Pigeonpea + Groundnut with low external input IPM

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Executive Summary

India's agricultural performance has been one of the most significant achievements after independence. The gains in agricultural development were however more visible in irrigated regions than in rainfed regions resulting in widening disparities. The crop production in rainfed regions is dependent on monsoons and therefore highly risky. Apart from the climate-induced risk, incidence of insect pests and diseases also limit the productivity of rainfed crops, especially when farmers are not in a position to afford chemical-based plant protection measures. In order to mitigate the risk, farmers have diversified their farming systems over years. In the process, inter- and mixed cropping systems, the popular forms of crop-crop diversity, have become more popular in the rainfed regions. These systems provide opportunities to create situations that are less pest-prone compared to the sole crop situations or the monocultures. Efforts were therefore made to identify intercropping systems that attract less pest incidence and when combined with other components of integrated pest management, necessitate least investments on plant protection without significant losses in yields and incomes from pigeonpea, which is an important pulse crops and mostly grown in rainfed conditions. Specifically, an attempt was made to identify the pigeonpea cultivar of appropriate duration, an intercrop in the presence of which the crop suffers less pest incidence and a low external input IPM module for obtaining economic pest management.

A three-step methodology was followed to achieve the intended outcome. In the first step, an experiment was conducted at the research farm in order to test different pigeonpea cultivars of different maturity and intercrops. The more effective and efficient combinations along with some other systems suggested by or popular with the farmers were then evaluated in on-farm situation. In the third step, different low external input IPM modules were superimposed on the systems found effective and efficient earlier.

Short and medium duration pigeonpeas offered greater degree of protection against insect pest attack. Medium duration pigeonpea, in addition to being attacked by fewer pests, exhibited less flower shedding during dry spells, making it more suitable to dryland conditions. The diversity created by introducing sorghum, greengram and groundnut as intercrops in pigeonpea resulted in a build up of natural enemies of the major pests of pigeonpea and also resulted in less congenial conditions for insect pests. As a result of the changes in microclimate and build up of natural enemies, there was much less pest incidence and damage in pigeonpea intercropped with sorghum, greengram and groundnut compared to sole pigeonpea. Further these systems were more efficient agronomically in terms of Land Equivalent Ratio, aggressivity, competitive ratio and relative crowding coefficient. Economic analysis also showed these intercropping systems to be more profitable than sole pigeonpea. It can be concluded that medium duration pigeonpea intercropped with sorghum, greengram or groundnut is better protected from adverse climate as well as pest attacks, resulting in higher yields and economic returns. The adoption of Low External Input Integrated Pest Management module consisting of sequential application of neem seed kernel extract 5%, neem oil 5%, extract of *V. negundo* 1/10 w/w, pongamia oil 5%, erection of bird perches and mechanical collection of larvae was found effective in managing/controlling the pests. Choice of medium duration pigeonpea and intercropping with sorghum, greengram or groundnut may be integrated into the effective LEIIPM module as a component.

Crop-crop diversity as a key component of IPM in pigeonpea

1. Introduction

India's agricultural performance has been one of the most significant achievements after independence. The green revolution of the late 1960s, responsible for such a rapid agricultural growth, was however largely confined to irrigated areas and crops bypassing the vast rainfed tracts. Nearly one half of the cultivated area in India will remain rainfed even after realizing the full irrigation potential. Rainfed lands produce bulk of coarse cereals, pulses, oilseeds and fiber crops. More importantly, these rainfed regions provide livelihood to a majority of rural poor and as a result they are often described as concentrations of mass poverty and hot spots for civic strife. The productivity of crops grown in rainfed areas is considerably lower than the potential and much lower than that of irrigated crops. Enhancing the productivity of rainfed crops is therefore important from the view points of growth, equity and sustainability.

Crop production in rainfed regions is by nature dependent on monsoon behaviour and is therefore highly risky. Rainfed regions are also highly heterogeneous in terms of land terrain, soil productivity, climate and socio-economic conditions. All these factors come in the way of realizing the potential productivity of the crops. Another important factor that affects crop production is the incidence of pests and diseases. When combined with the meager capacity of the farmers to take up the necessary plant protection measures, the incidence of pests and diseases can lead to significant loss of productivity and income to the farmers.

In order to mitigate the effects of uncertain weather conditions and the incidence of pests and diseases, farmers in rainfed regions have diversified their farming systems. Thus, rainfed regions are more diversified compared to irrigated tracts, which tend to specialize in production of a few crops. The small and marginal farmers, who predominate in rainfed farming, often grow more crops per unit area of their land in the form of inter and mixed cropping systems (Walker and Ryan, 1990). These systems, apart from meeting the diverse family needs are also less prone to the incidence of pests and diseases. As the components in the system differ in their growth behaviour and nutrient and water requirements, these systems also help in reducing the risk that is characteristic of rainfed farming.

Dependence on chemical pesticides has led to the problems such as insect pests developing resistance to commonly used chemicals on one hand and to the escalating cost of cultivation on the other. Considering the ill effects of excessive dependence on chemical pesticides and the growing preference for chemical-free agricultural products, efforts have been under way to develop and popularize Integrated Pest management (IPM) technologies. Such technologies need to be affordable to the farmers in terms of cost and should fit into the existing farming or cropping systems. Research has shown that the farmers more readily take up the adoption of such components of IPM as intercropping and border crops. In other words, cultural components of IPM need to be further explored as they require relatively less external inputs and are more likely to be adopted by the farmers.

Crop diversity is a situation wherein different crops are grown simultaneously in the same piece of land. Crop-crop, crop-border and crop-weed diversities are different forms of crop diversity (Baliddawa, 1985). Intercropping and mixed cropping systems are more popular forms of crop-crop diversity practiced in rainfed agriculture. These systems provide opportunities to create situations that are less pest-prone compared to the single crop situations or the monocultures. The genetic uniformity of monocultures also leads to susceptibility to the pests (Bhatnagar and Davies, 1979). The factors that contribute to reduced pest populations in intercropping include physical protection from wind, shading (Litsinger and Moody, 1976), prevention of dispersal (Kayumbo, 1975), production of adverse stimuli, olfactory stimuli camouflaged by main crop (Aiyer, 1949), presence of natural enemies (Russell, 1989 and Tonhasca, 1993) and availability of food (Fukai and Trenbath, 1993) Research in diversified agro-ecosystems demonstrated that these systems tend to support less herbivore load than the corresponding monocultures (Risch,1981 and Altieri and Letourneau,1982).Thus, there is considerable scope to develop a system that is diverse and less prone to pests and diseases. When other pest management technologies are superimposed on such systems, it becomes much easier and cheaper for the farmer to manage the pests than in monocultures which are more prone to pest incidence and require considerable investments in pest management. Low external input IPM (LEIIPM) seeks to optimize the use of local available resources by combining the different components of the farming system.

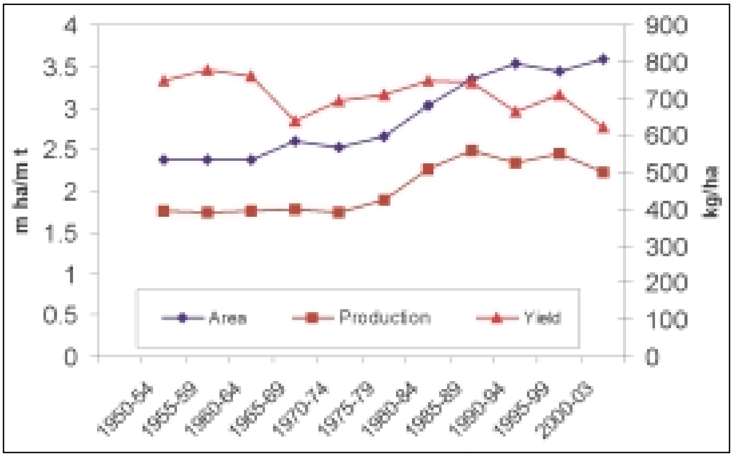
Keeping these considerations in view, research was conducted to harness the potential benefits of crop-crop diversity by identifying cropping systems that are less prone to pest incidence, more efficient, remunerative and acceptable to the farmers. We focused our efforts on pigeonpea, a major rainfed crop that suffers from serious damage by insect pests necessitating investment by the farmers for pest management. This publication puts together such work conducted at CRIDA during 1998-2005. A considerable part of the research was funded by the ICAR in the form of an AP Cess Fund project *"Crop-crop diversity as a key component of IPM in dryland crops".*

Creation of crop diversity by the introduction of
one crop into another crop is known as crop-crop diversity.

Intercropping and mixed cropping are
more popular forms of crop-crop diversity.

Pigeonpea is an important pulse crop grown under rainfed conditions in India. It is often grown as an intercrop with cereals like maize, sorghum and other commercial crops such as castor and groundnut. It is also grown as a sole crop. The area under pigeonpea increased from about 2.37 m ha during 1950-54 to 3.58 m ha during 2000-03. The production increased from 1.77 m t to 2.22 m t during this period. The scenario with respect to productivity is not encouraging. The productivity, which was about 750 kg/ha during the 1950s came down to about 622 kg/ha during 2000-03. (Fig 1)

Fig 1.Trends in area, production and productivity of pigeonpea in India 1950-2003



The fluctuations in productivity levels of pigeonpea arise from two main reasons. First, it is grown as a *kharif* rainfed crop and being a long duration crop is subject to the vagaries of the monsoon. Second, it attracts a large number of pests, the gram pod borer being the major crop pest. In certain pockets, wilt also reduces the productivity. The crop is seldom grown under irrigated conditions as can be seen from the fact that only five percent of the crop was irrigated during 2000-03.

The stagnation in productivity of pigeonpea can be attributed among other things to incidence of insect pests. More than 200 species of insects have been found feeding on pigeonpea, although only a few of these cause significant and consistent damage to the crop (Reed *et al.,* 1989; Lateef and Reed, 1990). In pigeonpea, cultivars of different maturity and plant structure are available and they offer scope for manipulating the environment with different intercrops for possible reduction in incidence of insect pests. Growing medium and long duration pigeonpea with short season crops like sorghum is common (Ariyanagam and Singh, 1994). The differing durations of the main (pigeonpea) and the intercrop will influence incidence of pests. Thus, the spatially fluid nature of arthropod populations and the intercrop interactions present some real challenges (Kennedy and Margolies, 1985). Keeping these considerations in view, we attempted to examine how the incidence of insect pests differs in a crop-crop diversity system compared to a sole crop situation.

2. Methodology

A three-step methodology was followed to achieve the intended outcome. In the first step, experiments were conducted at the research station to test different pigeonpea cultivars of different maturity and intercrops. Combinations found effective along with some other systems popular with the farmers or suggested by them were then evaluated in farmers' fields. In the third step, different LEIIPM modules were superimposed on the systems found effective and efficient in the earlier steps.

2.1 Identification of cultivar and intercrop

Field experiments were conducted during rainy seasons of 1998 and 1999 in a two factor randomised block design (RBD) with 3 pigeonpea cultivars of varying durations (short (ICPL 84031), medium (PRG 100) and long (LRG 30)) and 4 crop diversity systems (sole pigeonpea, pigeonpea + sorghum (1:2), pigeonpea + castor (1:1) and pigeonpea + greengram (1:2). The cropping systems are replicated thrice.

2.2. On-farm evaluation

Eight intercrops were tested with pigeonpea as the base crop in farmers' fields and also in the research farm of CRIDA during rainy seasons of 2003, 2004 and 2005. Ten farmers who served as replications grew each system. The villages and farmers selected represent typical dryland farming situation. Various participatory rural appraisal (PRA) tools were used to identify the farmers and ensure their participation. The experiments were subjected to analysis of variance (ANOVA) for RBD.

2.3. Low external input IPM modules

Three low external input IPM modules were evaluated in three most effective crop diversified systems identified in the earlier step. These experiments also were taken up on-station and in farmers' fields with the active participation of the farmers during 2005.

Plate 1 : Rice and maize pops for bird predation

The sequential application of various components was adopted in different ways. The low external input IPM modules were —

IPM module I: Neem Seed Kernel Extract (NSKE) 5%, extract of *Vitex negundo* 1/10 w/w, NSKE 5% and extract of *V. negundo* 1/10 w/w

IPM module II: Neem oil 5%, Pongamia oil 5%, Jatropha oil 5%, Neem oil 5%

IPM module III: NSKE 5%, Neem oil 5%, extract of *V. negundo* 1/10 w/w, Pongamia oil 5%

All modules included bird perches and mechanical collection of larvae by shaking of the plants. Rice and Maize pops were applied in the field to increase bird predation (Plate 1).

The pest population and yield data were subjected to ANOVA for 2 factor RBD with the IPM module as factor 1, intercrop as factor 2 and the individual farmer as replicate.

2.4. Data Set

Weekly insect counts were recorded from ten randomly labeled pigeonpea plants in each plot at various stages of crop growth in the on-farm and on-station experiments. Three terminals per plant were selected. Field observations of insect pest and predator (coccinellids and spiders) populations were recorded during the cool hours of the day (7 to 9.30 am and 4 to 6 pm) as per standard procedure (Pradhan, 1964). The weekly pest counts were summed to obtain cumulative pest units (CPU) to serve as an index of pest load experienced by the crop (Srinivasa Rao *et al,* 2004 a) and mean weekly pest count was also calculated.

The incidence of insect pests like leaf hopper, *Empoasca kerri,* aphid, *Aphis craccivora,* thrips, *Megalurothrips usitatus* and leaf folder, *Grapholita critica* were observed during vegetative stage of the crop. During flowering and pod formation stage, insects like blister beetle, *Mylabris pustulata* and lepidopteran pod borers viz., *Helicoverpa armigera, Exelastis atomosa, Maruca vitrata,* pod fly *Melanagromyza obtusa,* were noticed in Pigeonpea based cropping systems. The data on pod damage was collected initially from 100 pods sampled randomly from each system. The sampled pods were categorized primarily into healthy and damaged pods. The damaged pods were further grouped into four categories viz., pods damaged by *H. armigera, E. atomosa, M. vitrata* and *M.obtusa* based on characteristic nature of the feeding hole. The mean pod and grain damage were calculated.

Data on microclimate variables were also recorded at weekly intervals to measure differences in microclimate among intercrop canopies. Canopy - temperature (Tc) and canopy air temperature differential (CATD) were recorded from three locations in each plot, using Teletemp AG-42 Infrared Thermometer* (Plate 2). Relative humidity within crop canopy was determined by using Digital Psychrometer at regular intervals (Kumar *et al,* 1999). (*Not the recommendation of institute.)

Plate 2 : Recording of canopy - air temperature

The data on the weekly observations on pest incidence, natural enemies, weather parameters etc was subjected to ANOVA as applicable (Gomez and Gomez, 1984). The yield data were further used to construct various indices such as Competitive Ratio (CR), Aggressivity (A), Relative Crowding Coefficient (RCC), Land Equivalent Ratio (LER) against which the treatments were evaluated using standard procedure (Rao and Willey, 1980). Economic analysis was done by considering the market prices of the inputs used and farm harvest prices (FHP) of the crops concerned. Further, the relationship between the pest population and other variables such as natural enemies or microclimate was studied using correlation and regression procedures.

3. RESULTS

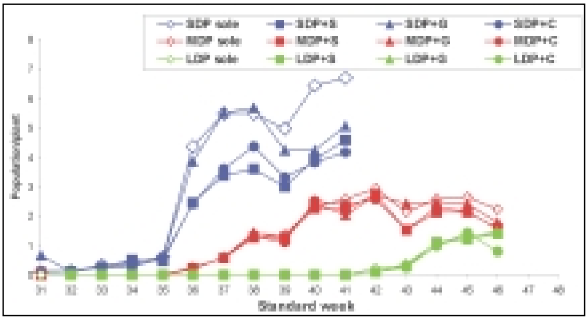
3.1. Identification of cultivar and intercrop

The temporal variation in the incidence of *E.kerri, M.vitrata* and *H.armigera* observed among cropping systems is discussed hereunder. The infestation varied significantly among short duration (SD), medium duration (MD) and long duration (LD) pigeonpea cultivars and also among crop diverse conditions.

Leafhopper incidence was first noticed 3 weeks after sowing (WAS) i.e., 29th standard week (SWK) and continued up to 14 WAS (40 SWK) in all the cropping systems. The leafhopper incidence was noticed for a period of 12-15 weeks from third week of July to second week of October with one peak level of infestation in all the cropping systems. The infestation varied significantly among short, medium and long duration pigeonpeas as noted by low cumulative pest units (CPU) and mean population in short duration (SD) pigeonpea (78.39/ 5.65) compared to medium duration (MD) pigeonpea (86.05/5.92) and long duration (LD) pigeonpea (88.32/6.03) (Table 1). Castor and sorghum as intercrops reduced the leafhopper infestation than the sole crop. Interaction effect between cultivars of pigeonpea and intercrops was significant. SD pigeonpea + sorghum, SD pigeonpea+ castor, LD pigeonpea+ castor and MD pigeonpea+ sorghum had low leafhopper population.

The temporal variation in incidence of *M. vitrata* is depicted in figure 2. The pest was first recorded around seven WAS (33 SWK) and continued till the harvest. The incidence varied significantly among the three cultivars of pigeonpea. It was noticed to be associated with flower bud initiation (11-19 WAS in SD pigeonpea and a further 3-5 weeks delay in MD and LD pigeonpeas). SD pigeonpea suffered significantly higher infestation both in terms of CPU and mean infestation levels (32.64/2.83) than MD pigeonpea (19.86/1.66) and LD pigeonpea (9.97/0.85) respectively (Table 1). Among the three intercrops tested, pigeonpea intercropped with castor and with sorghum experienced low infestation of *M. vitrata.*

Fig 2. Impact of cultivar and intercrop incidence of *M.vitrata* in pigeonpea



The density of *H. armigera* population differed significantly across intercropping systems. The incidence of *H. armigera* started with the flowering of pigeonpea cultivars and attained peak levels during 15-16 WAS in SD pigeonpea and 17-19 WAS in MD and LD pigeonpeas The level of infestation did not vary significantly among the three cultivars of pigeonpea. The effect of intercrops was evident temporally. Sole crops had higher infestation and intercropping with sorghum and castor reduced the infestation (Table 1).

Table1. Insect populations in short, medium and long duration pigeonpeas under different crop diverse systems.

Cropping Systems	*E.kerri*		*M.vitrata*		*H.armigera*	
	CPU	Mean*	CPU	Mean*	CPU	Mean*
SDP sole	85.13	6.25	38.93	3.38	5.97	0.54
SDP+sorghum	71.02	5.19	29.07	2.51	4.22	0.39
SDP+green gram	84.57	6.18	33.77	2.93	5.48	0.50
SDP+castor	72.85	4.97	28.80	2.49	4.98	0.45
MDP sole	92.73	6.65	21.32	1.79	7.59	0.58
MDP+sorghum	77.40	5.23	19.22	1.61	5.12	0.38
MDP+greengram	94.35	6.45	19.88	1.67	6.27	0.47
MDP+castor	79.72	5.35	19.03	1.59	5.38	0.40
LDP sole	101.10	7.01	6.967	0.85	6.38	0.58
LDP+sorghum	81.88	5.56	6.75	0.83	4.87	0.44
LDP+green gram	93.80	6.40	7.25	0.89	5.72	0.52
LDP+castor	76.50	5.10	6.90	0.84	4.75	0.43
SEm±	6.72	0.527	2.077	0.221	0.763	0.052
LSD at 0.05	13.94	1.093	4.329	0.459	1.582	0.108
Factor 1						
SDP	78.39	5.65	32.64	2.827	5.16	0.47
MDP	86.05	5.92	19.86	1.663	6.08	0.46
LDP	88.32	6.03	9.967	0.853	5.43	0.49
SEm±	3.370	0.329	1.029	0.111	0.382	0.03
LSD at 0.05	6.99	0.684	2.160	0.231	0.801	NS
Factor 2						
Sole	92.99	6.64	22.41	2.01	6.63	0.54
Sorghum	76.77	5.33	18.34	1.65	4.73	0.40
Green gram	90.91	6.34	20.30	1.83	5.82	0.50
Castor	76.36	5.16	18.24	1.64	5.04	0.43
SEm±	3.879	0.264	1.198	0.128	0.439	0.030
LSD at 0.05	8.069	NS	2.494	0.266	0.916	0.063
CV (%)	9.80	11.05	12.87	15.31	17.13	13.69

SDP: Short duration pigeonpea; MDP: Medium duration pigeonpea; LDP: Long duration pigeonpea
NS: Not-significant *population/plant

Pest infestation and flower shedding were minimum with medium duration pigeonpea.

The incidence of insect pests significantly varied by the duration of cultivar of pigeonpea and intercrops. Lower incidence was observed with short and medium duration pigeonpea with sorghum and castor as intercrops. Considering lower of incidence of *M. vitrata* and relatively less flower shedding during dry spells, the medium duration cultivar was chosen for further evaluation on farmers' fields.

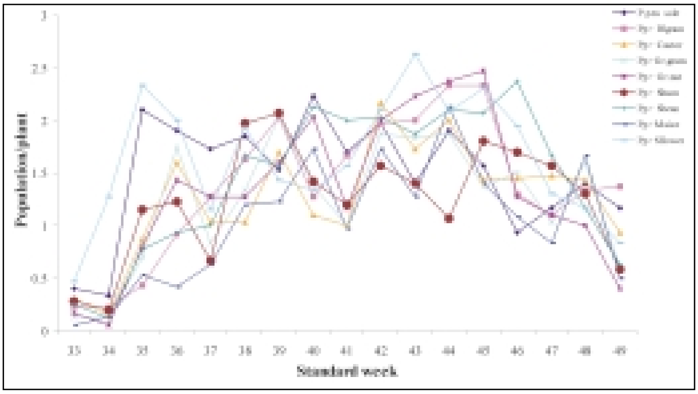
3.2. On-farm evaluation

In the second step the above findings were evaluated in farmers' fields (Plate 3). In addition, some other intercrops suggested by the participating farmers' were included. Ten farmers' came forward to participate in the on-farm trials after thorough discussion on the nature and objectives of trials. Each farmer was regarded as a replicate.

Plate 3 : Monitoring of on-farm experiments

3.2.1. Impact of Crop-crop diversity on incidence of insect pests

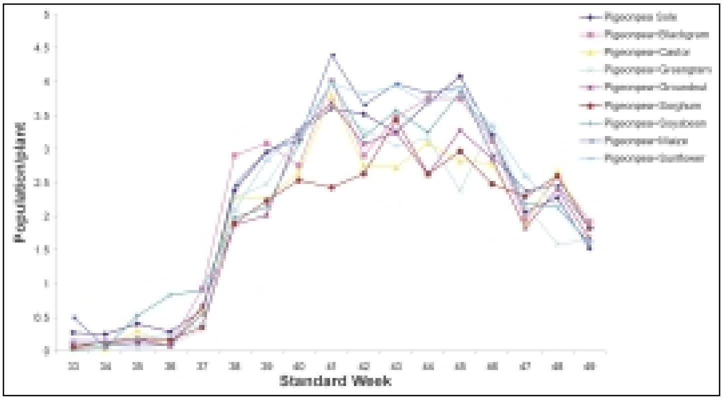
Fig 3. Impact of crop-crop diversity on incidence of *E.kerri* in pigeonpea



The population of adult leafhopper fluctuated across different crop diversified systems during the crop period. The incidence of leafhopper was observed from 33rd - 49th SWK. High population of leafhoppers (2.5 per plant) was observed initially during 33-36 SWK in pigeonpea sole and pigeonpea+ sunflower systems (Fig 3). In the remaining systems, peak population was noticed during 39-46 SWK period. The incidence of leafhopper population was low in pigeonpea + sorghum, pigeonpea + greengram and pigeonpea + castor systems followed by pigeonpea + maize.

The seasonal occurrence of *H. armigera* in various crop diversity systems is depicted in figure 4. The incidence was noticed at 33 SWK (8 WAS) in pigeonpea cropping systems uniformly and reached its peak around 50% flowering of the pigeonpea crop (13-16 WAS) coinciding with 38-41 SWKs. The infestation remained high throughout flowering and pod formation stages. Significant differences were observed among the crop diversity systems in respect of mean density of population. Intercrops influenced the pest incidence. Pigeonpea intercropped with sorghum (1.90 to 3.43 per plant), groundnut (1.87 to 3.25 per plant), blackgram and castor registered significantly lower level of population than sole crop of pigeonpea. Pigeonpea + sunflower (2.08 to 3.93 per plant) and pigeonpea + maize (2.47 to 4.40 per plant) recorded higher population.

Fig 4. Impact of crop-crop diversity on incidence of *H.armigera* in pigeonpea



Polycultures recorded least incidence of insect pest than the monocultures.

The pod damage by *H. armigera* was distinguished by a clear circular hole on pods. The intercrops significantly influenced the pod damage by *H. armigera* and were least with sorghum as intercrop (16.50%). It was significantly superior over rest of cropping systems and sole crop of pigeonpea. Blackgram and groundnut as intercrops recorded significantly lower level of pod damage. Higher pod damage (30.22 and 29.67%) was noticed in pigeonpea+ soybean and sole pigeonpea systems. The differences in pod damage by *E. atomosa* were not found significant. The damage to pods by *M. vitrata* varied significantly among cropping systems. The pod damage was less in pigeonpea intercropped with sorghum (1.81%) and greengram (2.40%) and groundnut (2.58%) than in the sole crop (4.83%) as well as when intercropped with maize (5.33%) and sunflower (5.67%). The pod damage by *M. obtusa* was significantly affected by intercrops. The pod damage was lowest in pigeonpea grown with sorghum (16.90%), blackgram (18.33 %) and groundnut (19.00%) as intercrops than sole pigeonpea (25.50%) and other cropping systems (Table2).

Table 2. Impact of crop-crop diversity on damage by pod borers of pigeonpea

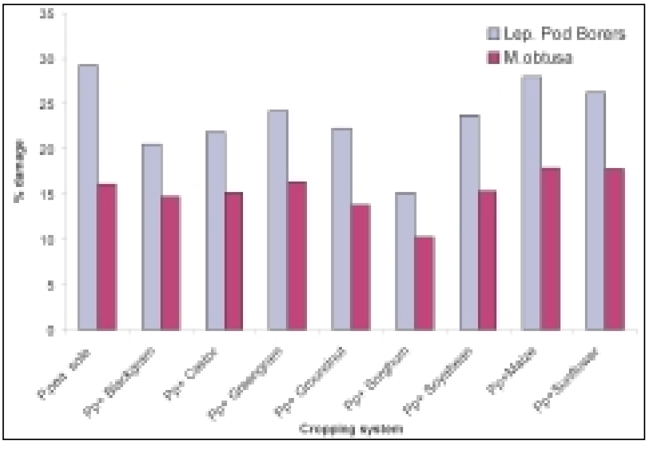
Cropping system	**Pod damage (%)**			
	H.armigera	***E. atomosa***	***M. vitrata***	***M.obtusa***
Pigeonpea sole	29.67(32.91)*	12.67 (20.82)	4.83 (12.69)	25.50 (29.83)
Pigeonpea + Blackgram	22.17(27.94)	6.50 (14.67)	2.67 (9.38)	18.33 (23.39)
Pigeonpea + Castor	27.47(31.41)	8.79 (17.21)	3.97 (11.48)	26.00 (30.61)
Pigeonpea + Greengram	27.30(31.45)	7.30 (15.50)	2.40 (8.80)	24.70 (29.75)
Pigeonpea + Groundnut	24.00(29.05)	8.10 (16.51)	2.58 (9.27)	19.00 (25.75)
Pigeonpea + Sorghum	16.50(23.76)	5.63 (13.71)	1.81 (7.67)	16.90 (24.22)
Pigeonpea + Soybean	30.22(33.16)	7.72 (16.09)	2.75 (9.36)	25.17 (30.00)
Pigeonpea + Maize	28.50(32.25)	10.83 (19.13)	5.33 (13.33)	24.17 (29.42)
Pigeonpea + Sunflower	28.50(32.10)	10.50 (18.84)	5.67 (13.76)	24.17 (29.40)
SEm±	0.78	0.93	0.62	0.93
LSD at 0.05	2.36	2.79	1.81	2.75
CV %	14.49	19.53	19.85	15.72

*Figures in parentheses are angular transformed values.

Grain damage

The pod borer complex (*M.vitrata, E. atomosa* and *H. armigera*) was grouped into one category as lepidopteran borers and grain damage caused by this group was differentiated from the damage caused by pod fly (Plate 4). The average grain damage is depicted in figure 5. Significant difference in grain damage by lepidopteran borers was noticed among cropping systems. Pigeonpea + sorghum registered lowest level of grain damage (15.15%) and the intercrops groundnut and blackgram also reduced the grain damage. Similar trend was observed with the grain damage by pod fly, which was significantly different among cropping systems.

Fig 5. Impact of crop-crop diversity on grain damage in pigeonpea



M.vitrata *E.atomosa* *H.armigera* *M.obtusa*

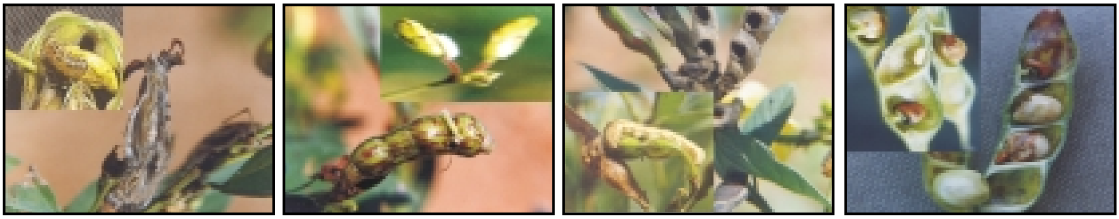


Plate 4 : Pod borer complex of pigeonpea

Significant fluctuation in pest incidence was observed among different cropping systems. Deterrence of colonization through intra field diversity is probably one of the promising means of controlling the insect pests because only a little additional diversity in the crop field may have a profound effect on colonization by insects. This was well documented in case of intercropping (Risch *et al.,* 1983). Any such delay in pest colonization therefore results in subsequent delays in the pest buildup. The present results showed that intercropping had positive influence with pigeonpea + sorghum dicrop combination which reduced the infestation. This suggests that pest migration after initial establishment was possibly inhibited by the non host plants as physical barriers to inter or intra row migration within intercrop treatment which had crop species both sorghum or castor arranged in rows. The conspicuous pest reduction in sorghum - pigeonpea dicrop combination may be because sorghum made inter row migration very difficult for *M.vitrata* during later stages of pigeonpea crop development. Amoako Atta *et al.* (1983) made similar observations in cowpea intercropped with maize. The reduction of pest incidence over time was also reflected in terms of pod and grain damage.

The reduction of *H. armigera* infestation due to sorghum as intercrop can be attributed to two factors. The simultaneous flowering of pigeonpea and sorghum might have caused distribution of *H. armigera* population on main crop pigeonpea and intercrop, leading to less incidence of the pest on main crop. The time of incidence and attack to the crop species by the pest clearly coincided with the reproductive and maturation stages of the pigeonpea and the intercrop. Overlapping of pod formation and flowering of pigeonpea with ear-head formation of sorghum might have reduced the feeding damage to main crop pigeonpea by the pest. These findings agree with those of Amoako Atta *et al.* (1983) and Duffield and Reddy (1997). That the short and medium duration pigeonpea cultivars have significant role in cultural and agronomic manipulation to minimize insect damage was also noted by Shanower *et al.,* 1999.

3.2.2. Crop-crop diversity and natural enemy population

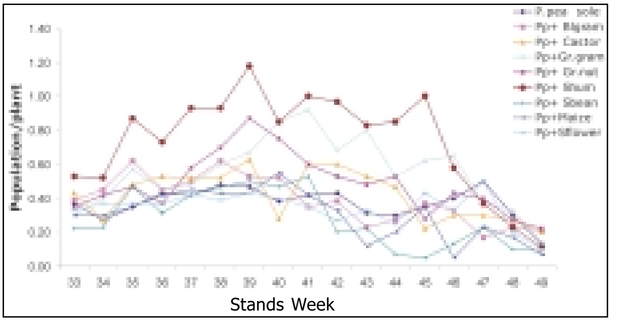
The occurrence of the common predators of insect pests of pigeonpea was monitored at regular intervals in different cropping systems. Among various species of coccinellid predators, viz., *Menochilus sexamaculatus* (F), *Brumoides suturalis* (F). *Illois indica* Timberlake, *Coccinella transversalis* (L) and *Coccinella septempunctata* (L), *M. sexamaculatus* was found most dominant accounting for more than 80% of the total coccinellid population (Plate 5). The other natural enemies like *Cotesia sp.* cocoons, *Chrysoperla sp.* eggs, *Orius sp.* bugs and *Trichogramma* adults were also recorded (Plate 6). The coccinellids were considered as a group and their presence was recorded in all the cropping systems.

Four species of spiders were observed in the cropping systems under study. These belong to the families Clubionidae, Araneidae, Linyphilidae, and Thomisidae. Among various spiders recorded, *Clubiona* spp was dominant. All the spiders irrespective of the family to which they belong were recorded together as one unit.

Coccinellids

The coccinellid population varied significantly across cropping systems throughout the crop growth period. The activity of coccinellids was recorded within a month after sowing and continued till the harvest of the pigeonpea crop. The peak activity of coccinellids occurred prior to flowering stage of pigeonpea. The peak activity of coccinellids (0.80-1.00per plant) was recorded at 38-43 SWK in pigeonpea + sorghum, pigeonpea + greengram, and pigeonpea + groundnut cropping systems and maintained their activity even up to pod maturity stage of the crop (Fig 6). The higher population of coccinellids coincided with the peak activity of *E. kerri, H. armigera* and other pests. Pigeonpea with soybean and maize recorded lower population of coccinellids than sole pigeonpea.

Fig 6. Impact of crop-crop diversity on coccinellids in pigeonpea



> Crop-crop diversity facilitated *in-situ* culturing of natural enemies.

Relationship between insect pests and coccinellids

Coccinellids and spiders were found to have significant negative correlation with *E.kerri.* The low incidence of insect pests in intercrops is often attributed to abundance of predators and parasites (Tonhasca, 1993). The population of *H. armigera* was significantly and negatively correlated with that of coccinellids in pigeonpea intercropped with sorghum. The above predatory groups can be regarded as generalist predators (Duffield and Reddy, 1997). Initially aphids and shoot bug on sorghum represented the main prey, followed by *E. kerri, H. armigera* and *M. usitatus,* on pigeonpea after flowering, which is reflected in correlation coefficients that are significant.

Temporal behaviour of coccinellids

An examination of population dynamics of insect pests and coccinellids over time shows that both followed a quadratic trend (Table 3). Initially population of coccinellids increased with insect population and later started decreasing. The coccinellids followed similar fashion, as they are host dependent factors.

Plate 5 : Coccinellids and spiders

Table 3. Estimated quadratic time trend equations for insect pests and coccinellids

		R^2
Pigeonpea + groundnut		
E.kerri	$y = -0.6096 + 0.5277\ SWK - 0.0268\ SWK^2$	0.75
H.armigera	$y = -1.1045 + 0.5616\ SWK - 0.0214\ SWK^2$	0.84
Coccinellid	$y = 0.3565 + 0.0726\ SWK - 0.0049\ SWK^2$	0.59
Pigeonpea + sorghum		
E.kerri	$y = -0.0125 + 0.3268\ SWK - 0.0160\ SWK^2$	0.54
H.armigera	$y = -1.5883 + 0.8099\ SWK - 0.0358\ SWK^2$	0.81
Coccinellid	$y = 0.2089 + 0.2002\ SWK - 0.0123\ SWK^2$	0.88

Predator - pest relationship

In order to examine the effect of the predator (coccinellid) population on the incidence of jassids, a double log regression equation was fitted with the coccinellid population in the preceding week as the independent variable. A significantly negative regression coefficient was observed (Table 4). Such a negative relationship reflects the dependence of predator on pest population. Once the natural enemy population reaches a threshold peak level, it starts to exert a significant impact on the pest population. Multiple coefficient of determination in pigeonpea + groundnut and pigeonpea + sorghum systems varied from 0.43-0.51.

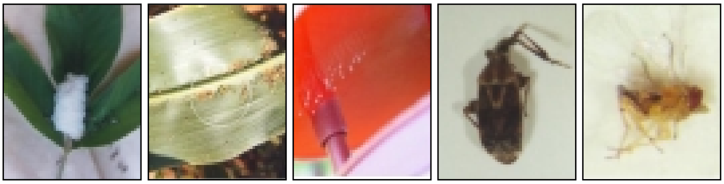


Plate 6 : Other Natural Enemies

Table 4: Estimated predator- pest relationship in pigeonpea

		R^2
Pigeonpea+groundnut		
Jassids	Log Y = 0.443* - 0.828*Log (Cocci SWK-1) (0.146) (0.257)	0.43
Pigeonpea+sorghum		
Jassids	Log Y = 0.588 - 0.681*Log (Cocci SWK-1) (0.594) (0.161)	0.51

The activity of spiders was observed during 31-49 SWK periods in cropping systems. Majority of systems recorded higher population than sole crop of pigeonpea. Wide fluctuation in activity was noticed and the peak population was during 34-39 SWK. Pigeonpea with intercrops like blackgram, groundnut, sunflower and sorghum recorded higher population (0.8-0.6 /plant).

To sum up, the population of natural enemies is higher in the intercropping systems compared to the monocultures. In a diverse crop situation, the natural enemies are more likely to find their prey (pests on the intercrops) and multiply sooner and thus have a higher possibility to reduce the insect pests of the main crop.

3.2.3 Effect of intercropping on microclimate

The three-microclimate variables viz., canopy temperature (Tc), canopy - air temperature differential (CATD) and relative humidity in crop canopy (CRH) of the crop were altered due to presence of intercrop. In majority of observations, Tc was higher in pigeonpea with

> Microclimate variation was evident in intercropping.

intercrops than in sole crop of pigeonpea. Castor and greengram as intercrops resulted in higher Tc of 35.9⁰ C and 36.3⁰ C and were at par at 12 WAS. Sorghum as intercrop increased the Tc to 32.5⁰ C compared to 30.5⁰ C in sole pigeonpea (30.5⁰ C) High CRH values was recorded in pigeonpea with sorghum and castor as intercrops. The sole pigeonpea and pigeonpea intercropped with greengram had relatively low values.

If the differences in all the three microclimate variables are seen together, high RH leads to the development of latent heat on crop canopy which increases canopy temperature than air temperature leading to low values of CATD in majority of observations made. The relationship pattern between microclimate and insect pests is less studied compared to plant pathogens (Trenbath, 1993). The higher relative humidity under tall canopy together with shading is likely to favour the activity of insects in intercrops also (Srinivasa Rao *et al,* 2004 b and Gethi and Khaemba, 1991)

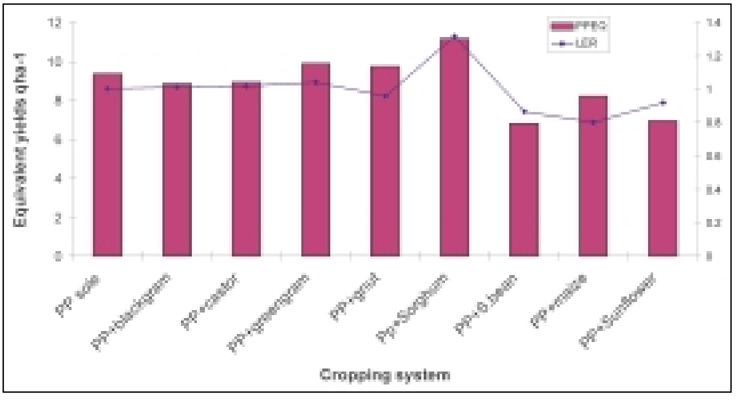
3.2.4 Agronomic evaluation

Fresh and dry weights

The fresh and dry weights of pigeonpea were recorded at various intervals in all the cropping systems. Increase in weight was more evident after 60 DAS among various cropping systems. Highest fresh weights were recorded in pigeonpea + sorghum (upto 1000gms) followed by pigeonpea + blackgram, pigeonpea + groundnut and sole pigeonpea. The fresh weights of main crop were less in pigeonpea + castor (upto 600gm). Similar trend was observed even after drying of the plant samples.

Equivalent yields and LER

Fig 7. Impact of crop-crop diversity on equivalent yields and LER in pigeonpea



Pigeonpea equivalent yields were calculated considering the farm harvest prices (FHP) of main and inter crops as per standard procedure. Pigeonpea + sorghum, pigeonpea + greengram and pigeonpea + groundnut recorded higher pigeonpea equivalent yields (Fig 7). Pigeonpea + blackgram was the next best. The equivalent yields were lower in pigeonpea + sunflower, pigeonpea + soybean and pigeonpea + castor systems. From the unit area utilization point of view, pigeonpea + sorghum ranked best (1.31) followed by pigeonpea + greengram (1.04). LER values are less than one for majority of systems (pigeonpea + groundnut, pigeonpea + sunflower, pigeonpea + maize and pigeonpea + soybean) and nearly equal to one in case of pigeonpea + castor and pigeonpea + blackgram. This indicates that the former group is relatively more efficient and the latter is just as efficient as sole pigeonpea.

Agronomic indices of cropping systems

The agronomic evaluation of cropping systems indicated that aggressivity (A) values for pigeonpea were positive and those of intercrops were negative showing the dominance of main crop i.e., pigeonpea. This trend indicated that pigeonpea was vigorous in growth habit and was dominant in the mixture. The competitive ratio (CR) values showed that pigeonpea was more competitive than the intercrops and the difference between CR values of main and intercrops was less in pigeonpea + sorghum and pigeonpea + groundnut and indicated that intercrops were not suppressed significantly. The relative crowding coefficient (RCC) values were more than unity in all intercropping systems except pigeonpea+ maize. RCC was highest in pigeonpea+ sorghum system. (Table 5).

Table 5. Agronomic evaluation of pigeonpea based cropping systems

Cropping systems	**Competitive Ratio**		**Aggressivity**		**Relative Crowding Coefficient**	
	MC	**IC**	**MC**	**IC**	**MC**	**IC**
Pigeonpea + Blackgram	1.74	0.32	0.74	-0.74	2.00	0.30
Pigeonpea + Castor	1.25	0.36	0.53	-0.53	1.34	0.43
Pigeonpea + Greengram	1.97	0.28	1.49	-1.49	4.08	0.39
Pigeonpea + Groundnut	1.78	0.31	0.79	-0.79	1.71	0.37
Pigeonpea + Sorghum	1.77	0.38	1.03	-1.03	19.59	0.65
Pigeonpea + Soyabean	1.79	0.26	0.77	-0.77	1.85	0.23
Pigeonpea + Maize	2.60	0.17	0.69	-0.69	0.69	0.11
Pigeonpea + Sunflower	1.38	0.33	1.09	-1.09	1.39	0.82
SEm±	0.11	0.01	0.03	0.03	1.84	0.04
CD (0.05%)	0.34	0.04	0.09	0.09	5.58	0.13
CV %	10.86	6.73	5.76	-5.76	18.17	17.42

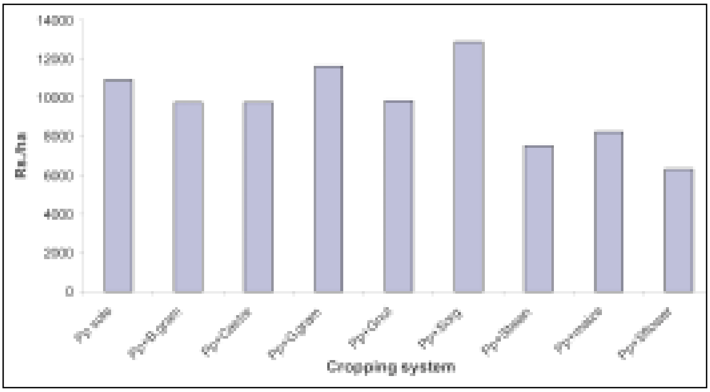
MC = Main crop IC = Intercrop

> Aggressivity, Competitive Ratio and Relative Crowding Coefficient indicated that pigeonpea was vigorous in growth habit and was dominant.

3.2.5 Economics

The economics of pigeonpea based cropping systems during *kharif* season is depicted in figure 8. The variable cost of cultivation which includes costs incurred on fertiliser, seed, labour and bullock labour, was found highest in case of pigeonpea + groundnut (5107Rs/ha) followed by pigeonpea+ sunflower and

Fig 8. Impact of crop-crop diversity on gross margin for pigeonpea



pigeonpea+ maize intercropping systems. The cost structure indicated that human labour was the single most important factor contributing to the total variable cost. The relative expenditure on seed and labour was also more in case of intercropping systems compared to the sole crop. The gross margin as indicated by returns over variable costs was found highest in case of pigeonpea+ sorghum (Rs 12,862 /ha) and pigeonpea+ greengram (Rs11,642/ha) and least in pigeonpea+ sunflower (Rs 6332 /ha).

The effective and efficient systems were further taken forward wherein different IPM modules were superimposed and evaluated for their effectiveness and profitability.

The variable costs of cultivation of the cropping systems considered are presented in table 6. It can be seen that inclusion of intercrops increased the cost of cultivation in all cases. The cost of cultivation was found to be highest in case of pigeonpea+groundnut (Rs.4831/ha). A look into the cost structure indicated that human labour was the most important factor contributing to the total cost. In case of pigeonpea+groundnut, the expenditure on seed was found to account for about 18% of total variable costs. In all the systems, bullock labour was used for preparatory cultivation, sowing and interculture. Thus the cost of bullock labour was observed to be same in all the systems.

Table 6. Composition of variable costs in different cropping systems (Rs/ha)

Cropping systems	Seed	Fertiliser	Human labour	Bullock labour	Total
Pigeonpea sole	310(8.3)	850(22.7)	1589(42.4)	1000(26.7)	3749(100)
Pigeonpea +Sorghum	395 (9.1)	1023(23.6)	1919(44.2)	1000(23.1)	4337(100)
Pigeonpea +G.gram	435(10.1)	1029(23.9)	1837(42.7)	1000(23.3)	4300(100)
Pigeonpea +castor	413(9.7)	1025(24.1)	1820(42.7)	1000(23.5)	4258(100)
Pigeonpea +Gnut	882(18.2)	981(20.3)	1969(40.7)	1000(20.7)	4831(100)
Pigeonpea +Bgram	435(10.6)	850(20.7)	1820(44.3)	1000(24.4)	4105(100)
Pigeonpea +Sflower	464(10.5)	1029(23.3)	1919(43.5)	1000(22.7)	4411(100)
Pigeonpea +Maize	455(10.1)	1204(26.8)	1837(40.9)	1000(22.2)	4495(100)

Figures in parentheses are percentages

3.3. Low external input IPM modules

Three systems namely pigeonpea + sorghum, pigeonpea + groundnut and pigeonpea + blackgram were found to perform better in terms of lower pest incidence, better LER and higher gross margin. On these three systems three IPM modules as defined in section 2.3 were superimposed. All these modules consisted of only farm generated inputs. The findings from a two factor RBD analysis showed that the three modules and the three intercrops differed significantly in terms of incidence of pests, pod damage, yield and gross margin.

Table 7. Impact of Low External Input – IPM modules on *H.armigera*

Cropping Systems	MEAN	
	CPU	Mean pop.
PP +Bl gram – IPM 1	12.32	1.54
PP +Gr.nut – IPM 1	12.65	1.58
PP +Sorghum – IPM 1	12.18	1.52
PP Sole – IPM 1	13.83	1.73
PP +Bl gram – IPM 2	20.40	2.55
PP +Gr.nut – IPM 2	22.13	2.77
PP +Sorghum – IPM 2	12.73	1.59
PP Sole – IPM 2	12.77	1.59
PP +Bl gram – IPM 3	16.36	2.05
PP +Gr.nut – IPM 3	17.39	2.17
PP +Sorghum – IPM 3	12.46	1.56
PP Sole – IPM 3	13.29	1.66
PP +Bl gram – UT	19.73	2.47
PP +Gr.nut – UT	19.99	2.49
PP +Sorghum – UT	16.73	2.09
PP Sole – UT	19.23	2.40
SEm ±	0.88	0.11
LSD at 0.05	2.54	0.32

Factor 1	MEAN	
	CPU	Mean pop.
IPM 1	17.88	1.86
IPM 2	17.01	2.13
IPM 3	12.74	1.59
UT	18.92	2.36
SEm ±	0.44	0.06
LSD at 0.05	1.27	0.16
Factor 2		
B.gram	17.20	2.15
G.nut	18.04	2.26
Sorghum	13.53	1.69
Ppea sole	14.78	1.85
SEm ±	0.44	0.06
LSD at 0.05	1.25	0.18
CV (%)	9.60	9.30

The incidence of *H. armigera* varied across different treatments having different combinations of intercrops and IPM modules. The incidence in terms of both CPU and mean population per plant varied significantly across the treatments. The effect of both the factors was found significant. The incidence of *H armigera* was particularly low in pigeonpea when intercropped with sorghum (13.53 CPU and 1.69 larvae/plant) and when protected with IPM module III (12.74 CPU and 1.59 larvae/plant). The interaction effect was also found significant. Similar results were obtained in case of other insect pests also. These differences in pest infestation were also reflected in the grain yield and damage.

The IPM3 module (consisting of sequential application of botanical extracts, oils, erection of bird perches and mechanical collection of larvae) on pigeonpea + sorghum was found to suffer from least pest incidence, attract more natural enemies, give higher yields and returns, followed by the pigeonpea + groundnut system. These two systems can thus serve as a cultural component or platform on which the low external input or bio-intensive modules of crop protection can be adopted.

> Use of rice and maize pops instead of cooked rice increased the bird predation.

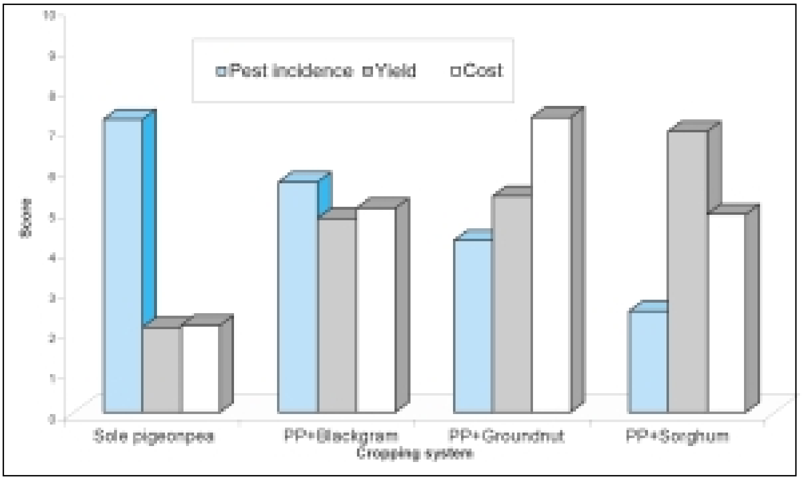
Further these modules were also comparable to the recommended IPM package in terms of pest management and yields. However the cost incurred in LEIPM modules was much less because of the avoidance of external inputs like bio agents and chemical insecticides.

4. Farmers' Feedback

Focus group discussions were held with farmers before commencement of the on farm experiments. It came out during the interactions that farmers were practicing the inter- and mixed cropping system more as a strategy to meet the diverse family needs and to reduce risk. In this process, the farmers' choice of intercrops, varieties and the row ratios were determined by what they have been used to over time rather than by the other principles like optimization of yields and costs. Not many farmers were aware about the differential pest infestation that the monocultures and diverse crop systems suffer. Dependence on chemical insecticides was more a rule rather than an exception in pest management. Though some farmers were aware about various components of IPM, adoption was not significant.

Similar focus group discussions were held again with the same set of farmers as before. Farmers expressed that the diverse crop systems in fact suffered less pest infestation than the monocultures. Farmers were asked to rate each cropping system on a scale of 1 to 10 with respect to three parameters viz., pest incidence, yield and cost of cultivation. The average scores obtained are presented in figure 9. As can be seen from the figure, the pigeonpea + sorghum system fared better with a score of 2.5 for pest incidence, 6.95 for yield and 4.9 for cost and was considered superior to all other systems. However, the costs incurred were least with sole pigeonpea. Farmers also opined that the yield from the pigeonpea + groundnut system was comparable to that of pigeonpea + sorghum, but required high investments towards seed.

Fig 9. Farmers' rating of different cropping systems



As a result of frequent visits by project staff, farmers are now able to recognize a number of insect pests, their feeding habits and natural enemies as well. The benefits of choosing a particular variety of pigeonpea and the intercrop in terms of higher yields, saving on cost and better cash flow are also better appreciated by the farmers. Farmers were also convinced about the effectiveness of LEIPM modules. However, how this awareness translates into action remains to be seen. Yet, since the components tested were easily adoptable, it is expected that farmers will adopt LEIIPM components easily compared to the other practices.

5. Conclusions

Creation of crop diversity by the introduction of one crop in to another crop is known as crop-crop diversity. Intercropping and mixed cropping systems are more popular forms of crop-crop diversity practiced in rainfed agriculture. These systems provide opportunities to create situations that are less prone to pests compared to the single crop situations or the monocultures. Research was conducted on-station and in farmers' fields on crop-crop diversity as key component of Integrated Pest Management in pigeonpea. The following conclusions are drawn from the results of the research.

Short and medium duration pigeonpeas offered greater degree of protection against insect pest attack. Medium duration pigeonpea, in addition to being attacked by fewer pests, exhibited less flower shedding during dry spells, making it more suitable to dryland conditions. The diversity created by introducing sorghum, greengram and groundnut as intercrops in pigeonpea resulted in a build up of natural enemies of the major pests of pigeonpea and also resulted in less congenial conditions for insect pests. As a result of the changes in microclimate and build up of natural enemies, there was much less pest incidence and damage in pigeonpea intercropped with sorghum, greengram and groundnut compared to sole pigeonpea. Further these systems were more efficient agronomically in terms of land equivalent ratio, aggressivity, competitive ratio and relative crowding coefficient. Economic analysis also showed these intercropping systems to be more profitable than sole pigeonpea. It can be concluded that medium duration pigeonpea intercropped with sorghum, greengram or groundnut is better protected from adverse climate as well as pest attacks, resulting in higher yields and economic returns. The adoption of Low External Input Integrated Pest Management module consisting of sequential application of neem seed kernel extract 5%, neem oil 5%, extract of *V. negundo* 1/10 w/w, pongamia oil 5%, erection of bird perches and mechanical collection of larvae was found effective in managing/controlling the pests. Choice of medium duration pigeonpea and intercropping with sorghum, greengram or groundnut may be integrated into the effective LEIIPM module as a component.

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Some examples of crop-crop diversity


Psole pigeonpea


Pigeonpea + Greengram


Pigeonpea + Blackgram


Pigeonpea + Maize

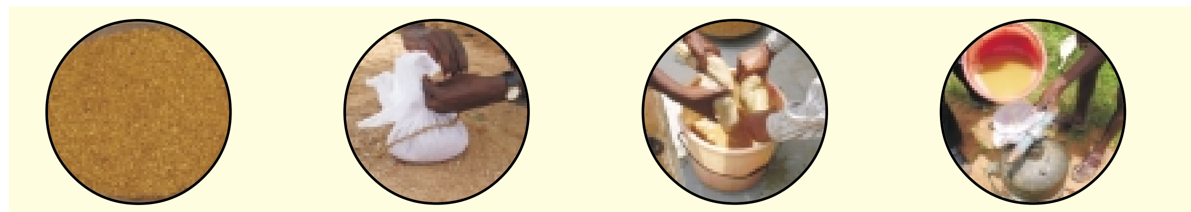

Pigeonpea + Groundnut


Pigeonpea + Sorghum

Low external inputs for IPM


Pigeonpea + Groundnut


Vitex negundo extraction


NSKE extraction


Bird Perches


Mechanical collection