hot climates. It emerges and establishes rapidly to minimise the risk of heat and moisture stress in areas where soil surface temperatures often exceed 40°C. Seeds germinate after 1 or 2 days and germination rate is favoured by a sharp optimum temperature in the range 30-35°C. Pearl millet has very fast root development, especially during the vegetative phase (until three weeks

after emergence) that will allow exploration of a large volume of soil in a short time (Khairwal, Ram & Chhabra, 1990). The root elongation rate for pearl millet at 25 to 30°C ranged from 2 to 3 cm per day (Garcia-Huidobro, Monteith & Squire, 1982) but much higher rates (4.5 to 7.1 cm/day) were also reported (Azam Ali, Gregory & Monteith, 1984). The greatest root density for pearl millet crops is found in the upper 20 cm of the soil profile (Chopart, 1983; Hafner, George, Bationo & Marschner, 1993, Azam-Ali *et al.*, 1984). Moreover, pearl millet seed is readily available to farmers at lower cost (5 IR/kg equivalent to 0.1 UK£/kg ) than seed of other cereal crops. The small seed size (3-12 g/1000 grains) (Khairwal *et al.*, 1990) permits a dense sowing without prohibitive costs. We report in this paper the influence of trap cropping with pearl millet on the incidence of peanut clump disease under three different agro-ecological environments in India, on station as well as in farmers' fields.

## Materials and methods

### *Selection of sites*

In Andhra Pradesh, experiments were conducted on station at ICRISAT, Patancheru, during the rainy season, and on farm at Ganapavaram in Guntur district during the post rainy season. In the northern state of Rajasthan, experiments were conducted during the rainy season in farmer's fields at Rampura villages in Jaipur district. At ICRISAT the experimental field was mostly used to grow rainy season groundnut crops and since 1994, groundnut was rotated with wheat grown in the post rainy season. In Guntur district groundnut is mostly grown during the post rainy season and rotated with rice (*Oryza sativa* L.), finger millet (*Eleusine coracana* [L.] Gaertner), chillies (*Capsicum annuum* L.) and various vegetables. In Rajasthan, groundnut is exclusively grown during the rainy season and mainly rotated with winter crops such as barley (*Hordeum vulgare* L.), mustard (*Brassica juncea* L.) and wheat (*Triticum aestivum* L.).

### *Experimental details*

Fields infested by IPCV were identified in the various locations and infested patches were selected for homogenous distribution of clump disease in groundnut crops grown during the season preceding each of the experimental seasons. The fields in Patancheru, Ganapavaram and Rajasthan were respectively infested with the Hyderabad (IPCV-H),

Bapatla (IPCV-B), and Durgapura isolate (IPCV-D) of IPCV. IPCV-B and IPCV-D are serologically related while IPCV-H is a distinct serotype (Nolt *et al.*, 1988). At all locations the soil was sandy and irrigation was given to facilitate soil preparation and germination. The details of the experiments are summarised in Table 1. Square blocks were demarcated in infested patches and divided into square plots of size limited to 0.25 m<sup>2</sup> or 1 m<sup>2</sup> to minimise the influence of variability due to uneven distribution of *P. graminis* inoculum in the soil (Chapter 5-1). The number of replication blocks ranged from 6 to 16 according to the infested areas available in each field. The treatments were as follows. In each infested block, one plot (chosen at random) was left as fallow (untreated plot) while others were sown by broadcasting pearl millet seed (cv. ICMH-451, 10g/1000 grains) either at 20 or 100 kg seed/ha to facilitate complete soil exploration. A second irrigation was given during the growth of pearl millet if soil moisture provided at the time of field preparation was no longer sufficient for plant establishment. Two weeks after sowing, the pearl millet crop was chopped, ploughed into the soil, and groundnut (cv. NCAc 17090) was sown in lines (5 and 10 lines of each 10 plants for 0.25 and 1 m<sup>2</sup> plots respectively) in both treated and untreated plots. The intended population of groundnut plants was kept high to obtain representative percentages of IPCV incidence.

Pearl millet was also used solely as a source of organic matter (green manure) to assess if the effect on virus incidence, in plot where pearl millet was incorporated, was the result of organic matter supply to the soil or due to the trapping of viruliferous *P. graminis* inoculum during the growth of pearl millet. For this purpose pearl millet was sown in disease-free areas of the experimental fields and raised for two weeks. At the time of sowing with groundnut, these plants were uprooted, the soil was eliminated from the roots, and the plants were chopped and thoroughly incorporated into the soil of the experimental infested plots. In each plot the disease incidence in groundnut was monitored at regular intervals on the basis of visual symptoms. A final scoring was done close to maturity and apparently healthy looking plants were tested for virus presence by DAS-ELISA (Reddy *et al.*, 1998). At ICRISAT after harvesting complete plants on 19 November in 1996 season, and 30 October in 1998 season, the production of each plot was dried at 35°C for 48 h in a ventilated drier. Various yield components of groundnut (Table 3) were analysed.

The root density of the pearl millet crop after 2 weeks of growth and the amount of fresh organic matter brought to the soil by these plants at the time of ploughing, were assessed by sampling 5 millet plants in each plot, roots were washed free of soil and the plant fresh weight measured. The

total root length was measured for each plant by counting and measuring the root segments, and the millet plant population was estimated in plots chosen at random.

**Table 1.** Experimental details of the field trials on trap cropping with pearl millet, at ICRISAT (inland) and Ganapavaram (coastal area) in the southern state of Andhra Pradesh and at Bobas and Rampura in the northern state of Rajasthan.

	ICRISAT		Ganapavaram	Rampura
Virus isolate <sup>a</sup>	IPCV-H		IPCV-B	IPCV-D
Season	rainy	rainy	post-rainy	rainy
	1996	1998	1996-97	1997
PM-20	no	no	no	yes
PM-100	yes	yes	yes	yes
PM-organic	no	yes	no	no
Untreated plots	yes	yes	yes	yes
Date of sowing with pearl millet	26/06/96	25/06/98	31/01/97	15/06/97
Date of sowing with groundnut	10/07/96	10/07/98	15/02/97	02/07/97
Block size	1.5 x 1.5 m		1.5 x 1.5 m	3 x 3 m
Number of blocks	6	16	7	12 + 12 <sup>b</sup>
Plot size	0.5 x 0.5 m		0.5 x 0.5 m	1 x 1 m
No of groundnut seed per plot	50	50	50	100
Yield assessments	yes	yes	no	no
Final scoring for symptoms	30/09/96	14/08/98	18/03/97	11/08/97

PM-20: pearl millet crop sown at a seed rate of 20 kg/ha and raised for 2 weeks before being chopped and ploughed into the soil prior to sowing with groundnut.

PM-100: same as PM-20 but at a seed rate of 100 kg/ha.

PM-organic: same as PM-100 but the millet crop was grown for two weeks in a disease free area of the field, uprooted and brought to the experimental infested plots to be incorporated into the soil prior to sowing with groundnut.

Untreated: plots kept as fallow during the pearl millet growth and sown with groundnut concomitantly with the plots where trapping was done. A sowing rate of 100 kg/ha correspond approximately to a millet plant population of 800/m<sup>2</sup>.

<sup>a</sup> The virus isolates IPCV-B (Bapatla, Andhra Pradesh) and IPCV-D (Durgapura, Rajasthan) are serologically related while IPCV-H (Hyderabad) belongs to a separated serotype.

<sup>b</sup> Twelve blocks each were used in two field areas where either wheat or mustard was grown during the previous winter season.

To confirm that infection by *P. graminis* and IPCV occurred during the two weeks pearl millet was grown in infested plots, pearl millet plants were assayed for virus presence by DAS-ELISA and for *P. graminis* by microscopic observation of stained roots. For each replication block, 5 pearl millet plants collected at the time of ploughing the crop into the soil were initially assayed for virus presence in their leaves. The plants were then transplanted in sterile sand and maintained for one month in a glasshouse at 25-30°C to allow virus replication and vector multiplication. After this incubation period to facilitate detection, plants were assayed for virus and *P. graminis* presence in their roots.

### *Data analysis*

After angular transformation ( $\theta = \arcsin \sqrt{\%}$ ), the proportions of infected plants were analysed using ANOVA with fixed (treatments) and random (blocks) effects. When treatments were significant in ANOVA, the proportion of infected plants were compared in multiple comparison procedure using Tukey's honestly significant difference test (transformed data). The yield data were analysed by ANOVA without transformation.

## **Results**

### *Pearl millet development.*

At ICRISAT during the 1998 rainy season, the pearl millet roots after 2 weeks of growth were found mostly in the upper 15 cm of the soil profile. Few roots reached 20 cm below soil surface. The total root length per plant was calculated to be  $138 \pm 38$  cm (mean  $\pm$  stdev) and the root density in the 0-15 cm layer was estimated to be  $0.75 \pm 0.20$  cm/cm<sup>3</sup> in plots sown at 100 kg seed per ha. The plant population in these plots reached approximately 800 plants/m<sup>2</sup>. The fresh weight of pearl millet organic matter from infested and disease free plots were similar,  $2.0 \pm 0.9$  kg per 0.25 m<sup>2</sup> plot sown at a seed rate of 100 kg/ha. At the other locations, the depth reached by the pearl millet roots was also found to vary between 15 and 20 cm below soil surface.

### *Virus and P. graminis detection in the pearl millet trap crop.*

Leaf samples from Rajasthan, collected at the time of ploughing the pearl millet crop into the soil gave a weak reaction in DAS-ELISA. Many of the transplanted plants died during incubation to facilitate virus and *P. graminis* detection. The surviving plants were tested by DAS-ELISA for virus presence in their roots. For the field located at Rampura, Rajasthan, 20% (2/10) and 14% (1/7) of the pearl millet plants tested positive by ELISA respectively for the areas where wheat and mustard were grown during the previous winter season. At ICRISAT in 1998, after collection from the field, plants were quickly transplanted into sterile sand in individual container and watered with nutrient solution to reduce water stress. After one month of incubation period under glass house conditions, out of 54 plants that survived, 30 (55%) were found to contain *P. graminis* resting spores in their roots and 1 reacted positively in DAS-ELISA for

virus presence in both leaves and roots. The *P. graminis* infected plants originated from 12 out of 16 replication plots.

**Table 2.** Effect of trap cropping with pearl millet on IPCV incidence in the ensuing groundnut crop at three major locations in India.

Location and season	IPCV incidence in groundnut <sup>1</sup>				ANOVA 2-ways	n/N <sup>2</sup>
	min (%)	max (%)	mean (%)	total proportion		
ICRISAT rainy 1996						
PM-100	4	29	13 <sup>a</sup>	47/350	$F(1,5)=81.6$ $P=0.00002$	6/6
Untreated	32	94	61 <sup>b</sup>	198/334		
ICRISAT rainy 1998						
PM-100	0	43	7 <sup>a</sup>	43/607	$F(2,30)=15.5$ $P=0.00002$	14/16
PM-organic	0	56	14 <sup>a</sup>	97/617		
Untreated	2	71	26 <sup>b</sup>	177/673		
Ganapavaram post-rainy 1996-97						
PM-100	2	10	7 <sup>a</sup>	23/315	$F(1,6)=9.4$ $P=0.0221$	6/7
Untreated	3	39	20 <sup>b</sup>	72/364		
Rampura rainy 1997 <sup>3</sup>						
<u>Mustard field</u>						
PM-20	8	24	35 <sup>a</sup>	350/946	$F(2,22)=4.9$ $P=0.0174$	6/12
PM-100	1	56	24 <sup>b</sup>	248/1020		
Untreated	2	87	37 <sup>a</sup>	383/988		
Mean (mustard)			32	981/2954		
<u>Wheat field</u>						
PM-20	50	96	77 <sup>a</sup>	878/1138	$F(2,22)=5.2$ $P=0.0138$	6/12
PM-100	29	88	61 <sup>b</sup>	663/1102		
Untreated	42	97	76 <sup>a</sup>	830/1095		
Mean (wheat)			71	2371/3335		

PM-20, PM-100, PM-organic and Untreated plots: see table 1.

A sowing rate of 100 kg/ha corresponds approximately to a pearl millet plant population of 800/m<sup>2</sup>

<sup>1</sup> Virus incidences for one experiment followed by the same letter do not differ at  $P \leq 0.05$  in multiple comparison procedure of angular transformed means (Tukey's honestly significant difference test). Means were calculated between the replication blocks and the total proportion represented the observation for all the blocks combined.

<sup>2</sup> Number of blocks where IPCV incidence in plots treated with pearl millet was lower than in untreated plots.

<sup>3</sup> Twelve blocks each were used in two areas of the same field where either wheat or mustard was grown during the previous winter season.

### *Effect of trap cropping with pearl millet on virus incidence and yield in groundnut*

In most of the locations IPCV incidence was significantly reduced where pearl millet was used as a trap crop and sown at the high seed rate of 100 kg/ha (Table 2). The percentage reduction in disease incidence in plots where pearl millet was sown at 100 kg/ha compared to untreated plots varied from 20% at Rampura in the field where wheat was grown, to 79% at ICRISAT during the 1996 season. Additionally, the reduction in disease

incidence was observed in the majority of the replication blocks. It was also apparent that crop grown in the preceding season influenced the IPCV incidence. At Rampura, virus incidence in plots where wheat was grown during the post rainy season (71%) was higher than in plots where mustard was grown (32%). When used at the seed rate of 20 kg/ha, trap cropping with pearl millet had no effect on virus incidence. When pearl millet was grown in disease free area and incorporated into infested plots as a source of organic matter, the incidence at ICRISAT during the 1998 rainy season was also reduced compared to untreated plots but the reduction in virus incidence (48%) was less than that obtained with the millet crop actually grown in the infested plots (74%). Incorporation of pearl millet seedlings influenced groundnut yield. Indeed at ICRISAT in 1998, the total biomass in plots where pearl millet was sown at 100 kg/ha was significantly higher than in untreated plots (Table 3). This effect was clearly visible in the field for both 1996 and 1998 season. Groundnut plants in plots treated with pearl millet were larger and had more vigorous foliage compared to plants from untreated plots. Plots where pearl millet was used as a source of organic matter showed similar biomass production as compared to untreated ones ( $P>0.05$ ). Trapping with pearl millet or incorporation of green manure did not improve significantly the other yield components such as pod and seed number and weight (Table 3).

**Table 3.** Effect of trap cropping with pearl millet on various yield components of groundnut crops grown in IPCV infested areas at ICRISAT, Andhra Pradesh.

	Yield per plot of 0.25 m <sup>2</sup>				
	Total biomass (g)	No of Pods	Pod weight (g)	No of seeds	Seed weight (g)
Rainy season 1996 (n=6)					
PM-100	-	140 <sup>a</sup>	121.7 <sup>a</sup>	266 <sup>a</sup>	79.2 <sup>a</sup>
Untreated	-	150 <sup>a</sup>	97.5 <sup>a</sup>	251 <sup>a</sup>	63.3 <sup>a</sup>
ANOVA $F(1, 5)$		0.142	1.520	0.080	1.260
$P$ -value		0.7219	0.2724	0.7862	0.3133
Rainy season 1998 (n=16)					
PM-100	249.8 <sup>a</sup>	40 <sup>a</sup>	17.7 <sup>a</sup>	-	9.0 <sup>a</sup>
PM-organic	227.3 <sup>ab</sup>	63 <sup>b</sup>	20.7 <sup>a</sup>	-	10.4 <sup>a</sup>
Untreated	201.8 <sup>b</sup>	52 <sup>ab</sup>	18.4 <sup>a</sup>	-	9.5 <sup>a</sup>
$P$ -value	0.018	0.038	0.659		0.731

PM-100, PM-organic and Untreated plots: see table 1

All weights were measured after drying at 35°C for 48h.

If the treatment was significant in ANOVA ( $P$ -value $\leq$ 0.05), means for one experiment in the same column were analysed in multiple comparison procedure. If followed by the same letter, means do not differ significantly (Tukey's honestly significant difference test,  $P\leq$ 0.05).

- not measured.

## Discussion

For a trap cropping strategy to be efficient, the roots of the host have to grow fast to reach and stimulate immobile resting spores of *P. graminis*. Moreover the parasitic zoospores have a limited mobility in the soil (Tuitert, 1993). Reasons for selecting pearl millet to serve as a trap crop were given in the introduction and furthermore its suitability was assessed. The crop sown at a seed rate of 100 kg/ha provided a dense plant population (800 plants/m<sup>2</sup>) and a roots density of 0.75 cm/cm<sup>3</sup> mostly concentrated in the top 20 cm soil layer. These results are comparable to previous reports on pearl millet root density in the soil profile (Chopart, 1983; Hafner *et al.*, 1993; Azam-Ali *et al.*, 1984). Pearl millet appeared thus as the ideal crop to explore a large volume of soil in a short time interval and trap a maximum inoculum of *P. graminis* in the upper layer of the soil profile where viruliferous inoculum is believed to be highest. Indeed infection of groundnut plants occurs mostly at young stages of crop growth (Delfosse *et al.*, unpublished) and most of the groundnut root system is generally concentrated at a depth of 5-35 cm (Narasinga Rao, 1936 quoted by Ramanatha Rao & Murthy, 1994).

After infection *P. graminis* requires 10 to 12 days to produce new resting spores in the cortical root cells of sorghum and pearl millet (Ratna *et al.*, 1991; Legrève *et al.*, 1999). The trapping method allowing the millet crop to grow for only 2 weeks was therefore preferred to restrict the multiplication of *P. graminis* in millet roots. Indeed, in 2 weeks *P. graminis* can produce few resting spores, as the obligate parasite will be in the plasmodial and zoosporangial stages. Whether or not these stages of *P. graminis* can survive in moribund roots of millet plants ploughed into the soil is yet to be elucidated. Nevertheless, difficulty to retrieve *P. graminis* from plants exposed to water stress (pearl millet plants collected from Rajasthan and transplanted at ICRISAT) suggested that survival of *P. graminis* in plants ploughed into the soil is unlikely. Additionally if *P. graminis* resting spores are produced, they are likely to be immature or dormant and therefore they do not represent, a priori, an immediate risk for the succeeding groundnut crop. Longer periods of millet development were not tested. Maintaining pearl millet for a longer time would probably result in higher root density in the soil, thus increasing the probability of trapping the inoculum. This is, however, not advisable because it increases the risk of multiplying *P. graminis* inoculum and would lead to delayed sowing of groundnut which is known to cause substantial yield loss and reduction in kernel quality especially in rainy season crops (Smartt, 1994).

Results presented have shown that trap cropping with pearl millet resulted in reduction of IPCV incidence at three locations infested with three distinct IPCV isolates. The reduction of IPCV incidence due to trap cropping with pearl millet appeared to be a combined effect of actual trapping of the inoculum by the millet roots and a change in soil organic matter content which affects the virus inoculum by an unknown process. Presumably pearl millet root system trapped *P. graminis* inoculum efficiently and virus transmission did occur during the two weeks of pearl millet growth. This was demonstrated by the presence of *P. graminis* resting spores in roots of more than half of the pearl millet plants analysed at ICRISAT in 1998. Virus incidence in pearl millet plants was low. This was expected because pearl millet is a relatively poor host for IPCV compared to wheat, barley, maize and groundnut (Delfosse *et al.*, 1996). The virus is rarely detected in its leaves and the short time interval between sowing and the ELISA test did not facilitate virus detection. On the other hand we have shown that if millet is used solely as a source of organic matter, the reduction in disease incidence is lower than that achieved with the actual trapping. How the organic matter brought by the millet crop influenced the inoculum potential of viruliferous *P. graminis* is yet to be elucidated. A modification of the soil microflora that increased the antagonist pressure on *P. graminis* or a soil texture and water holding capacity improved by incorporation of organic matter, favourable to healthier growth of groundnut plants, are among many possible explanations.

Trap cropping with pearl millet improved the total biomass production by increasing mostly the vegetative production (foliage) of groundnut. Nevertheless there was no significant effect on pod and seed yield of groundnut. Previous reports have shown that IPCV does not affect flowering and seed viability in groundnut (Reddy *et al.*, 1988; Reddy *et al.*, 1998). However the virus strongly suppressed crop growth, both root and shoot development being affected (Reddy *et al.*, 1988), reducing mineral uptake and photosynthesis and consequently, pod yield. Yield measurements in the framework of this research gave only relative information on the effect of trapping with pearl millet on groundnut production. The groundnut plant population in the small experimental plots was intentionally kept very high ( $1-2 \times 10^6$  plants per ha) to facilitate consistent estimation of virus incidence and yield cannot be compared to production under normal farming practices. The optimal plant population under rainfed conditions is  $1 \times 10^5$  plants per ha. Higher or lower plant density causes yield reduction and high plant population affects kernel quality (Smartt, 1994). It is difficult to conduct trials on a large scale using

a normal groundnut plant population because of the uneven distribution of clump disease in infested field.

We could not measure the long term effect of trap cropping with pearl millet on IPCV incidence in the following rainy season crops of groundnut. Indeed, plots were of small size and field preparation for post rainy season crops disturbed identification marks and caused soil movement. Nevertheless, at ICRISAT and Ganapavaram, negligible IPCV incidence in the following groundnut crop, in areas of the fields where trap cropping experiments were conducted (data not presented), indicated that pearl millet may not have contributed to enhancement of IPCV inoculum as a result of formation of sporosori.

In conclusion, trap cropping with pearl millet reduced clump disease incidence and appeared promising in leading to reduction of inoculum potential of IPCV in soil. It is likely that it could also apply to peanut clump virus (PCV), a similar virus occurring in western Africa. The method is only applicable to farms provided with irrigation facilities and could be included in an integrated approach to the management of peanut clump virus disease. Trap cropping with pearl millet in conjunction with cultural practices such as the use of virus free seeds (Reddy *et al.*, 1998), crop rotations which avoid cereals supporting *P. graminis* multiplication, and clean cultivation (removal of grassy weeds) (Delfosse *et al.*, 1996; Delfosse *et al.*, 1997) are to date among the strategies available to Indian farmers to protect from this destructive virus. To our knowledge, this is the first report which examines trap cropping as an option for the management of a *Polymyxa*-transmitted virus.

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### **5-3. Early sowing before the onset of monsoon rains reduces Indian peanut clump virus (IPCV) incidence in groundnut crops.<sup>11</sup>**

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#### **Abstract**

Experiments were conducted at three major locations in India to assess the influence of the date of sowing on clump disease incidence. Early sowing of rainy season groundnut crops before the onset of monsoon clearly reduced disease incidence and improved yield in the northern state of Rajasthan and in the southern state of Andhra Pradesh. The reduction percentage in virus incidence ranged from 21 to 78% in fields infested with two distinct serotypes of IPCV. Additionally, trials conducted on station at ICRISAT demonstrated that susceptibility of groundnut plants to IPCV infection was reduced as the plants aged. Two and 3 wk old plants grown under glasshouse conditions in sterile sand prior to transplanting in the field mostly escaped the disease while younger plants were susceptible to infection. The amount and distribution of rainfall appeared to be the key factors contributing to variation in disease incidence in rainy season groundnut crops. The later the plants were exposed to large irrigation during crop growth, the less they were infected. The results of these experiments suggested that early sowing of groundnut prior to the onset of monsoon rain is a promising strategy for the management of clump disease.

**Key words:** IPCV, *Pecluvirus*, *Polymyxa graminis*, epidemiology, management

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<sup>11</sup> To be submitted for publication

## Introduction

Seasonal variation in clump disease incidence was reported. For instance, groundnut crops sown with the onset of monsoon rains were usually severely affected by clump disease while post rainy season crops sown at Hyderabad (Sanga Reddy District, Andhra Pradesh) in November and Bapatla in December-January (Guntur District, Andhra Pradesh) mostly escape the disease (Nolt & Reddy, 1984, Reddy *et al.*, 1988, Delfosse *et al.*, 1996). Additionally when rainy season crops were sown before the onset of monsoon rains the disease incidence was negligible. This was observed in Pakistan in April sown crops and in the Indian states of Punjab and Rajasthan when different sowing dates were experimented (Reddy *et al.*, 1988, Delfosse *et al.*, 1995).

Epidemiological studies on IPCV and its vector *P. graminis* were conducted to understand how the date of sowing affects clump disease incidence. Extreme heat and drought during the summer season (April-June), prior to crop sowing in rainy season, were believed to play an important role in the disease epidemiology (Delfosse *et al.*, 1996). Later, they were shown to be crucial factors that favour infection potential of resting spores of the vector, *P. graminis* (Legrève *et al.*, 1999). The quantity and distribution of rainfall were also shown to play an important role in the disease epidemiology. *P. graminis* zoospores require free-water in the soil in order to swim towards to roots of the host. Heavy rains were shown to favour infection by the vector *P. graminis*. They resulted in high disease incidence and severe stunting of groundnut plants especially if they occurred when the crop was young (Delfosse *et al.*, 1996).

In this paper we report on field experiments conducted at several locations in India to determine the effect of the date of sowing, in relation to rainfall and the age of groundnut plants, on clump disease incidence.

## Materials and Methods

### *Influence of the date of sowing on disease incidence*

Experiments were conducted in sandy soil in three regions in India. In Andhra Pradesh, trials were conducted on station at ICRISAT, Patancheru (near to Hyderabad, an inland area) during the rainy season, and on farm at

Ganapavaram in Guntur district (a coastal area) during the post rainy season. In the northern state of Rajasthan, experiments were conducted during the rainy season in farmer's fields at Bobas and Rampura villages in Jaipur district. Details on the cropping system practised at these locations has been given elsewhere (Chapter 5-2).

**Table 1.** Experimental details of the field trials on the influence of the date of sowing on IPCV incidence in groundnut crops conducted at ICRISAT (main land area) and Ganapavaram (coastal area) in the southern state of Andhra Pradesh and at Rampura in the northern state of Rajasthan, India.

Virus isolate <sup>a</sup>	ICRISAT		Ganapavaram	Rampura
	IPC-V-H		IPC-V-B	IPC-V-D
Season	rainy 1996	rainy 1998	post-rainy 1996-97	rainy 1997
Date of sowing				
GN-1	26 Jun	25 Jun	25 Dec*	15 Jun
GN-2	10 Jul*	10 Jul*	31 Jan	2 Jul*
GN-3	24 Jul	-	15 Feb	-
Block size	1.5 x 1.5 m		1.5 x 1.5 m	3 x 3 m
Number of blocks	6	16	7	12 + 12 <sup>b</sup>
Plot size	0.5 x 0.5 m		0.5 x 0.5 m	1 x 1 m
No of groundnut seed per plot	50	50	50	100
Yield assessments	yes	yes	no	no
Final scoring for symptoms	30/09/96	14/08/98	18/03/97	11/08/97

<sup>a</sup> The virus isolates IPCV-B (Bapatla, Andhra Pradesh) and IPCV-D (Durgapura, Rajasthan) are serologically related while IPCV-H (Hyderabad) belongs to a distinct serotype.

<sup>b</sup> Twelve blocks each were used in two field areas where either wheat or mustard was grown during the preceding winter season.

At Ganapavaram, in 1996-97, GN-1 was sown by the farmer at a seed rate of 70 seeds/m<sup>2</sup> equivalent to 17 seeds/plot and not 50 seeds/plot.

Dates followed by an asterisk (\*) are in the range of a normal date of sowing for the region and the season analysed.

Fields infested by IPCV were identified at the various locations and infested patches were selected for their homogenous distribution of clump disease in groundnut crops grown during the season preceding each of the experimental seasons. The fields in Patancheru, Ganapavaram and Rajasthan were infested with IPCV-H (Hyderabad), IPCV-B (Bapatla), and IPCV-D (Durgapura) isolates, respectively. IPCV-B and IPCV-D are serologically related while IPCV-H is a distinct serotype (Nolt *et al.*, 1988). At all locations irrigation was given to facilitate soil preparation and seed germination. The design of the field trials was identical to those previously described (Chapter 5-2) and the details of the experiments are summarised in Table 1. Square blocks were demarcated in infested patches and divided into small square plots of 0.25 m<sup>2</sup> or 1 m<sup>2</sup>. This is to minimise the variability due to possible heterogeneous distribution of *P. graminis* inoculum in the soil (Chapter 5-1). The number of replication blocks

ranged from 6 to 16 according to the number of infested patches available in each field. The treatments were as follows. In each infested block, in plots chosen at random, groundnut (cv. NCAc 17090) was sown in lines each of 10 plants (5 and 10 lines in 0.25m<sup>2</sup> and 1 m<sup>2</sup> plots respectively). Sowing was repeated at 15 day intervals using one plot at each sowing. The intended population of groundnut plants was kept high to obtain representative percentages of IPCV incidence. In each plot the disease incidence in groundnut was monitored at regular intervals on the basis of visual symptoms. A final scoring was done close to maturity and disease incidence based on visual symptoms was compared for the various dates of sowing. At ICRISAT after harvesting the whole plants at maturity, various yield components of groundnut were analysed (Table 3).

#### *Influence of the age of the crop on disease incidence*

These experiments were conducted on the ICRISAT farm to assess if the susceptibility of groundnut plants to infection by IPCV was reduced with crop age. The experiments conducted during the 1997 and 1998 rainy seasons, consisted of sowing/transplanting groundnut plants of various ages at regular time intervals in an IPCV infested field under natural conditions. For the 1997 season, 6 replication blocks (1m x 3m) were demarcated and each divided into 6 plots of equal size (1m x 0.5m). Groundnut plants aged 0, 1, 2 and 3 weeks were sown (0 week old plants) or transplanted (1-3 week old plants) in 4 distinct sub-plots. The sowing/transplanting was done on six occasions in July and August (Table 4). For each age and each date of sowing/transplanting, 12 groundnut plants (2 lines of six plants) were used per replication. Prior to transplanting in the field, 1-3 week old plants were grown under glasshouse conditions in sterile sand and watered with nutrient solution. The groundnut plants were raised in the field for two months under natural rainfall and then IPCV incidence was recorded on the basis of visual symptoms. During the 1998 season the plants were sown/transplanted at 8 successive dates in July and August (Table 4). Plots sown in July were harvested on 3 November and those sown in August were harvested from 7 to 21 December. Various yield components were analysed (Table 5).

#### *Influence of the irrigation pattern in relation to the age of the plants on disease incidence*

As mentioned in the introduction it is suspected that groundnut plants are mostly susceptible to infection when they are young. To test this

hypothesis, experiments were designed where groundnut plants received one heavy irrigation to stimulate virus infection at increasing ages. These experiments were conducted in a field of the ICRISAT farm, under rain-out shelters (2 x 2m) covered with white polythene sheets. Each shelter had two lateral windows for ventilation and protected one replication block. Each block (1.5 x 1.5 m) was divided into 4 square plots of 0.25 m<sup>2</sup> with a distance between plots of 0.5 m. Each plot was bordered by an aluminium dam that emerged 20 cm above the soil level and penetrated to a depth of 30 cm into the soil. The dam was installed to limit water movement from one plot to another. Each plot was sown with 50 groundnut seeds. Four irrigation regimes (IR) were tested: 40 mm on day 0 and on day 4 (IR-0); 40 mm on day 7 and day 10 (IR-7); 40 mm on day 14 and day 17 (IR-14); and finally 40 mm on day 28 and day 31 (IR-28). Irrigation was done manually with the help of a watering can. Additionally, life support irrigation of 2 x 4mm was given during the weeks the plots were not treated with the above irrigation regimes. The plants were maintained under the shelters for a period of approximately 3 months, a time considered as adequate to reach the plateau of virus incidence in groundnut crops (Delfosse *et al.*, 1996). The disease incidence was then recorded based on ELISA tests conducted on young leaves from individual plants (Reddy *et al.*, 1998). In 1998, the experiment was repeated. A first batch of plants was sown on 25 June and a second one was sown in 6 new replication blocks on 4 August. Pods were harvested at maturity to analyse the yield (Table 6).

### *Data analysis*

All the trials were conducted as a randomised complete block design. After angular transformation ( $\theta = \text{arc sine } [\sqrt{\%}]$ ), the proportions of infected plants were analysed using ANOVA with fixed (treatments) and random (blocks) effects. When treatments were significant in ANOVA, difference between mean virus incidences ( $\theta$ ) were compared to the SED. The yield data were measured after drying the harvest at 35°C for 48h in a ventilated dryer and analysed by ANOVA without transformation.

## **Results**

### *Effect of the date of sowing on IPCV incidence and yield*

In the case of rainy season crops raised at ICRISAT in 1996 and 1998, and at Rampura in Rajasthan in 1997, an early sowing before the onset of

monsoon rains (GN-1) clearly reduced IPCV incidence compared to crops sown with the onset of monsoon (GN-2) (Table 2). The percentage in reduction of disease incidence ranged from 21% at Rampura in a field where mustard was grown as the previous crop, to 78% at ICRISAT in 1996.

At ICRISAT in 1996 the highest virus incidence was observed for the crop sown with the onset of monsoon rains (GN-2) and high rainfall occurred during the 15 days that followed the sowing (186 mm). On the contrary, crops sown early, before monsoon (GN-1), and crop sown 15 days beyond the onset of monsoon (GN-3) showed low disease incidence. Their sowing was followed by a relatively low rainfall during the subsequent 15 days of crop development (Table 2).

Rainy season crops sown early produced higher yield than those sown 2 to 4 weeks later (Table 3). An early sowing increased the total biomass and the number of pods and seeds. The effect on the size of the pods was not substantial, only pods from the crop sown on 25 June 1998 showed a slightly higher weight compared to the crop sown on 10 July.

In the case of post rainy season crops grown at Ganapavaram during 1996-97, the disease incidence in irrigated crops was the highest for the crop sown by the farmer on 25 December 1996 (GN-1). The incidence was reduced for the two following sowing dates, 31 January (GN-2) and 15 February 1997 (GN-3).

*Influence of the date of sowing in relation to the age of the plants on  
disease incidence*

The IPCV incidence recorded during the 1997 experiment was very low. Few groundnut plants either sown or transplanted with the onset of monsoon rains on 4 and 11 July were infected by IPCV, 5/285 and 1/287 plants respectively. None of the plants exposed later in the field showed symptoms. There was a 43 mm rainfall between the 4<sup>th</sup> and 11<sup>th</sup> July which was followed by a period of drought. From the 25<sup>th</sup> July onwards there were evenly distributed rains of low intensity. In 1998, symptomatic plants were recorded for all the dates of sowing/transplanting (Table 4). Virus incidence tended to increase gradually in July and reached a plateau in August but the effect was not significant. Rains in 1998 were abundant and well distributed compared to 1997. There were high rainfalls between the 16<sup>th</sup> and 30<sup>th</sup> July.

**Table 2.** Influence of the date of sowing on IPCV incidence in groundnut crops at three major locations in India during the rainy and post rainy seasons.

Location and season	IPCV incidence in groundnut <sup>1</sup>				total proportion	ANOVA 2-ways	n/N <sup>2</sup>	Rain <sup>3</sup> (mm)
	min (%)	max (%)	mean (%)	Mean (θ)				
<b>Rainy seasons</b>								
ICRISAT 1996								
GN-1: 26 Jun	4	59	13 <sup>a</sup>		86/280	$F(2,10)=10.9$ $P=0.0031$ *	6/6	41
GN-2: 10 Jul	32	94	61 <sup>b</sup>		198/334		186	
GN-3: 24 Jul	11	44	23 <sup>a</sup>		62/264		6/6	37
ICRISAT 1998								
GN-1: 25 Jun	0	43	12 <sup>a</sup>		95/726	$F(1,15)=25.8$ $P=0.0001$ *	14/16	19
GN-2: 10 Jul	2	71	26 <sup>b</sup>		177/673		111	
Rampura 1997 <sup>5</sup>								
<u>Mustard field</u>								
GN-1: 15 Jun	3	58	29		186/607 <sup>a</sup>	$F(1,11)=1.4$ $P=0.2661$ ns	6/12	23
GN-2: 2 Jul	2	87	37		383/988 <sup>b</sup>		109	
Mean (mustard)			33		569/1595			
<u>Wheat field</u>								
GN-1	50	96	35 <sup>a</sup>		251/715	$F(1,11)=29.8$ $P=0.0002$ *	12/12	23
GN-2	42	97	76 <sup>b</sup>		830/1095		109	
Mean (wheat)			55		1081/1810			
<b>Post rainy seasons</b>								
Ganapavaram 1996-97								
GN-1: 25 Dec <sup>4</sup>	53	87	66 <sup>a</sup>		68/103	$F(2,12)=16.2$ $P=0.0004$ *		Irrig.
GN-2: 31 Jan	4	49	26 <sup>b</sup>		102/401		7/7	Irrig.
GN-3: 15 Feb	3	39	20 <sup>b</sup>		72/364		7/7	Irrig.

<sup>1</sup> Means were calculated between the replication blocks and the total proportion represented the observation made for all the blocks combined (angular transformation,  $\theta = \arcsin [\sqrt{\%}]$ ).

<sup>2</sup> Number of blocks where IPCV incidence in plots sown before or beyond the normal date of sowing was lower than in plots sown according to the farming practice in force at the location.

<sup>3</sup> Rainfall recorded during the subsequent 15 days after sowing. For Rampura this is the rainfall recorded at Durgapura near Jaipur, at a distance of about 10 km from the experimental sites. There was no rain at Ganapavaram and the field was irrigated.

<sup>4</sup> The sowing was done by the farmer at a seed rate of approximately 70 seeds/m<sup>2</sup>.

<sup>5</sup> Twelve blocks each were used in two areas of the same field where either wheat or mustard was grown during the previous winter season.

**Table 3.** Influence of the date of sowing on various yield components of groundnut crops grown in IPCV infested plots at ICRISAT, Andhra Pradesh, India.

	Dry yield components <sup>1</sup>					
	Total biomass (g)	No of Pods	Pod weight (g)	No of seeds	Seed weight (g)	Weight of 1 pod (g)
<b>Rainy season 1996 (n=6)</b>						
GN-1: 26 Jun.	-	251 <sup>a</sup>	192.1 <sup>a</sup>	421 <sup>a</sup>	129.4 <sup>a</sup>	0.78 <sup>a</sup>
GN-2: 10 Jul.	-	150 <sup>b</sup>	97.5 <sup>b</sup>	251 <sup>b</sup>	63.3 <sup>b</sup>	0.67 <sup>a</sup>
GN-3: 24 Jul.	-	103 <sup>b</sup>	76.0 <sup>b</sup>	211 <sup>b</sup>	46.8 <sup>b</sup>	0.72 <sup>a</sup>
SED		28.6 <sup>**</sup>	20.8 <sup>**</sup>	59.7 <sup>*</sup>	13.6 <sup>**</sup>	0.05 <sup>ns</sup>
<b>Rainy season 1998<sup>1</sup></b>						
Infested plots (n=16)						
GN-1: 25 Jun.	386.8 <sup>a</sup>	170 <sup>a</sup>	67.8 <sup>a</sup>	-	36.3 <sup>a</sup>	0.43 <sup>a</sup>
GN-2: 10 Jul.	201.8 <sup>b</sup>	52 <sup>b</sup>	18.4 <sup>b</sup>	-	9.5 <sup>b</sup>	0.31 <sup>b</sup>
SED	15.7 <sup>**</sup>	18.2 <sup>**</sup>	7.4 <sup>**</sup>	-	4.2 <sup>**</sup>	0.04 <sup>**</sup>

GN-1, GN-2 plots: see Table 1

Treatments were: <sup>ns</sup> not significant, <sup>\*</sup> significant at 5% level, <sup>\*\*</sup> significant at 1% level.

<sup>1</sup> Yield measured for 0.25 m<sup>2</sup> plots with a population of approximately 50 plants. All weights were measured after drying at 35°C for 48h. Means.

- not measured.

**Table 4.** Influence of the date of sowing/transplanting and of the age of groundnut plants on IPCV incidence. Trials conducted at ICRISAT, Andhra Pradesh, India during the 1998 rainy seasons.

Season	IPCV incidence in groundnut <sup>1</sup>					Rainfall (mm) <sup>2</sup>
	min (%)	max (%)	mean (%)	mean (θ)	Total proportion	
<b>Date of sowing/transplanting<sup>3</sup></b>						
3 Jul	0.0	100.0	8.3		16/248 <sup>a</sup>	48.2
9 Jul	0.0	58.3	8.4		19/252 <sup>a</sup>	59.2
16 Jul	0.0	91.7	9.3		26/262 <sup>ac</sup>	129.8
23 Jul	0.0	66.7	10.0		24/235 <sup>ac</sup>	127.7
30 Jul	0.0	80.0	21.8		43/214 <sup>b</sup>	83.0
6 Aug	0.0	100.0	15.9		38/234 <sup>bc</sup>	98.8
13 Aug	0.0	58.3	16.3		44/245 <sup>b</sup>	54.6
20 Aug	0.0	80.0	13.1		34/244 <sup>bc</sup>	49.8
angular SED						
<b>Age of the plants<sup>4</sup></b>						
0 (seeds)	0.0	91.7	34.2 <sup>a</sup>		178/508	
1 week	0.0	42.8	10.1 <sup>b</sup>		45/486	
2 weeks	0.0	12.5	3.0 <sup>c</sup>		14/485	
3 weeks	0.0	20.0	1.6 <sup>c</sup>		7/455	
angular SED						

<sup>1</sup> Virus incidences, based on visual symptoms (angular transformation,  $\theta = \arcsin \sqrt{\%}$ ). Means were calculated between the replication blocks and the total proportion represented the observation made for all the blocks combined.

Means were combined for all ages in the case of (<sup>3</sup>) and for all dates in the case of (<sup>4</sup>).

Treatments were: <sup>ns</sup> not significant, <sup>\*\*</sup> significant at 1% level.

<sup>2</sup> Cumulative rainfall during the week that followed sowing/transplanting.

The age of the plant had a clear effect on IPCV incidence. This was true for both 1997 and 1998 rainy seasons. In 1997 the incidence was observed only in plants actually sown in the field and in 1 week old plants transplanted to the field. In 1998 the incidence was also highest for the plants sown in the field. Virus incidence gradually decreased (Table 4) whereas yield increased (Table 5) with the age of the plants at transplanting.

As it has previously been reported for groundnut (Smart, 1994), delaying the sowing or transplanting date caused substantial yield loss in 1998. It mostly reduced the number of pods and seeds produced per plot (Table 5).

**Table 5.** Influence of the date of sowing and of the age of groundnut plants on various yield components. Trial conducted during the 1998 rainy season in IPCV infested field at ICRISAT, Andhra Pradesh, India.

	No of pods per plot	No of pods per plant	Pod weight (g)	Weight of 1 pod (g)	Seed weight (g)
Date of sowing/transplanting <sup>2</sup>					
3 Jul.	57	5.6	19.6	0.34	11.2
9 Jul.	44	4.2	12.4	0.27	6.4
16 Jul.	25	2.2	5.8	0.18	2.8
23 Jul.	16	1.6	4.1	0.17	2.1
30 Jul.	20	2.3	5.3	0.25	2.8
6 Aug.	18	1.8	5.3	0.25	2.8
13 Aug.	12	1.2	4.6	0.34	2.4
20 Aug.	12	1.1	4.1	0.31	1.9
SED	5.48**	0.50**	2.25**	0.06*	1.34**
Age of the plants <sup>3</sup>					
0 (seeds)	19	1.9	5.4	0.26	2.8
1 week	24	2.3	7.1	0.25	3.7
2 weeks	28	2.7	8.7	0.27	4.5
3 weeks	30	3.0	9.4	0.28	5.1
SED	2.74**	0.26**	1.13*	0.03 <sup>ns</sup>	0.72*

Yield measured for 0.25m<sup>2</sup> plots with an intended population of approximately 12 plants. All weights were measured after drying individual production of each plot at 35°C for 48h.

Means combined for all ages in the case of (<sup>2</sup>) and for all dates in the case of (<sup>3</sup>).

Treatments were: <sup>ns</sup> not significant, \* significant at 5% level, \*\* significant at 1% level.

### *Influence of the irrigation pattern in relation to the age of the plants on IPCV incidence and yield*

In 1997, plants that received the high level of irrigation immediately after sowing, clearly showed the highest IPCV incidence (Table 6). Plants that were irrigated with a large amount of water after one, two and four weeks of growth, showed negligible incidence. In 1998 a similar situation was noticed. The highest IPCV incidence was observed for the plants that

received the large irrigation immediately after sowing. The irrigation regime had little effect on yield both in 1997 and 1998. Plants sown on 25 June clearly produced higher yield than those sown on 4 August (Table 6).

**Table 6.** Influence of irrigation regime (IR) on IPCV incidence and various yield components in groundnut crops grown under rain-out shelters in IPCV infested field at ICRISAT, Andhra Pradesh, India during the 1997 and 1998 rainy seasons.

Season	IPCV incidence <sup>1</sup>			Yield per plot <sup>2</sup>		
	Mean (%)	Mean ( $\theta$ )	Total proportion	No. of Pods	Pod weight (g)	Seed weight (g)
<b>1997</b>						
IR-0	4.1 <sup>a</sup>	9.3	12/325	-	50.3 <sup>a</sup>	-
IR-7	0.0 <sup>b</sup>	1.0	0/358	-	44.7 <sup>a</sup>	-
IR-14	0.2 <sup>b</sup>	1.9	1/352	-	48.3 <sup>a</sup>	-
IR-28	0.6 <sup>b</sup>	2.9	2/337	-	42.6 <sup>a</sup>	-
SED		2.33 <sup>**</sup>			10.1 <sup>ns</sup>	
<b>1998</b>						
IR-0	4.8 <sup>a</sup>	11.6	38/785	79.9 <sup>a</sup>	44.3 <sup>a</sup>	25.6 <sup>ab</sup>
IR-7	4.3 <sup>ab</sup>	10.4	34/793	73.3 <sup>a</sup>	39.6 <sup>a</sup>	22.7 <sup>a</sup>
IR-14	3.7 <sup>ab</sup>	9.6	29/791	94.4 <sup>a</sup>	35.2 <sup>a</sup>	32.6 <sup>b</sup>
IR-28	1.6 <sup>b</sup>	5.2	13/790	73.9 <sup>a</sup>	42.9 <sup>a</sup>	25.6 <sup>ab</sup>
SED	5.772	1.65 <sup>**</sup>		9.19 <sup>ns</sup>	5.58 <sup>ns</sup>	3.42 <sup>*</sup>
Block sown on 25 Jun.	4.2	9.7	67/1569 <sup>a</sup>	104.3 <sup>a</sup>	73.2 <sup>a</sup>	43.9 <sup>a</sup>
Block sown on 4 Aug.	2.9	8.8	47/1590 <sup>b</sup>	56.5 <sup>b</sup>	17.9 <sup>a</sup>	9.4 <sup>b</sup>
SED	0.258	1.74 <sup>ns</sup>		8.47 <sup>**</sup>	4.66 <sup>**</sup>	2.79 <sup>**</sup>

Irrigation regimes: IR-0: 40 mm on day 0 and on day 4; IR-7: 40 mm on day 7 and day 10; IR-14: 40 mm on day 14 and day 17; IR-28: 40 mm on day 28 and day 31. A life support irrigation of 2 x 4 mm was given during the weeks the plots were not treated with high irrigation.

Treatments were: <sup>ns</sup> not significant, <sup>\*\*</sup> significant at 1% level.

<sup>1</sup> Virus incidences based on ELISA tests (angular transformation,  $\theta = \arcsin \sqrt{\%}$ ). Means were calculated between the replication blocks and the total proportion represented the observation made for all the blocks combined.

<sup>2</sup> Yield measured for 0.25m<sup>2</sup> plots with a population of approximately 50 plants. All weights were measured after drying at 35°C for 48h. For 1998, there was no interaction between "irrigation regime x "date of sowing" ( $P>0.05$ )

## Discussion

Previous experiments have shown the important role played by the amount and distribution of rainfall on IPCV incidence (Delfosse *et al.*, 1996, Chapter 4). High rainfall induced high virus and *P. graminis* incidence in plants exposed for short periods in the field. However if high rainfall occurred at later stages of groundnut development, they neither induced high virus incidence nor severe stunting symptoms. For instance, crops sown after initial heavy rains, until 15 days after the onset of the monsoon, were weakly affected by the disease. In the present experiments, IPCV incidence was reduced if the crops were sown early, before the onset of monsoon rains, and maintained with judicious irrigation, sufficient for

plant establishment but low enough not to favour *P. graminis* and IPCV infection. IPCV incidence was very low and stunting less severe compared to that of crops sown with the onset of monsoon rains. An early sowing clearly increased the yield in rainy season groundnut crops. It increased mostly the total biomass and the number of pods produced. However the increase in yield appeared to result from the effect of the early sowing (Smart, 1994) rather than from the reduction in disease incidence. These results confirmed previous observation made in Pakistan where farmers traditionally sow groundnut in April when few showers provide enough moisture to the soil for seed germination and groundnut development up to the four leaf stage. Sowing is done at a depth of approximately 30 cm to protect the plant from the drought and the severe heat that occur in May. The crop pursues its growth with the monsoon rains in June-July. Clump disease incidence was low in such traditional fields whereas crops sown in July showed very severe incidence (Delfosse *et al.*, 1995, Chapter 2).

On the other hand, in the frame work of this research, crops which were sown later during the rainy season and exposed to relatively low rainfall during the first 15 days of crop development also showed low disease incidence. This confirms the observation made by Reddy *et al.* (1988) for rainy season crops sown in August in the Punjab. It is however not advisable to delay the sowing of groundnut because it is known to produce substantial yield loss and reduction in kernel quality (Smartt, 1994). Moreover, delayed sowing would expose groundnut crops to low temperature or drought at the end of the cropping season which can cause a delay in maturity or plant susceptibility to seed infection by *Aspergillus flavus*, a fungus responsible for aflatoxin contamination (Mehan, 1988).

The mechanism involved to explain the lower susceptibility of well established groundnut plants to infection is not yet understood and it was beyond the scope of this research. Nevertheless, the characteristics of the groundnut root system may be one of the factors responsible for this. Groundnut roots are generally concentrated at a depth of 5-35 cm (Narasinga Rao, 1936 quoted by Ramanatha Rao & Murthy, 1994) and therefore the soil profile explored by groundnut roots varies little during crop growth. Infection by *P. graminis* takes place in the root hair zone which is the area of greatest root-permeability (Barr, 1988). The root hair life is usually short (2 days) (Devlin and Witham, 1983) and most annual plants produce new root hair during their growth. Groundnut is an exception; it produces root hairs only at a very young stage of growth. Root hairs tend to disappear a few days after sowing and are occasionally present in older plants at the base of root laterals particularly in air spaces of high humidity (Ramanatha Rao & Murthy, 1994). Groundnut roots

present a dry and sloughing surface and absorption occurs mainly in young primary roots with active meristematic cells underlying the drying outer layer. It is highly probable that a young epidermis is more susceptible to infection by *P. graminis* than the sloughing and suberised layers which constitute the root surface of mature groundnut plants. Another explanation could be chemical in nature. *P. graminis* is suspected to require specific stimuli such as root exudates for germination (Habibi, 1969). These specific stimuli may not be produced at sufficient level by mature groundnut plants.

In post rainy season crops it was difficult to assess the effect of the date of sowing on IPCV incidence because these crops were irrigated by the farmer and the amount of water provided during irrigation were not recorded. As in the case of rainy season crops we can assume that minimal irrigation during the early stages of crop growth will be beneficial to avoid high clump disease incidence. Seasonal variation in clump disease incidence has long been reported. Nolt & Reddy (1984) and Reddy *et al.* (1988) already stated that post rainy season groundnut crops mostly escaped the disease. Reddy *et al.*, 1988 reported that low temperature prevailing in post rainy season may contribute to low incidence. Legrève *et al.* (1999) confirmed that temperatures below 23°C already repressed infection by *P. graminis* involved in IPCV transmission and below 19°C, colonisation by *P. graminis* does not occur. Ganapavaram is situated in the coastal area of Andhra Pradesh where warm temperatures and a period of drought prior to sowing in December-January allow clump disease occurrence even in post rainy season groundnut crops. However incidence is relatively low compared to rainy season crops (Reddy *et al.*, 1988). In the northern states of India such as Punjab and Rajasthan, winters are too severe to grow groundnut and clump disease is not encountered. Stunting symptoms in infected plants sown in the post-rainy season at Hyderabad or at Ganapavaram are as severe as those observed in rainy season crops. It is therefore not that disease expression is affected by low temperatures in the post rainy season but disease incidence. Less plants are infected.

The mechanisms that trigger the germination of *P. graminis* resting spores have not been extensively studied. It has been noted, however, that drying soil samples (Brakke & Estes, 1967; Slykhuis, 1975) or storage of dried inoculum at temperatures above 30°C (Legrève, Vanpee, Delfosse & Maraite, 1999) resulted in an increased incidence of *P. graminis* in bait plants. Legrève *et al.* (1999) concluded that drought and heat favoured the maturation of *P. graminis* resting spores. Naturally occurring inoculum is exposed to severe drought and heat during the Indian summer in April-May. Rainy season crops which are sown in June-July are thus exposed to

a large number of mature resting spores which germinate soon after the initial monsoon rains, exposing the plants to high virus transmission and consequently high disease incidence occurs. The period of severe drought and heat prior to sowing groundnut does not apply to post rainy season crops and therefore clump disease occurs at low incidence.

Temperature is probably not the only factor responsible for low incidence in post rainy season crops of groundnut. IPCV has a wide temperature range and wheat crops can show high virus incidence in the post rainy season (Delfosse *et al.*, 1999). The host-vector interaction, including the production of specific stimuli as mentioned above, is probably also a factor of great influence to explain the difference in IPCV incidence between groundnut and wheat crops in the post-rainy season.

Early sowing of the groundnut crop thus appears to be a judicious strategy for the management of peanut clump disease. It complies with the requirement of productive yield and kernel quality. Among the methods available to reduce damage caused by peanut clump disease, it is the most efficient strategy to date. Compared to trap cropping with pearl millet (Chapter 5-2), early sowing results in a higher reduction in disease incidence and does not require extra field preparation. In Rajasthan, thanks to financial subsidy provided by the government, irrigation is now available to many groundnut growing farmers. Irrigation gives them the opportunity to sow early (June) before the onset of monsoon rains and we can expect that this new practice will reduce the damage due IPCV in these areas.

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