Pesticides on millet in Mali (NRI Bulletin 50)

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PESTICIDES ON MILLET IN MALI

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Summaries

SUMMARY

(i) The Mali Millet Pest Project (Projet Pilote Britannique), financed by Britain's Overseas Development Administration (ODA) studied the control of millet pests in north-west Mali between 1985 and 1991. The project was executed by Mali's Service National de Protection des Végétaux (SNPV) and ODA's Natural Resources Institute (NRI). These six years of observations, field trials and socio-economic research have produced a wealth of information on the pests of Sahelian millet.

(ii) Short-cycle *souna* millet is the principal crop in the Sahelian zone of Mali, accounting for around two-thirds of the cultivated area. Pest damage affects *souna* production significantly. In the project's zone in 1990, for example, pests reduced yields by more than 50% (see Section 2).

(iii) The project considered several pest control techniques, but concentrated upon the study of ultra-low volume (ULV) insecticides, since their use on Sahelian millet is already widely promoted by foreign donors.

(iv) Rainfall in the Sahel is low and variable; this, combined with variability in soil quality and pest attack produces low and variable millet yields. In 1987, for example, the 25% families with the highest *souna* yield produced 348 kg/ha on average, whereas the 25% with the lowest yield produced only 45 kg/ha. This ecological variability could not have been reproduced in research stations. To provide a useful model of reality, therefore, trials were conducted in farmers' fields (see Section 3).

(v) For the trials to produce statistically significant results despite the trial zone's ecological variation, it was necessary to use large trial plots (1 ha) and large samples (350 farmers participated in 1990) (see Section 3).

(vi) The pest complex of the zone's millet changed throughout the project's life. The millet head-miner (*Heliocheilus albipunctella*) was abundant in 1985 and 1986, but was unimportant by 1990. The flower-feeding beetles *Pachnoda interrupta* and *Psalydolytta* spp. were only important in 1989 and 1990 respectively. Spatial variation in pest attack was also marked (see Section 5).

(vii) The project observed millet heads and interviewed farmers to obtain information upon pest attack. Grasshoppers, the millet head-miner, the millet stem-borer and flower-feeding beetles were major pests in at least one year. In no year were birds and plant diseases of importance for *souna* millet (see Sections 5 and 6).

(viii) A study of the millet stem-borer, *Coniesta ignefusalis*, showed that it does not affect the quantity of grain on a millet head, but reduces the number of heads per plant.

(ix) For a pest control strategy to be recommended to farmers, it must not only increase yields. It must also be safe, consistently profitable, affordable and consonant with existing systems of social organization. The project appraised the application of ULV insecticides by hand-held sprayer with regard to these five criteria (see Section 7).

(x) It was confirmed that the grain and leaves of millet treated with ULV Ripcord or Karate did not contain insecticide residues in harmful quantities and that hand-held ULV sprayers could easily be used safely by local farmers (see Section 7).

(xi) The project showed that a single ULV treatment significantly reduces damage by the millet head-miner and stem-borer. It does not, however, reduce damage by grasshoppers or flower-feeding beetles, because they can re-invade the field when the insecticide's effect has worn off (see pages 27-30).

(xii) A study of the millet head-miner's life-cycle suggested that ULV insecticides would reduce its damage most if applied during the millet's male flowering. The project's trials confirmed the relationship between the timing of the ULV treatment and its effectiveness against the head-miner (see page 27).

(xiii) ULV insecticides significantly increased mean yields in all years, but the mean yield increases were not consistent between trials and within each trial there was huge variation about the mean yield increases. Variation in grasshopper and flower-feeding beetle attack was one cause (see Section 9).

(xiv) The project intended to conduct trials in a representative number of poor farmers' and women's fields. This goal was not achieved, because many poor farmers and all women did not cultivate plots large enough to produce statistically significant results (see Section 10).

(xv) Farmer surveys showed that the cost of ULV spraying was disproportionately high in relation to farmers' current levels of expenditure. Cash investment in agriculture in the project zone in 1990 was under US$ 4/ha, whereas ULV spraying costs over US$ 12/ha (see page 40).

(xvi) The project zone's farmers' first investment priority was to extend their cultivated area by hiring labour for weeding. This strategy produces an expected financial return in excess of 100% and reduces exposure to drought and pest risk. By comparison, the financial returns to ULV spraying would have been too low and variable to interest farmers (see pages 37/40).

(xvii) The project's conclusions demonstrated the importance of using socio-economic research methodologies to let farmers' priorities determine the direction of research.

(xviii) On the basis of the project's trial results, one cannot recommend the promotion or subsidization of ULV pesticides for millet in the Sahel (see Section 11).

RÉSUMÉ

(i) Le Projet Pilote Britannique (Projet sur les ennemis du mil au Mali), financé par l'ODA, Administration Britannique du Développement Outremer, a étudié entre 1985 et 1991 la lutte contre les ennemis du mil dans le nord-ouest du Mali. Ce projet a été appliqué par le Service National de Protection des Végétaux (SNPV) du Mali et la NRI (Institut des Ressources Naturelles de l'ODA – Ministère du Développement Outremer de Grande-Bretagne). Ces six années d'observations, d'essais sur le terrain et de recherche socio-économique, ont produit une masse d'informations sur les ennemis du mil sahélien.

(ii) Le mil *souna*, à courte période, est la culture principale de la zone sahélienne du mali, représentant environ les deux tiers de la surface cultivée. Les dégâts causés par l'ennemi affecte de manière marquée la production de *souna*. En 1990, par example, dans la zone du projet, les ennemis ont réduit les rendements de plus de 50% (cf. Section 2).

(iii) Le projet a examiné plusieurs techniques de lutte contre les ennemis, tout en se concentrant sur l'étude des insecticides à volume ultra-faible (vuf), car leur usage sur le mil sahélien est déjà largement recommandé par des donateurs étrangers.

(iv) Au Sahel, la pluviositée est faible et variable; ceci, joint à la variabilité de la qualité du sol et aux attaques des ennemis provoque des rendements de mil faibles et variables. En 1987, par exemple, les 25% de familles qui avaient le plus fort rendement en *souna* produisaient en moyenne 348 kg/ha, tandis que les 25% qui avaient le plus faible rendement n'en produisaient que 45 kg/ha. Cette variabilité écologique n'aurait pas pu être reproduite en station de recherche. Pour fournir un modèle utile de réalité, on entreprit donc des essais dans les champs des cultivateurs (cf. Section 3).

(v) Pour que les essais donnent des résultats statistiquement significatifs, en dépit de la variation écologique de la zone d'essai, il était nécessaire d'utiliser de grandes parcelles d'essai (1 ha) et de grands échantillons (350 cultivateurs y ont participé en 1990) (cf. Section 3).

(vi) Le complexe d'ennemis du mil de la zone a changé pendant la durée du projet. La mineuse des épis du mil (*Heliocheilus albipunctella*) abondait en 1985 et en 1986, mais son importance avait diminué en 1990. Les coléoptères floriphages *Pachnoda interrupta* et *Psalydolytta* spp. n'ont eu d'importance qu'en 1989 et 1990 respectivement,. La variation spatiale des attaques d'ennemis a également été très nette (cf. Section 5).

(vii) Le projet a observé les épis de mil et a interrogé les cultivateurs pour s'informer sur les attaques d'ennemis. Les acridiens, la mineuse des épis du mil, la foreuse des tiges du mil et les coléoptères floriphages ont été les ennemis principaux pendant au moins un an. Pendant aucune année les oiseaux, ni les maladies des plantes, n'ont causé de graves dégâts au *souna* (cf. Sections 5 et 6).

(viii) Une étude de la foreuse des tiges du mil, *Coniesta ignefusalis*, a montré qu'elle n'affecte pas la quantité de grain d'un épi, mais réduit le nombre d'épis par plant.

(ix) Pour recommander une stratégie de lutte aux cultivateurs, il faut non seulement qu'elle augmente le rendement mais aussi qu'elle soit sans danger, constamment rentable, à portée financière et compatible avec les systèmes existants d'organisation sociale. Le projet a étudié l'application d'insecticides à vuf par pulvérisateur manuel, en tenant compte de ces cinq critères (cf. Section 7).

(x) Il est confirmé que les grains et les feuilles de mil traités au moyen de Ripcord ou Karaté à vuf ne contiennent pas de résidus d'insecticides en quantités dangereuses et les pulvérisateurs manuels à vuf peuvent être utilisés facilement et sans danger par les cultivateurs locaux (cf. Section 7).

(xi) Le projet a montré qu'un simple traitement à vuf réduit significativement les dégâts de la mineuse des épis et de la foreuse des tiges du mil. Néanmoins, un tel traitement ne réduit pas les dégâts par les acridiens, ni par par les coléeoptères floriphages, parce que ces derniers peuvent ré-envahir le champ quand l'effet de l'insecticide s'est dissipé (cf. pp. 27–30).

(xii) Une étude du cycle vital de la mineuse des épis du mil semble montrer que les insecticides à vuf en réduiraient les dégâts, surtout si le traitement était effectué pendant la floraison mâle du mil. Les essais du projet ont confirmé le rapport entre le moment du traitement à vuf et son efficacité contre la mineuse des épis (cf. p. 27).

(xiii) Les insecticides à vuf ont acru à un point significatif les rendements moyens de toutes les années, mais les augmentations des rendements moyens n'étaient pas constantes entre les essais et, à l'intérieur de chaque essai, des variations énormes se produisaient entre les augmentations des rendements moyens. La variation des attaques par acridiens et par coléoptères floriphages était l'une des causes (cf. Section 9).

(xiv) Le projet visait à mener à bien les essais dans un nombre représentatif de champs de cultivateurs pauvres et de femmes. Cet objectif n'a pourtant pas été atteint, parce qu'un grand nombre de pauvres cultivateurs et toutes les femmes ne cultivaient pas de parcelles assez grandes pour produire des résultats statistiquement significatifs (cf. Section 10).

(xv) Les enquêtes par les cultivateurs ont montré que le coût des pulvérisations à vuf était hors de proportion avec les niveaux actuels de dépenses des cultivateurs. L'investissement en numéraire dans l'agriculture de la zone du projet en 1990 était inférieur à US$ 4/ha, tandis que les coûts de pulvérisation à vuf dépassaient US$ 12/ha (cf. p. 40).

(xvi) Les premières priorités d'investissement des cultivateurs de la zone du projet consistaient à accroître la superficie cultivée en louant de la main d'oeuvre pour le sarclage. Cette stratégie produit un rapport financier prévu au-delà de 100% et réduit l'exposition à la sécheresse et au risque des ennemis. Par comparaison, les rapports financiers de la pulvérisation à vuf auraient été trop faibles et trop variables pour intéresser les cultivateurs (cf. pp. 37/40).

(xvii) Les conclusions du projet ont démontré l'importance d'utiliser les méthodologies de la recherche socio-économique pour que les priorités des cultivateurs déterminent l'angle de la recherche.

(xviii) Sur la base des résultats des essais du projet, on ne peut pas recommander de promouvoir ou de subventionner les pesticides à vuf pour le mil du Sahel (cf. Section 11).

Section 1

Introduction

In 1983, Mali's plant protection service, the Opération Protection Semences et Récoltes (OPSR) requested an ODA Technical Co-operation project to investigate methods of controlling grasshopper pests of millet. In response, evaluation missions from TDRI (Tropical Development and Research Institute) visited the most affected part of north-west Mali in 1983 and 1984.

Although grasshoppers were a major pest in these years, the evaluation mission of 1983 concluded that the millet head miner moth (*Heliocheilus albipunctella*) caused greater crop losses. A preliminary crop-loss assessment indicated that 40–60% of the millet crop was being destroyed by this pest and that the OPSR was neither trained nor equipped to deal with its control. In addition, contact between OPSR and farmers was minimal, materials necessary for pest control were lacking and there were no properly maintained stores for pesticides. OPSR provided free dust and granule formulation pesticides to farmers for use principally against grasshoppers and locusts, but did not monitor the effectiveness of these treatments or supervise their application.

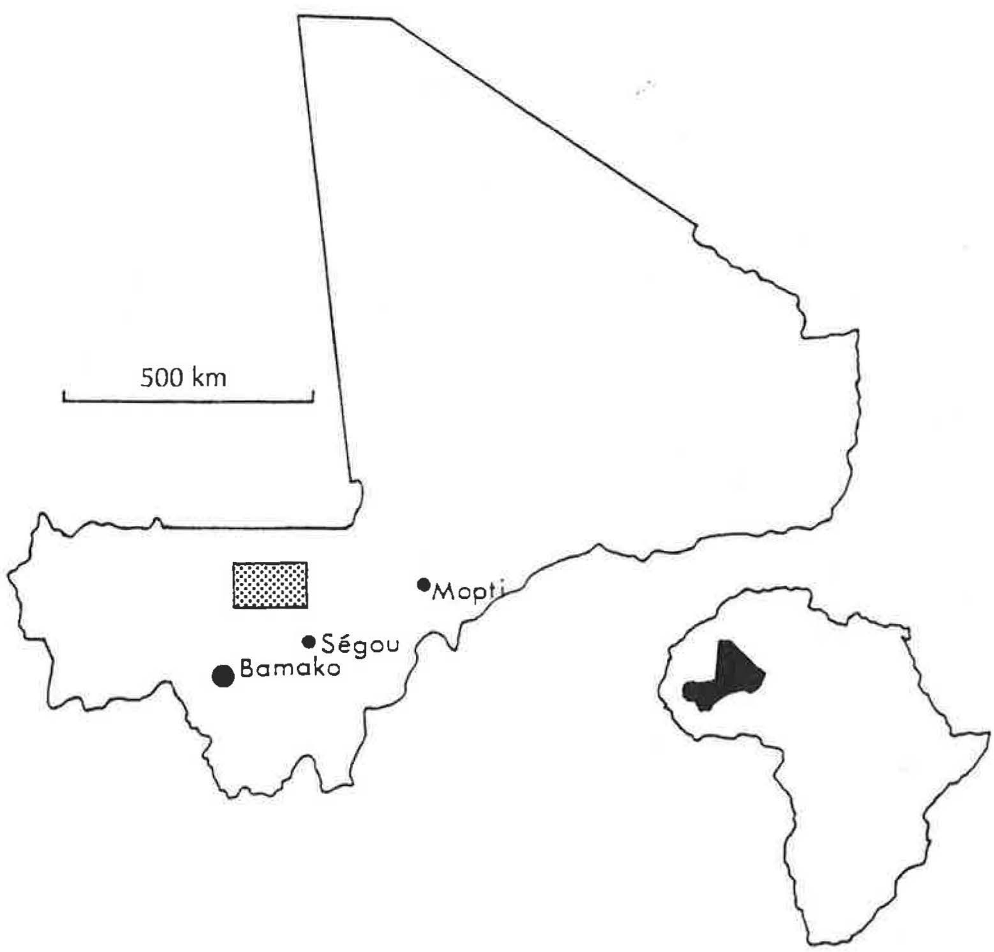

Figure 1 Map of the study area in northwest Mali ⚄, Nara Cercle; ■, Mali

The Mali Millet Pest Control Project was based in SNPV buildings at Mourdiah, in the Nara cercle of north-west Mali (Figure 1). Sub-bases were also established at Dilli, Nara and Fallou (Figure 2). All pest control trials were conducted in farmers's own fields in order to replicate real-life conditions. In view of the importance of balancing the technical aspects of pest control with an economic appraisal of the acceptability of such measures to the farmers, an integrated team of entomologists and agro-economists worked from the base at Mourdiah.

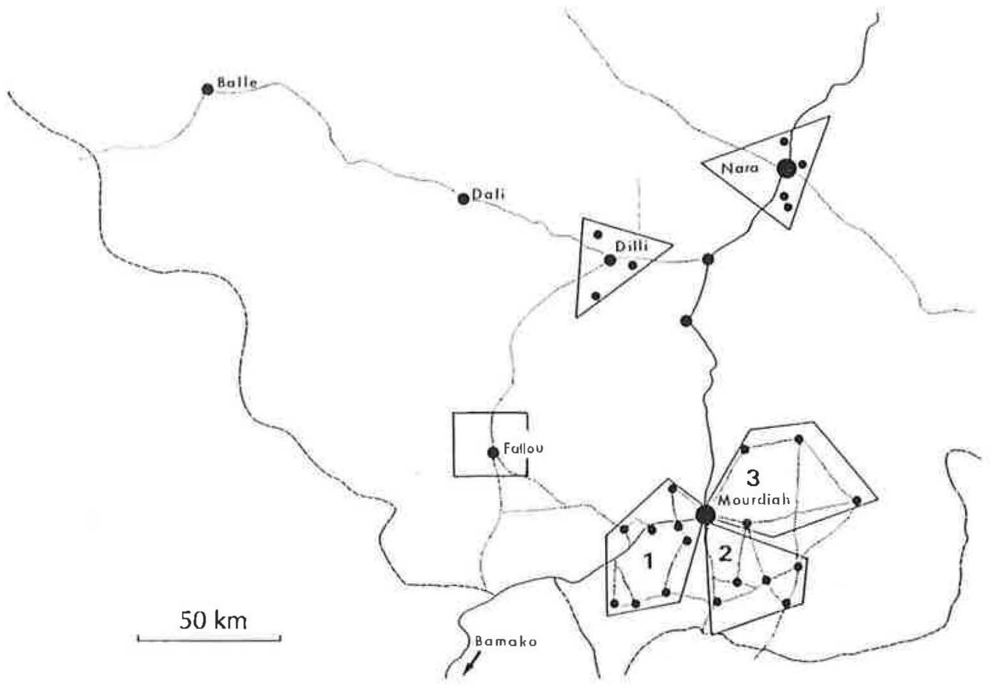

Figure 2 Map of the sub-bases

The project aimed to refine and demonstrate a practical system of pest management at farmer level, whilst working in association with the Service National de la Protection des Végétaux (SNPV) in north-west Mali (the SNPV replaced the OPSR in 1987). Project work centred upon the most effective and economic use of chemical control methods for crop protection, although other means of pest management such as the use of chemical fertilizers and other millet varieties were also investigated.

The principal objective of the project trials was to develop a viable self-financing pest control treatment that could be extended to farmers living in other areas within the Sahel, thereby preventing the need for external subsidies.

The findings of these trials have been described in detail by Lock (1990), Kremer and Sidibe (1991) and Jago, Kremer and West (1991). This report presents the essential results and conclusions gained throughout the entire period of the Mali Millet Pest Control Project.

Section 2

Description of the project region

The project area covers 30 000 km^2 and lies just to the south of the Mali/ Mauritania border (Figure 1) between the latitudes of 14°30′ N and 15°30′ N. Human population density in this area is very low (with an average of only 5 people per km^2) and there is little competition for land.

The main crop grown in the project region is pearl millet (*Pennisetum glaucum*), as seen in Figure 3. In some areas it is intercropped with sorghum (*Sorghum bicolor* (L.) Moench) which may replace it in the heavier, more clayey, soils. Both of these cereals come in several genotypes, including 'short-cycle' and 'long-cycle' varieties. The long-cycle millet, locally known as *sanyo*, takes about 120 days from germination to harvest whilst the short-cycle millet, locally known as *souna*, takes about 70 days. The proportion of short-cycle millet sown in fields in the project region is reported to have increased significantly following the droughts of the mid 1970s. Sorghum also has highly drought-resistant varieties. Although it is planted in late July, it produces grain at the same time as the long-cycle millets.

These crops are grown in the rainy season which normally starts in late June and ceases in late October. Both sorghum and millet may be intercropped with cowpea. Field margins are sometimes planted with okra, *Hibiscus* and hemp. Naturally-occurring grasses (such as *Cenchrus biflorus* and *Echinochloa colona*) may be harvested on a small scale and assume a greater importance in years of drought.

Crop residues remaining after harvest provide fodder for cattle, which in turn provide manure for the following season.

The decision to base the project at Mourdiah was taken for the following reasons:

(a) This site was thought to be representative of Sahelian rainfed millet growing areas in terms of soil type and rainfall;

(b) It is in an area in which the SNPV is active and where pest control was seen as one of the few possibilities for increasing grain yields;

(c) There is a road to Bamako with all-weather access.

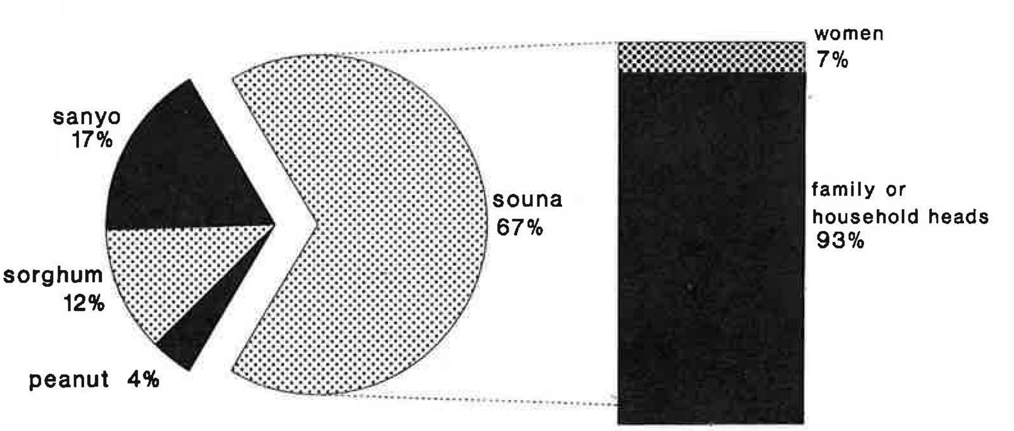

Figure 3 Land use in all the fields of three villages near Mourdiah, 1987

The dominant ethnic groups in the project region are the Soninke and Bambara, who are sedentary farmers growing mainly millet and sorghum. Two other groups, the Peul and Maur, are traditionally transhumant pastoralists, although the reduction in herd sizes which followed the droughts of the mid-1970s has served to increase the trend towards settlement and cereal production within the project region. The majority of the fields are managed by men, with women's fields covering, on average, only 5% of the total cultivated land within the project region (Lock, 1988) (Figure 3).

Rainfall in the project region is unpredictable with droughts occurring at irregular intervals. The first rains typically fall in June or July, with the highest rainfall in August. The average rainfall at Mourdiah, based on an analysis of records collected over the past 25 years, is seen in Table 1.

Between 1987–1990 there was considerable variation in total rainfall experienced in the different years, as seen in Table 2.

Thus rainfall was below average in 1987 but above average in 1988 and 1989. Whilst total rainfall provides an indication of the favourability of climatic conditions for cereal production, it is important to stress the value of heavy rainfall in August for *souna* millet and in September for *sanyo* millet and sorghum. Thus although rainfall was adequate in both July and September in 1990, drought in August severely reduced the *souna* harvest. Heavy rainfall can in itself cause damage to crops, as witnessed in 1988, since it can lead to flash-floods, the loss of topsoil and destruction of growing plants.

Table 1 Average rainfall (mm) at Mourdiah

	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Total
Rainfall	0	16	62	151	194	92	24	3	542

Table 2 Total rainfall (mm) recorded at Mourdiah

Year	1985	1986	1987	1988	1989	1990
Rainfall	354	393	388	608	638	450

Section 3

Methodology

The project sought to conduct all trials work in fields provided by farmers within six zones (Figure 2) in the project region. The number of farmers who supplied fields for project trials between 1985–1990 is shown in Table 3.

Each zone was assigned a team of project staff, which recruited farmers and explained the nature and aims of project trials to them. Each farmer was asked to provide 1 ha of land of his own choice. Once this hectare had been allocated, each survey team accurately marked out two adjacent 0.5 ha plots of land divided by a 1-metre access strip. The two 0.5 ha plots were chosen to be comparable in elevation, soil type and all other visible aspects. One of these plots was then defined as being the one to receive a ULV treatment, whilst the remaining plot served as a non-treated comparison. The ULV treatment was accompanied by an application of insecticide granules in 1987 only.

Farmers were requested to sow each plot with pure-stand short-cycle millet only and to manage both plots in a similar manner. Farmers were also asked to sow in straight lines in a north-south direction in order to make use of the prevailing winds during spraying of pesticides. Project teams visited the farmers and their plots regularly throughout the growing season in order to record the dates of sowing, weeding and harvest and to assess the development of the crop.

Project teams were also responsible for administering pesticide treatments to the experimental plots and for assessing the level of pest infestation in both treated and non-treated plots. Harvesting of the plots was undertaken by project teams using diesel-driven Bourgoin 'Bamba' threshing machines. Millet heads from each 0.5 ha plot were threshed separately, with the weight of grain produced being measured in the field so that the grain could immediately be given to the farmer.

An agricultural economics team was attached to the project from 1987 to 1991. Its role was to advise upon the trial procedures and to investigate whether the techniques being tested were suitable for extension to farmers. Between 1990 and 1991 the economist also studied the work of the national plant protection service and recommended organizational changes.

Table 3 Number of farmers working with the project

	1985	1986	1987	1988	1989	1990
Mourdiah	4	40	84	140	151	159
Dilli	–	20	40	62	68	68
Nara	–	20	43	60	69	69
Fallou	–	–	–	–	30	32
Total	4	80	167	262	318	328

Throughout the period between 1985 to 1990 there was found to be tremendous variation in climatic conditions, the nature and size of the pest complex, and the extent of grain productivity. This brief account of the project relies upon means and medians to describe its results. It is, however, important to stress that it is the variation about the mean or median which is essential to an understanding of the project environment.

Section 4

The crop cycle

An outline of the crop cycle is presented in Figure 4. *Souna* seed is sown by farmers before or after the first major rains of the season. It starts to tiller one month after sowing and to produce heads in late July and early August. Grain starts to form in August and matures in September.

Farmers sow by scooping holes in the soil with a hoe, dropping the millet seed into the hole and covering them with soil. In consequence, millet plants develop within distinct 'pockets'. Within the project region none of the farmers apply any chemical fertilizers to these plots either before or after sowing. The pockets of young millet are thinned 1–5 weeks after germination, with any weeds often being removed at the same time. Depending upon the availability of labour, the fields are weeded between 1–3 times during the growing season.

The project zone's millet fields were not homogeneous; farmers classify them as either 'village', 'bush', 'family', or 'private fields'.

- Village fields are near to the village. They have typically been cultivated continuously for more than 20 years, and therefore need manuring to maintain their fertility. The project trials were concentrated in village fields, because their soil favours the cultivation of *souna* millet.
- Bush fields are typically, cleared, cultivated and abandoned within 5 years. Rarely manured and relatively free of weeds, they usually support *sanyo* millet or sorghum.

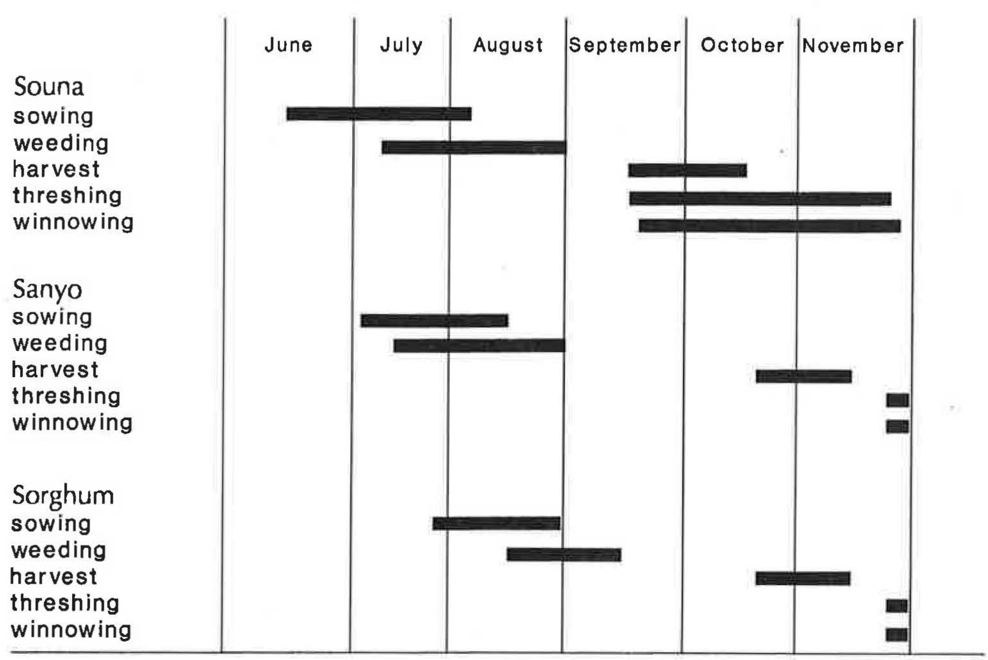

Figure 4 Agricultural calender in the Cercle of Nara

- Family fields are managed by the family head and worked by family members. The food they produce is stocked by the family head and goes towards family meals. The project trials were concentrated in family fields, because they account for over 80% of *souna* cultivation.
- Private fields are managed by a married man or woman. Accounting for a much smaller area than family fields, their produce can be sold for cash or eaten at home.

The density of millet sown in fields, as measured by the number of pockets growing within a plot, was observed to follow a similar pattern over the period between 1987–90, as seen in Table 4.

Table 4 Mean number of *souna* millet pockets per 0.5 ha plot

	1987		1988		1989		1990	
Zone	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Mourdiah 1	7848	887	6442	236	6590	238	687	249
Mourdiah 2	7300	628	6852	231	6771	288	6091	289
Mourdiah 3	6291	674	6205	257	6982	306	6651	284
Nara	4456	526	3784	207	3992	184	2982	114
Dilli	3404	441	3143	204	4592	257	3771	211
Fallou					4879	205	3590	177

As seen in Table 4, there is great similarity in the density of millet pockets in each of the project zones between the different years, although densities are almost twice as high in the more southerly zones than in the drier northern zones.

Adult females of the millet head-miner, *Heliocheilus albipunctella*, selectively oviposit on millet heads immediately before the development of male flowers (Guevremont, 1981). Each project team visited a representative sample of fields to determine the date upon which approximately 50% of the heads in the plot supported male flowers. This survey concluded that *souna* millet fields reach 50% male flowering in August/September, or just over two months after sowing.

The weight of grain harvested from non-treated plots in the different zones between 1987–1990 is shown in Table 5. The weight of grain typically harvested from millet fields in Sahelian environments averages 500 kg/ha. As seen in Table 5, such yields were only surpassed in the project region in 1988, which was a year of high rainfall (see Table 2).

Table 5 Variation in yield (kg/ha) in non-treated plots

	1987		1988		1989		1990	
Zone	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Mourdiah 1	471	114	921	54	526	75	382	76
Mourdiah 2	529	118	942	52	420	47	184	29
Mourdiah 3	349	88	770	58	417	97	318	63
Nara	357	56	460	49	111	16	270	38
Dilli	306	60	310	47	307	39	206	30
Fallou					201	28	86	23

Average yields obtained within a project zone are very misleading since there is tremendous variation between different fields, as seen in Figure 5.

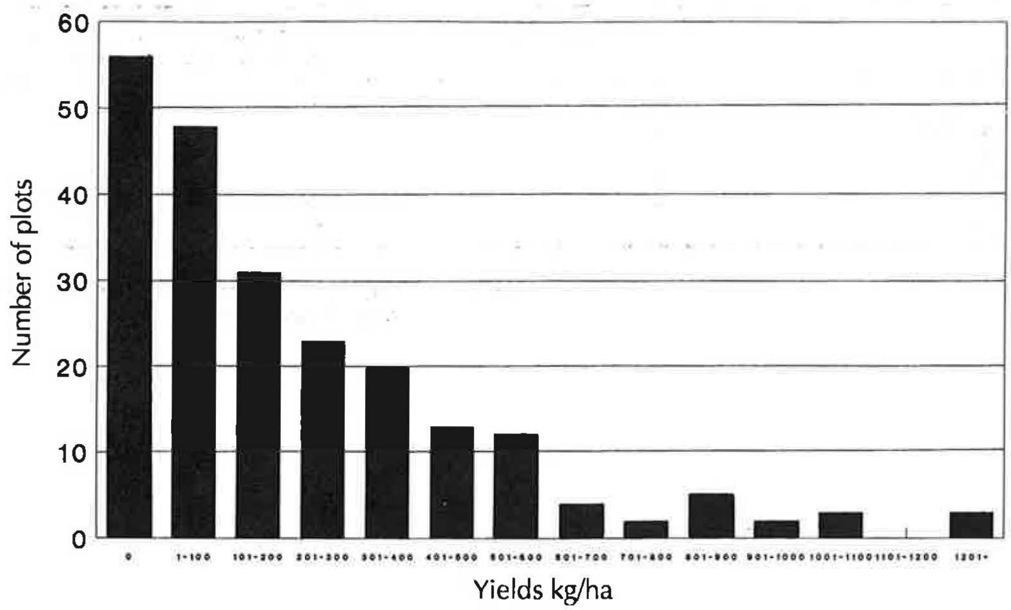

Figure 5 Souna yields in control plots, 1990 (kg/ha)

There is found to be a highly significant correlation between the yield obtained from the same plot in different years (r=0.46, p<0.0001, with regard to the correlation between yields obtained in non-treated plots in Mourdiah in 1988 and 1989). This variation in the productivity of fields could be a result of differences in soil quality and/or field management.

The variation in the average weight of grain per millet head (which can be calculated for each plot using information on the mean number of heads per pocket, the total number of pockets per plot and the total grain yield per plot) between the different project zones in the different years is shown in Table 6.

Table 6 Variation in grain weight per head (g) in non-treated plots.

	1987		1988		1989		1990	
Zone	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Mourdiah 1	8.7	0.4	17.7	1.2	10.5	1.6	5.4	0.4
Mourdiah 2	9.3	0.9	17.2	1.1	10.5	1.3	5.8	0.5
Mourdiah 3	8.7	0.6	16.1	1.2	9.1	2.2	5.1	0.4
Nara	8.8	0.9	16.0	1.0	3.6	0.4	3.6	0.2
Dilli	9.6	0.5	11.9	1.0	8.5	1.2	4.4	0.2
Fallou					5.0	0.6	3.2	0.4

No evidence was found to suggest that pests showed differential choice of millet heads based on size. Consequently, grain weights from undamaged heads can be considered to be representative of average grain weights of all millet heads in a field. Using information on the average weight of grain from undamaged heads, together with the estimated total number of heads per plot, it is possible to estimate the 'potential' grain yield that could be achieved in the absence of pest attack. The total grain losses observed in each of the project zones, as presented in Table 7, were calculated using crop-loss assessment methodology described in detail in Section 6. An estimation of the percentage grain loss in each of the project zones in 1990 clearly justifies the need for research into pest control measures.

Table 7 Effect of pest attack upon productivity of millet crops, 1990

	Potential grain yield in 1990	Estimated percentage grain loss due to pest attack in 1990*
Mourdiah 1	714	46
Mourdiah 2	461	60
Mourdiah 3	847	62
Nara	440	39
Dilli	404	49
Fallou	216	60

Note: * These estimates include abortion of the head caused by drought.

Section 5

The pest complex

The Sahelian ecosystem is robust and has survived millions of years of oscillating rainfall patterns. The fauna is adapted to drought conditions and large numbers of species migrate seasonally in search of food. There is a tendency for explosive population development among herbivorous insects due to the short growing season of emergent vegetation and numbers of each individual species are always fluctuating.

Of the species present within the project region, the following were all observed to cause damage to millet crops in all years between 1985–1990:

(a) The millet head-miner (*Heliocheilus albipunctella*);

(b) The millet stem-borer (*Coniesta ignefusalis*);

(c) Grasshoppers;

(d) Flower-feeding beetles (*Pachnoda interrupta* and *Psalydolytta* spp.);

(e) Birds;

(f) Weeds (principally *Striga hermonthica*).

MILLET HEAD-MINER (*Heliocheilus albipunctella*)

Heliocheilus albipunctella (Noctuidae), formerly known as *Raghuva albipunctella*, has been considered one of the major pests of millet since the first outbreak was recorded during the drought years of 1972–74 (Vercambre, 1978). This species has since been reported to cause damage to millet crops throughout the Sahel (Gahukar, 1986 *et al.*; Gahukar, 1988; Nwanze, 1990).

Adult moths start to emerge in August, with peak emergence occurring in late August (Figure 6). Adult moths exhibit a peculiar mating behaviour. Male moths have enlarged fore-wings which produce a buzzing sound when vibrated. This sound appears to attract females who then mate with the males. Female moths lay approximately 400 eggs, often in small groups at the upper end of flowering millet heads. Peak egg-laying occurs in August with the incidence of *Heliocheilus* infestation in millet varieties having been shown to depend to a large degree upon the synchrony between emergence and that of male flowering (Vercambre, 1978; Gahukar, 1982, 1983b, 1984a, 1987; ICRISAT 1984; Guevremont, 1982, 1983; Nwanze, 1990). A maximum of 93 eggs have been recorded in a single millet head (Bhatnagar, 1983).

The young larvae hatch in 3–4 days and then begin to feed on the flowers. During this time signs of pest attack can be detected by the presence of whitish granular excreta around the flowers. Larvae complete their development in 23–29 days. Mature larvae eat the floral peduncles with the result that grain formation is inhibited and/or that mature grains fall from the head. As the larvae continue to feed they produce characteristic spiral mines. Average larval densities of 230 000-350 000 per hectare have been recorded in Senegal (Gahukar *et al.*, 1986). Fully grown larvae descend to pupate in the soil at end of the growing season. After a short pre-pupal stage, they remain in diapause until emergence in the following season.

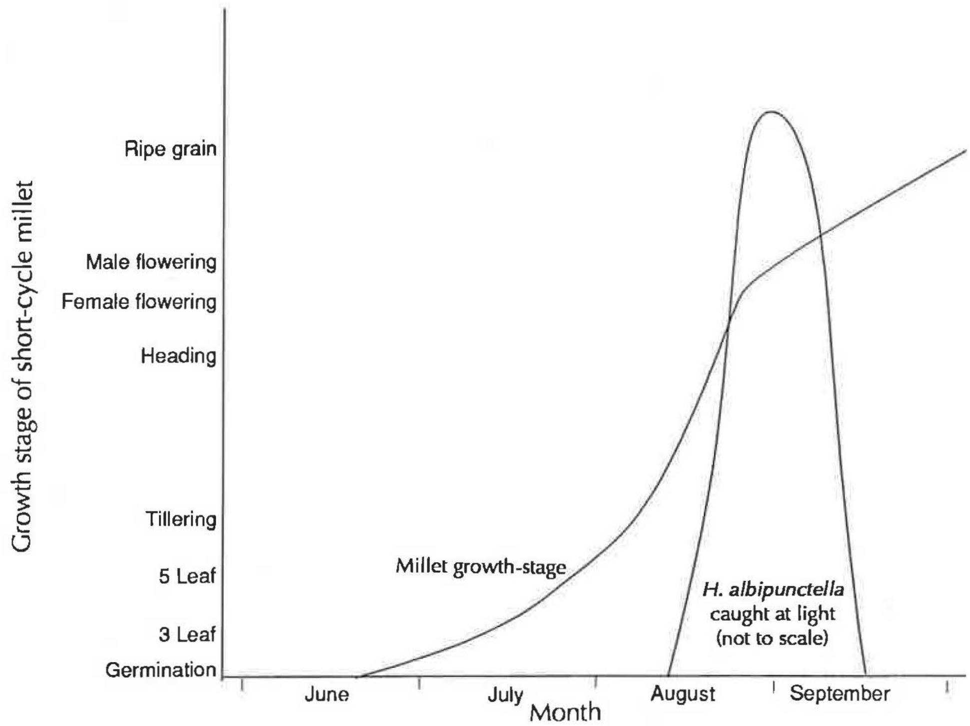

Figure 6 Emergence pattern of adult *Heliocheilus albipunctella* in relation to millet growth stage

The level of infestation by *Heliocheilus* in millet fields is commonly expressed as the percentage of damaged heads in a field (Guevremont, 1983; Nwanze, 1990). The percentage of millet heads attacked by *Heliocheilus* declined considerably within all zones in the project region over the period between 1987–1990, as seen in Table 8. Farmers report that *Heliocheilus* is more of a pest in years with poorer rainfall. Although this is supported by a comparison of the results in 1986 (high rainfall) and 1987 (poor rainfall), it does not explain the long-term decline in population densities observed throughout the project region between 1985 to 1990. Note that the percentage of attacked candles is not a sufficiently delicate measure of damage to correlate with crop loss. The NRI (ODA) project eventually used classes of damage based on mine numbers to estimate grain loss.

Table 8 Variation in the percentage of millet heads attacked by *Heliocheilus*

	1987		1988		1989		1990	
Zone	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Mourdiah 1	57.2	7.3	53.1	3.1	46.6	2.8	14.3	2.6
Mourdiah 2	59.9	4.1	52.0	2.9	64.6	3.0	11.7	3.3
Mourdiah 3	80.3	4.8	42.8	3.4	56.9	3.6	19.5	3.4
Nara	60.2	6.3	64.5	2.5	77.0	4.5	25.9	4.6
Dilli	70.0	4.3	63.0	2.5	70.3	3.9	45.5	4.7
Fallou					49.7	2.9	25.7	4.2

The level of *Heliocheilus* infestation in millet fields varies considerably (see Figure 7), with some fields in 1987 experiencing 0% attack whilst 100% of candles were infested in other fields. As seen in Table 9, for each project region in 1987 the percentage *Heliocheilus* infestation (*X*) was found to be significantly related to the date of 50% male flowering (*Y*). The regression slopes are not significantly different between the three project zones. A similar relationship was also found in 1986. It is therefore concluded that those fields which flower in early August, which is the time when peak numbers of *Heliocheilus* females are caught at light traps, suffer higher levels of attack by this pest than those fields which flower later in the year.

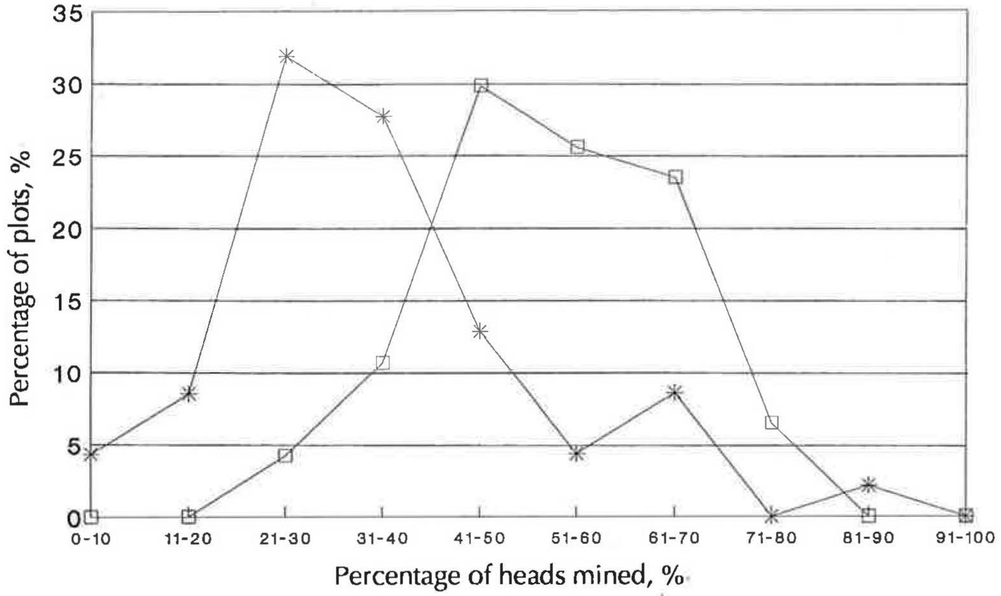

Figure 7 *Heliocheilus albipunctella* attack in 47 trial plots in the Mourdiah zone, 1988
-✳-, Treated plots; -□-, Untreated plots

Table 9 Variation between *Heliocheilus* infestation (*X*) and date of male flowering (*Y*) between 1 June and 30 September 1988

Zone	*r*	Significance	Regression
Mourdiah	–0.64	<0.001	$Y = 214.9 - 1.6\ X$
Nara	–0.83	<0.001	$Y = 286.3 - 2.3\ X$
Dilli	–0.34	<0.03	$Y = 166.8 - 1.0\ X$

Note: Day 0 on the *Y* axis is 1 June 1988

In Senegal it was estimated that this pest caused yield losses from *souna* millet of between 13–85% during the period 1974–78 and of between 3–82% during the period 1981–82 (Gahukar, 1982; Gahukar, 1989). Although larval parasitism was considered an important factor in reducing populations of this species, the only viable means of pest control was considered to be achieved by drift-spraying with ULV insecticides during heading and flowering (Gahukar *et al.*, 1986).

MILLET STEM-BORER (*Coniesta ignefusalis*)

Coniesta ignefusalis (Pyralidae), formerly known as *Acigona ignefusalis*, was first reported as a cereal pest in Mali and Senegal by Risbec (1950). Since then it has been regularly recorded on pearl millet (Nwanze, 1989) where it has been reported to cause considerable yield losses (Harris, 1962; Gahukar, 1984b; Nwanze, 1989).

This species has two to three generations per year, with adults in the first generation emerging 3–4 weeks after the first rains (Nwanze, 1989). The population of *Coniesta* peaks at the beginning of August. The larvae bore into shoots and stems, emerging from the stems to leave characteristic exit holes. The percentage of millet stems infested by *Coniesta* (as seen externally by the presence of exit holes) increased considerably within all zones in the project region over the period between 1987–1990, as seen in Table 10.

Table 10 Variation in percentage infestation of millet stems by *Coniesta*

	1987		1988		1989		1990	
Zone	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Mourdiah 1	5.4	3.1	3.0	2.3	19.7	3.1	32.5	4.2
Mourdiah 2	11.7	1.7	2.9	2.2	29.0	5.8	36.6	6.4
Mourdiah 3	29.0	1.0	2.7	2.6	39.4	5.6	39.9	5.7
Nara	30.2	1.9	29.0	1.9	58.8	3.6	31.8	1.8
Dilli	32.9	2.1	31.7	1.9	72.1	4.9	60.8	1.9
Fallou					20.6	1.9	66.9	4.8

A lower density of heads per pocket was found in non-treated fields in Mourdiah in 1988 which supported higher percentage infestations by *Coniesta* larvae. Similarly, a higher proportion of 'dead hearts' (millet plants which fail to produce viable candles) was found in those non-treated plots which experienced a higher percentage infestation by *Coniesta*. No experimental trials were undertaken to establish whether attack by *Coniesta* larvae was indeed responsible for these observations, nor were any studies undertaken to assess the effect of increasing larval densities upon the development of individual millet plants. Therefore, although the effects of *Coniesta* attack cannot be confirmed, these results imply that attack by *Coniesta* larvae may reduce the yield of millet fields by reducing the number of millet heads produced. A similar conclusion was reached by Gahukar (1990).

Attempts have been made to control *Coniesta* by destroying the stalks and crop residue after harvest (Gahukar, 1990). However, because crop residues are used by farmers for animal fodder, fencing and roofing of houses, the use of partial burning of millet stems has been proposed (Gahukar, 1990). Previous work has concluded that insecticide applications are neither economical nor practical for controlling this species (Gahukar, 1990).

GRASSHOPPERS

There are about 30 species of grasshopper present in the project area of which two, namely *Oedaleus senegalensis* and *Kraussaria angulifera* are common pests of millet. *Oedaleus senegalensis* has three generations per year and is highly mobile whilst *Kraussaria angulifera* has only one generation per year and is short-ranging. Other common grasshopper species which have caused economic damage in the project region between 1970 and 1990 include *Hieroglyphus daganensis, Diabolocatantops axillaris, Cataloipus cymbiferus, Kraussella amabile, Cryptocatantops haemorrhoidalis* and *Aiolopus simulatrix.*

The economic effect of any of these grasshopper species depends upon their seasonal occurrence, behaviour and mobility. Many of these grasshopper species migrate up to 100 kilometres as adults.

Millet crop losses due to grasshoppers occur throughout the growing season, but grasshopper attack between tillering and heading has little effect upon yields. At the onset of rains (during May around 14° N and between June and July above 14°30′ N) young millet plants are attacked principally by first generation

Oedaleus senegalensis. When grain on millet heads is at the 'milky' stage (between late August and early September above 14°30′ N) damage is caused principally by *Kraussaria* and *Oedaleus* (although only by *Oedaleus* at latitudes north of 15° N).

Grasshoppers eat young millet plants, causing 25% of fields to be abandoned or resown in 1990. Over 50% of project fields were destroyed by grasshoppers in 1989 as a result of early-season attack. The SNPV distributes limited quantities of free Sumithion dust to farmers in order to reduce these losses.

Grasshoppers also cause late-season crop damage by eating foliage, millet flowers and maturing grain. Grasshopper damage to grain is easily recognized: the individual grains look as if a part has been sliced off. Damage in late August/ early September coincides with heading and *souna* millet is the first crop to suffer. When a large southward migration of grasshoppers occurs *sanyo* millet and sorghum grain are damaged. Rough estimates indicate that farmers experience 70–90% crop loss due to grasshoppers every 5 years.

SCARABAEID BEETLES (*Pachnoda interrupta*)

Larvae of these beetles feed on decaying organic matter and roots and are therefore most abundant in the more manured fields. Adult beetles feed on a variety of flowers as well as the florets and young grain of millet. The damage caused by adults is difficult to distinguish from that caused by grasshoppers which also eat maturing grain. Late season crop losses attributed to either grasshoppers or *Pachnoda* were recorded in both 1989 and 1990.

During the period between 1985–1990, *Pachnoda* populations were only observed to reach levels at which they caused significant grain losses in 1989, with populations declining to low levels in 1990 throughout the project region. Damage caused by *Pachnoda* or grasshoppers in 1989 and 1990 is seen in Table 11.

Table 11 Variation in percentage damage to millet heads caused by grasshoppers and *Pachnoda* beetles

	1989		1990	
Zone	Mean	S.E.	Mean	S.E.
Mourdiah 1	16.0	2.0	7.8	0.7
Mourdiah 2	13.3	1.0	16.2	1.6
Mourdiah 3	10.4	2.6	31.0	4.3
Nara	38.6	1.9	19.6	3.8
Dilli	31.4	2.8	18.4	1.9
Fallou	5.5	1.4	26.6	2.9

MELOID BEETLES

About 20 species of Meloid beetles, commonly known as Blister beetles, have been collected from the project area. Certain smaller meloid species present in the project region, such as *Mylabris* spp. are not considered to be pests of millet since they feed on the male anthers of millet plants and it is believed to be highly unlikely that pollen loss would ever limit grain yields within millet fields. However, certain larger species, such as *Psalydolytta fusca*, feed on female flowers of millet in August and September thus preventing grain formation. The damage caused by these beetles is difficult to distinguish from that resulting from the effects of drought.

In the mid-1980s, meloid beetles were observed at low densities in millet fields. However, they were first noticed to be abundant and to inflict significant grain losses to millet yields at Fallou in 1989. Evidence of these species becoming pests only in recent years has been collated by other workers (Gahukar *et al.*, 1989). There were very high numbers of meloids, especially *Psalydolytta*, throughout the project region in 1990. It has been hypothesized that this population explosion is related to the large numbers of grasshoppers present in the region in 1989, since certain meloids (such as *Psalydolytta*) are parasitic on the egg-pods of some of the larger species of acridids such as *Cataloipus cymbiferus*.

The grain losses attributed to meloid beetles and/or drought, were very high throughout most of the project region in 1990, as seen in Table 12.

Table 12 Variation in percentage damage to millet heads caused by meloid beetles and/or drought

	1990	
Zone	Mean	S.E.
Mourdiah 1	43.9	4.1
Mourdiah 2	38.6	3.4
Mourdiah 3	52.8	3.9
Nara	10.9	2.3
Dilli	27.8	3.4
Fallou	43.0	4.0

BIRDS

A variety of birds, including weavers and quelea (*Quelea quelea*) are considered by farmers to cause significant grain losses to millet fields late in the season and prior to harvest. These birds eat mature grain, leaving characteristic 'holes' in millet candles. Although high levels of bird damage to millet fields were recorded in Dilli in 1989, it is generally thought that birds inflict higher levels of grain loss to the later developing sorghum crops. Grain losses caused by birds averaged less than 8% in all project zones in 1990.

FUNGAL PATHOGENS

Fungal pathogens are not considered as pests by farmers. Grain losses caused by fungal pathogens averaged less than 2% in all project zones in 1990.

WEEDS

Farmers invest considerable time and money into weeding millet fields, with 1 ha *souna* taking about 20 man-days of work to weed. One of the principal reasons why fields are abandoned by farmers is because of a lack of labour for weed control. Root parasites, such as *Striga* spp., attack both millet and sorghum, especially in less fertile fields.

RANKING OF PEST IMPORTANCE BY FARMERS

Farmer surveys established pest rankings for the project zone for 1988, 1989 and 1990 (as seen in Table 13). By using workdays allocated to planting and replanting as an instrument for cultivated areas, they also provided data upon the importance of grasshopper attack before flowering. This exercise revealed an apparent correlation between late planting and stand-reduction due to grasshoppers (see Figures 8 and 9).

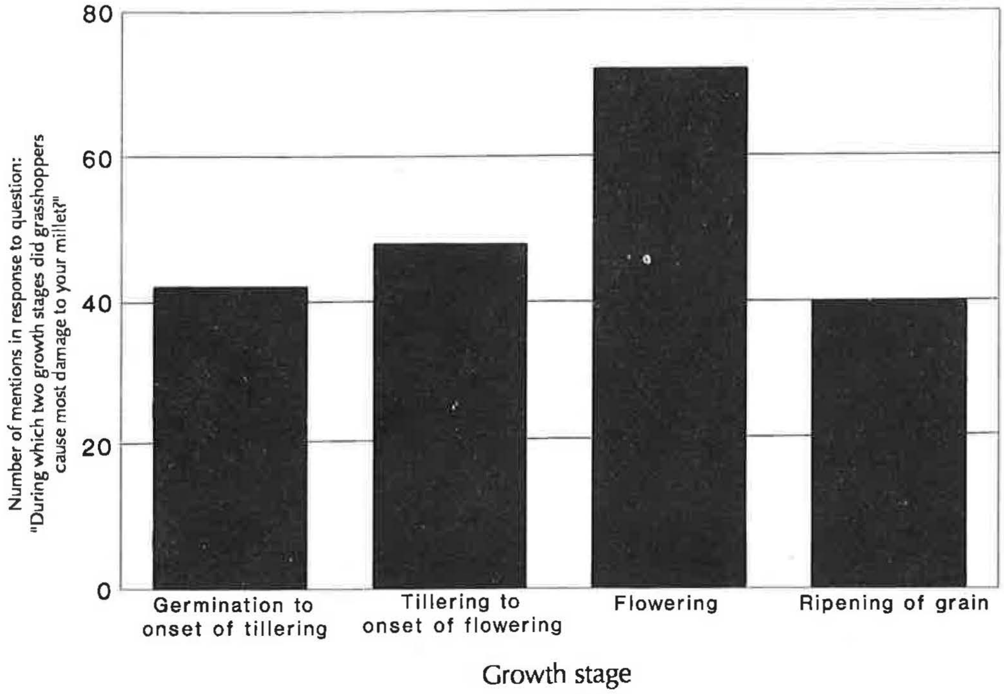

Figure 8 Damage to growth stages, as reported by farmers

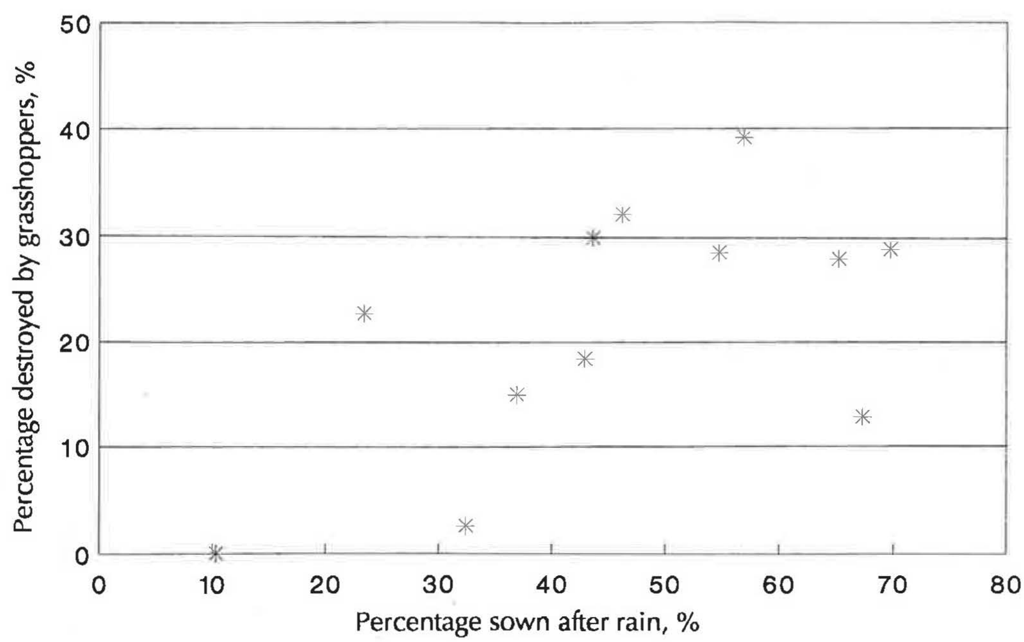

Figure 9 Grasshopper damage to souna millet before flowering in 12 villages near Mourdiah, 1990
✳, Village

Table 13 Ranking of pests by farmer survey, 1988–90

Year	1988	1989	1990
1st	'Insect worms'*	Grasshoppers	Grasshoppers
2nd	*Striga*	*P. interrupta*†	*Psalydolytta* spp.
3rd	Birds	*C. ignefusalis*†	*P. interrupta*
4th	*Psalydolytta* spp.	*Psalydolytta* spp.	*C. ignefusalis*

Notes * Probably *Spodoptera* spp.
† 3rd equal

Section 6

Crop-loss assessment

A variety of crop-loss assessment methods have been implemented for pearl millet (Nwanze, 1988; GTZ, 1991). A detailed method of crop-loss assessment was applied to the fields of 17 randomly selected farmers in each project zone in 1990. All the millet plants within 60 pockets in both treated and non-treated plots were collected before harvesting and were examined to give the following information:

(a) Total number of stems of cultivated and 'wild-type' millet;

(b) Number of 'dead hearts';

(c) Number of stems infested with *Coniesta* and with undamaged heads;

(d) Number of stems not infested with *Coniesta* and with undamaged heads;

(e) Number of stems infested with *Coniesta* and with heads attacked by pests.

The weight of grain was measured separately from undamaged heads of plants which were either infested or unattacked by *Coniesta*. A comparison of these results showed that there was no significant difference in the weight of grain produced. Therefore, although the effects of *Coniesta* attack upon millet growth, development and yield are widely debated (Gahukar *et al.*, 1986), results obtained in 1990 did not reveal any evidence to suggest that the presence of *Coniesta* in millet stems affects the amount of grain produced by each head, although the number of heads may be reduced (see pp. 18–19).

As discussed in Section 4, each of the pest species attacking millet heads do so in a different way, thereby allowing a visual separation of the damage caused by each pest. Damaged millet heads can therefore be sorted according to the percentage grain loss attributable to attack by *Heliocheilus*, grasshoppers, *Pachnoda*, birds, fungi, meloids and/or drought. The percentage of grain loss caused by each pest species was determined by a visual inspection of 50 randomly selected harvested heads from each non-treated plot. Millet heads in these samples were grouped into the following four damage classes: (i) 1–25% grain lost; (ii) 26–50% grain lost; (iii) 51–75% grain lost; (iv) 76–100% grain lost. *Heliocheilus* damage was divided into three categories: (i) Candles with 1 mine; (ii) Candles with 2–3 mines; (iii) Candles with 4 or more mines. Mean grain loss per mine was assumed to be 5 g.

Table 14 Mean grain loss (kg/ha) in non-treated fields caused by the different pest species in 1990

Zone	Grasshoppers and *Pachnoda*	Meloids and drought	Birds	Fungi	*Heliocheilus*	Total
Mourdiah 1	51	195	26	8	52	332
Mourdiah 2	41	161	28	1	46	277
Mourdiah 3	120	304	17	0	88	529
Nara	51	26	17	9	31	134
Dilli	37	51	16	1	93	198
Fallou	22	43	2	1	62	130

The weight of grain produced by the millet heads that had been damaged by each type of pest alone was then estimated. Using this information and the mean weight produced by undamaged millet heads, it was possible to calculate the grain loss caused by each of the different pests.

As can be seen in Table 14 the greatest grain losses in 1990 were attributed to damage by adult meloid beetles or drought, and to a lesser extent by *Heliocheilus* larvae and grasshoppers or adult *Pachnoda* beetles.

Estimates of crop losses caused by different pest species are based upon a number of assumptions, of which the most important are that:

- the harvested heads represent a random sample of those in the field;
- the 50-millet-head sample is a statistically representative sample size for the plot;
- it is valid to use the median percentage of a damage class.

Although these limitations mean that damage estimates must be treated as approximations only, it is of interest to note that estimates of crop loss caused by *Heliocheilus* are similar to those recorded in other regions of the Sahel (Nwanze, 1989; Nwanze, 1990).

A number of fields throughout the project region were completely destroyed by pests in 1990. Grasshoppers were responsible for destroying 10 paired plots at Nara in the early season, whilst a total of 47 fields were destroyed before harvesting by both grasshoppers and meloids. If it is assumed that those fields which were completely destroyed would have produced, on average, the same 'potential' yields as those estimated in harvested fields, then it is possible to estimate the loss of production resulting from such crop loss.

TOTAL ESTIMATED CROP LOSS

The average crop losses experienced per hectare from the different project zones in 1990 are presented in Table 15. The total grain loss from fields within the project region in 1990 (of which 235 were either completely destroyed or partially damaged by pests) is estimated to be approximately 71 tonnes, out of an estimated 'potential' yield of 122 tonnes from the same fields. It is therefore calculated that pest attack, together with the effects of late season drought, caused the loss of approximately 58% of grain production in the project region in 1990. Grain losses through similar factors in 1989 were estimated to be 32%.

Table 15 Estimated total *souna* millet losses from fields in 1990

	Grain loss (kg/ha)
Mourdiah 1	332
Mourdiah 2	277
Mourdiah 3	529
Nara	402
Dilli	198
Fallou	130

Section 7

Pest control using ULV applications of pyrethroids

In view of the total grain losses inflicted by pests throughout the project region, it was considered important to refine and develop a method of pest control that is able to significantly and predictably reduce populations of a diversity of pest species. This method had to be easily used by Sahelian farmers themselves, not conflict with existing farming practices, and be affordable and consistently profitable.

The use of ultra-low volume applications of pyrethroids to control pests attacking millet had been recommended by some researchers (Gahukar *et al.*, 1986; Gahukar, 1989) but not by others (Nwanze, 1985). In 1985 and 1986 trials were therefore undertaken with a small number of farmers using conventional hand-held ULV spraying equipment. However, this work led to a recognition of the following design limitations:

(a) The pesticide bottle usually has a capacity of only 0.5–1.0 litre which entailed frequent refilling when large areas need to be treated;

(b) Millet is a tall cereal crop (usually greater than 2 metres in height after heading) and conventional sprayers do not provide a sufficient reach above the crop for good drift spraying;

(c) The weight of the batteries in the handle and the weight of a full 1.0 litre pesticide bottle caused unacceptable fatigue to users, especially in view of ambient temperatures experienced during treatment within fields in August and September.

Following discussions with Micron Sprayers Ltd a modified prototype ULV sprayer was designed (Shah, 1988a, b). This sprayer comprised a Micro-Pack backpack pesticide reservoir with a Micro-Ulva atomizer attached to a long wooden handle. Power supply was provided by eight 1.2 or 1.5 V batteries in a shoulder-slung Turbair XJ battery pack. A clear plastic hose-line led from the base of the pesticide bottle to the base of the back pack and was secured by plastic clips and adapters. The hose-line included a tap.

The advantages of this design were that it reduced the need for users to handle pesticides directly, the long handle provided sufficient reach over tall cereal crops for good drift spraying whilst still proving effective for the treatment of grasshoppers in savannah and fallow ground. The disadvantages of this design were the low durability of batteries and the frequent damage to electrical connections and spinning discs.

It was found that a single sprayer can apply 30 litres of pesticide over 10 ha in approximately 4 h. The purchase price of the equipment was approximately £70 (US$ 112) less tax and including delivery to Mali (Jago and Shah, 1991).

ULV pyrethroid applications were made by walking through the experimental 0.5 ha plots along the rows of millet plants (which grew at 90° to the prevailing winds). A swath width of one metre was adopted, with the atomizer being held at the height of the millet heads. In fields where millet plants were very tall, the user was guided by people waving flags and blowing whistles at the field margins. All personnel using the spray equipment wore protective gloves, a body-suit and headgear with a visor.

Pesticide trials work was undertaken using ULV Ripcord (cypermethrin) and ULV Karate. The choice of these pesticides was based upon their availability in Mali, their relative safety, ease of use and their low cost.

The results of the analysis of plant material following treatment with ULV Ripcord and Karate at harvest found no significant pesticide residues and it was therefore concluded that there was no threat to human health from eating grain or stalks from plants treated by these methods.

Section 8

Effect of ULV treatments on pest damage to millet

ESTIMATION OF TREATMENT EFFICACY

The level of attack by different pests was measured in all non-treated and treated plots in all project zones. A comparison of the difference in the degree of attack by different pests between neighbouring half hectare plots provided an estimate of the treatments' effectiveness against these species.

EFFECT OF ULV APPLICATIONS ON *HELIOCHEILUS* INFESTATION

Date of treatment and *Heliocheilus* infestation

In 1986 ULV treatments (at a rate of 36 g active ingredient/ha) were applied to millet fields at different stages of development. As seen in Table 16, these treatments were more effective if timed to coincide with the period of 50% male flowering in August when peak egg-laying is occurring.

Variation in efficacy of ULV Ripcord and ULV Karate against *Heliocheilus*
In 1987 ULV treatments, using both Karate and Ripcord (at a rate of 36 g active ingredient per hectare (a.i./ha)) were applied as both single applications at 50% male flowering and as double applications, with the second application occurring 10 days after the first treatment. As seen in Table 17, all treatments significantly reduced the level of *Heliocheilus* infestation in treated fields.

Table 16 Variation in ULV efficacy and date of treatment

Treatment	Mean percentage reduction in infestation	S.E.
1 x 36 g a.i./ha (before heading)	6.2	2.1
1 x 36 g a.i./ha (50% male flowering)	32.5	5.4
2 x 36 g a.i./ha (50% male flowering and 10 days later)	37.5	5.6

Table 17 Effect of ULV Karate and Ripcord upon *Heliocheilus* infestation levels in 1987

Treatment	Mean percentage reduction in infestation	S.E.
1 x 36 g a.i./ha Ripcord	27.2	8.3
1 x 36 g a.i./ha Karate	30.4	7.2
2 x 36 g a.i./ha Ripcord	36.5	10.4
2 x 36 g a.i./ha Karate	48.7	9.1

It was found that the efficacy of each treatment, as measured by the extent to which *Heliocheilus* infestation levels are reduced, was significantly correlated to the date at which the first treatment was applied in 1988 (Table 18).

Using ANOVA it is found that there are no significant differences between the regression slopes for any of the ULV treatments and that consequently there is a single relationship between treatment date (X) in 1988 and treatment efficacy (Y), so long as the spray is applied after heading:

$$Y = 118.7 - 0.90\ X.$$

It is therefore concluded that the apparently greater treatment efficacy associated with a double application of ULV Karate, seen in Table 17, is simply the result of this treatment being applied significantly earlier than other ULV treatments. Ripcord is cheaper than Karate and is formulated in Mali, so all further trials work was conducted with this pyrethroid.

Effect of varying concentrations of ULV Ripcord and *Heliocheilus* infestation

In 1988 trials were undertaken to determine whether the cost of ULV Ripcord treatments could be reduced by lowering the concentration of active ingredient applied to fields without significantly affecting treatment efficacy. Four concentrations of ULV Ripcord were formulated in Mali for use during this trial, with all being applied to fields at 50% male flowering. As seen in Table 19, there were no significant differences between the effects of these four dose rates upon *Heliocheilus* infestation. Subsequent trials work therefore continued using ULV Ripcord at 36 g active ingredient per hectare and 9 g a.i./ha.

Variation in efficacy of ULV Ripcord treatments between different years

A single treatment of ULV Ripcord was applied to fields throughout the project region between 1987 to 1990. Statistical analysis found no evidence that the efficacy, as measured by the percentage reduction in *Heliocheilus* infestation levels between treated and untreated plots, of these treatments varied between project zones in any year. In addition, as seen in Table 20, the efficacy of treatments was very similar between different dose rates in a given year.

Table 18 Effect of variation in application date (X) of the different ULV treatments upon reduction in *Heliocheilus* infestation (Y)

Treatment	*r*	significance	*a*	*b*
1 x 36 g ai/ha Ripcord	–0.65	<0.01	100.6	–0.77
1 x 36 g ai/ha Karate	–0.65	<0.01	77.1	–0.50
2 x 36 g ai/ha Ripcord	–0.56	<0.01	98.6	–0.66
2 x 36 g ai/ha Karate	–0.50	<0.01	193.3	–1.65

Table 19 Variation in treatment efficacy and dose rate

Concentration	Mean percentage infestation in non-treated plots	Mean percentage reduction in infestation level	S.E.
9 g a.i./ha (in 2 litres)	50.4	14.6	3.0
9 g a.i./ha (in 3 litres)	45.3	17.9	2.2
30 g a.i/ha (in 3 litres)	47.2	18.5	2.1
36 g a.i./ha (in 3 litres)	51.1	20.3	2.4
51 g a.i./ha (in 3 litres)	45.8	18.0	3.2

Table 20 Variation in ULV Ripcord efficacy against *Heliocheilus* attack in different years

Year	36 g a.i./ha (in 3 litres) Mean percentage difference (NT–T)	S.E.	9 g a.i./ha (in 3 litres) Mean percentage difference (NT–T)	S.E.
1990	8.0	2.9	8.1	3.6
1989	15.1	1.8	11.5	1.8
1988	25.1	6.3	14.6	3.0
1987	27.2	8.3		

It is concluded that in those years when *Heliocheilus* infestation in non-treated plots is high (between 50–60% of millet heads attacked) a single treatment with ULV Ripcord, applied to fields at the time of 50% male flowering either at a dose of 36 g a.i./ha or 9 g a.i./ha, can consistently reduce the level of *Heliocheilus* infestation within millet fields to approximately 25–35%, thus representing a 50% overall reduction in infestation levels. In those years, such as 1990, when *Heliocheilus* infestation is low (between 10–20% millet heads attacked), a single treatment with ULV Ripcord reduces the level of *Heliocheilus* infestation by between 5–10% thus maintaining a consistent 50% reduction in overall infestation levels. It is therefore concluded that a single application of ULV Ripcord consistently reduces *Heliocheilus* infestation levels by approximately 50%.

EFFECT OF ULV RIPCORD ON *CONIESTA* INFESTATION

The efficacy of a single treatment of ULV Ripcord, applied at a rate of 36 g active ingredient per hectare at the time of 50% male flowering, upon the percentage infestation of millet stems with Coniesta in different years is presented in Table 21.

Both ULV Ripcord treatments reduced *Coniesta* infestation equally, but the reductions were only significant when *Coniesta* was present in large numbers. In 1988 neither ULV Ripcord treatment had any significant effect upon *Coniesta* infestation levels; in this year this pest species was present at only very low levels in fields in the Mourdiah area (see Table 10).

Table 21 Variation in ULV Ripcord efficacy against *Coniesta* infestation in millet fields at Mourdiah in different years

Year	36 g a.i./ha Mean percentage difference (NT–T)	S.E.	9 g a.i./ha Mean percentage difference (NT–T)	S.E.
1990	9.8	2.6	8.0	1.3
1989	11.4	3.8	8.8	2.5
1988	1.0	0.7	–0.8	0.3

EFFECT OF ULV RIPCORD UPON ATTACK BY OTHER PEST SPECIES

ULV Ripcord, applied in a single treatment at a rate of 36 g active ingredient per hectare at the time of 50% male flowering, was not found to reduce significantly the level of grain loss attributed to grasshoppers, *Pachnoda*, meloids or birds in 1990. In 1989 it was observed that only ULV Ripcord applied at a rate of 9 g a.i./ha, significantly reduced grain loss caused by grasshoppers, but only by 2.9%.

It is considered that, although the single application of ULV Ripcord kills grasshoppers, *Pachnoda* and meloids which are present in fields at the time of application, other individuals invade at a later date from non-treated areas to cause further grain losses. This finding has important implications for institutions contemplating the provision of subsidized pyrethroid pesticides for grasshopper control.

Section 9

Effect of ULV Ripcord treatments on crop yields

ESTIMATION OF TREATMENT EFFICACY

At the end of each crop season, farmers were asked whether there were any differences in the management of their treated and non-treated 0.5 ha plots that might in themselves cause significant differences between the yields of these plots. If differences in management had taken place, for instance unequal weeding or the application of organic manure, then these plots were rejected from comparative analysis of their yield differences. The efficacy of ULV Ripcord treatments in augmenting millet yields was therefore estimated by comparing only the yield differences between neighbouring treated and non-treated 0.5 ha plots for which there were no obvious differences in management.

VARIATION IN YIELD IMPROVEMENT BETWEEN FIELDS

The yield improvement on plots treated with ULV Ripcord varied tremendously between different farms. Some on-farm trials of insecticides demonstrated yield increases of up to 500 kg/ha by reduction of insect damage whilst other treated plots produced lower yields than their non-treated control plots (see Figure 10). Since it is highly unlikely that the treatment itself causes a yield loss, it must be concluded that there were differences between plots that were not accounted for simply in terms of the management practices recorded. To allow for this

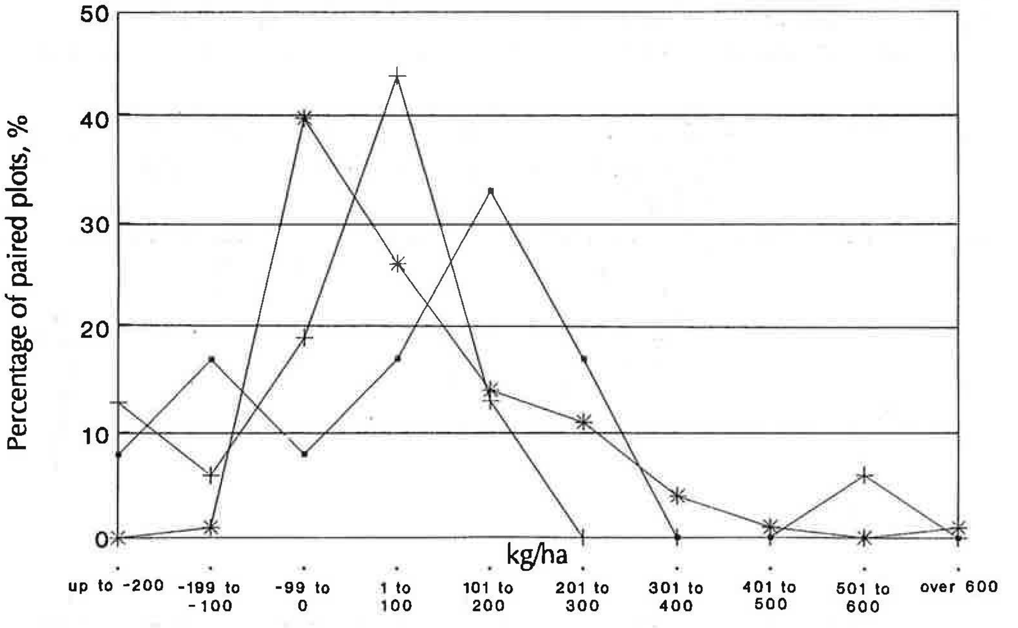

Figure 10 Changes in yield after treatment with ULV Ripcord (9 g in 3 1) on plots in Mourdiah and Fallou
✳, 1990; +, 1989; -□, 1988

variation, the treatments' effects upon yields have been expressed in terms of the median yield difference between plots, as well as the mean (Table 22).

YIELD IMPROVEMENTS ATTRIBUTED TO VARYING CONCENTRATIONS OF ULV RIPCORD

There was no recognizable relationship between the concentration of ULV Ripcord applied to fields in 1988 and the difference in grain yield observed in these treated plots (Table 22). The average yield increase obtained by all ULV Ripcord treatments in 1988 was 106 kg/ha.

Table 22 Variation in yield increases attributed to varying concentrations of ULV Ripcord in 1988

Concentration	Mean difference in grain weight (kg/ha) between treated and non-treated plot	S.E.	Median difference in grain weight (kg/ha) between treated and non-treated plots
9 g a.i./ha (in 2 litres)	89	5	76
9 g a.i./ha (in 3 litres)	148	88	108
30 g a.i/ha (in 3 litres)	37	54	65
36 g a.i./ha (in 3 litres)	116	36	175
51 g a.i./ha (in 3 litres)	112	58	84

VARIATION IN EFFICACY OF ULV RIPCORD IN DIFFERENT YEARS AND ZONES

ULV Ripcord was applied to fields throughout the project zone as a single treatment at concentrations of both 9 g active ingredient per hectare and 36 g active ingredient per hectare in all years between 1988 to 1990. The project zone was divided into a southern 'wetter' region, comprising fields at Mourdiah and Fallou and a northern 'drier' region comprising fields at Nara and Dilli. The variation in the efficacy of these treatments in increasing grain yields between different zones and different years is presented in Table 23. As this shows, ULV Ripcord treatments consistently increase average grain yields in treated plots, although there remains a high level of variation which could not be explained.

Table 23 Variation in yield increases attributed to ULV Ripcord treatments between project regions and different years

		36 g a.i./ha			9 g a.i./ha		
Year	Zone	Mean yield difference (NT–T)	S.E.	Median yield difference (NT–T)	Mean yield difference (NT–T)	S.E.	Median yield difference (NT–T)
1990	South	45	31	8	72	13	18
	North				54	22	36
1989	South	30	17	74	12	11	21
	North				61	23	84
1988	South	79	30	89	119	25	126
	North	145	19	135	147	32	117

Section 10

Farmer response to field trials

The 1985–90 field trials were conducted in farmers' fields in order to replicate as closely as possible the agronomic environment for which recommendations were being developed. One element of the programme was therefore to identify how inter-actions between the farmer and the project were affecting the trial results. This not only permitted the project to adjust its trial protocols but it also provided lessons on the management of research in the region. The principal observations covered are:

(a) Sampling difficulties;

(b) Farmers' perceptions of the programme;

(c) Bias from field management;

(d) Farmer participation in crop loss estimation.

SAMPLING DIFFICULTIES

When agricultural research programmes involve farmers, the resource-poor farmer is usually under-represented (Chambers and Jiggins 1987). Despite the Mali Millet Pest Project's deliberate efforts to recruit poor farmers, it nonetheless followed this pattern (as seen in Table 24), with project families being both bigger and wealthier than the average.

The project's attempt to recruit a representative number of poor farmers was unsuccessful for the following reasons:

(a) The heads of poorer families were more likely to be away seeking income during the recruitment of project farmers;

(b) Poorer farmers were less likely to have sufficient labour to manage the hectare of souna millet required by the project for trial plots;

(c) Poorer farmers held smaller food stocks. They therefore needed to harvest their millet sooner than other families. This conflicted with the project's requirement that farmers should wait for the project to thresh the trial plots;

Table 24 Unrepresentativeness of project farmers

	Project farmers	Population
Field workers/family (1990)*	5.2	3.2
Ploughs/family (1990)†	1.5	0.9
Agricultural investment/family‡	13 420	7 792
Mean *souna* millet yield¶	307	203

Notes
* means different at a 95% level of confidence
† means different at a 99% level of confidence
‡ FCFA, 1990
¶ kg/ha, 1987

(d) Participation was restricted to a certain number of farmers per village. The heads of wealthier families used their power as village chief or elder to propose themselves as pilot farmers;

(e) Poorer farmers were more cautious of modern technology and economic risk.

This said, however, no correlation between a family's resource endowment and its *souna*'s responsiveness to insecticides could be demonstrated (as seen in Table 25). The project did not therefore persist with 'positive discrimination' in favour of poor farmers.

The project also made a distinct effort to recruit women as project farmers. Women in this area manage millet cultivation under two arrangements. A very small number of families are headed by a woman, usually the widow of the previous family head. In this case she is responsible for managing the *foroba*, or family field. Some married women are also entitled to a private field, but such fields contain no more than 5% of the total area under millet.

It was therefore impractical to require women to provide one hectare of pure-stand *souna* for trial purposes although this area had been chosen for *foroba* trials. Women's trial plots consisted of a 0.125 ha treated plot and a 0.125 ha untreated control. Despite the plots' smaller size it was still difficult to recruit and retain women pilot farmers. In 1990, 21 women volunteered to work with the project, most from comparatively wealthy families. Of these, 10 withdrew during the season, either because they lacked labour or because they did not wish to grow pure-stand *souna*. This number would have been higher had the project not offered to hire labour to weed women's trial plots.

To conclude, the project's experience in recruiting farmers to provide fields for trials demonstrated that:

(a) The large plots and sample sizes required to produce statistically valid data in this region of high ecological variability impede a policy of ensuring the representation of women and poor farmers;

(b) In women's private fields, moreover, the variety of cropping patterns hindered the establishment of a homogeneous sample.

FARMERS' PERCEPTIONS OF THE PROGRAMME

Farmers' participation in the trials programme was largely in 'contract mode', as defined by Biggs (1989); farmers provided one hectare of *souna* for trial plots and received in return one or several applied inputs for their millet.

Project procedures stipulated that field staff explain the project's methods to farmers upon recruitment and at the start of each subsequent trial. Farmers were also to be instructed in ULV spraying skills when their plot was being treated. Regrettably, however, the high ratio of trial sites to field teams (60:1 in 1990), intended to ensure statistical force, appears to have impeded communication with farmers:

(a) Of 27 project farmers interviewed in 1990, 19 said they did not know the purpose of the 'not-to-be-treated' plot (that is, the control plot);

Table 25 Resource endowment and *souna* responsiveness to ULV pesticide, 1987.

Family wealth (indicated by ploughs/family)	No.	Yield response to ULV (kg/ha)
1	21	142
2	17	90
3	9	−2
4	5	107

(b) The majority of farmers, not necessarily family heads, who had actually participated in ULV treatments were unable to describe the timing, dosage, spacing or direction of treatment as recommended by the project;

(c) Most project farmers believed (or pretended to believe) that the project's main goal was to help local farmers by distributing inputs. This was a view encouraged by some project staff to keep farmers' goodwill. In 1990 a rumour, revealing but fortunately not widespread, was circulating to the effect that the project had added to the infestations of 1989 and 1990 by breeding grasshoppers in boxes.

Some farmers expressed a preference for gifts other than the insecticides built into the design of the Mali Millet Pest Project. A survey of 28 pilot farmers in 1990 revealed that the seed-dressing (US$ 1.75/ha) provided as a bonus was marginally more popular than the ULV insecticide (>US$ 10.50/ha) being tested.

In 1988, the project attempted to sell additional ULV treatments to 20 project farmers. The insecticide price was set at its cost in the capital plus 25%. No farmers displayed interest in the offer, either before or during the growing season.

BIAS FROM FIELD MANAGEMENT

As seen in Table 26, farmers gave better management to the treated plot than to the control, presumably in the hope of increasing the treatment's value. The tendency to weed the treated plot before the control may not be important if little time elapses between the two, but the heavier manuring of the treated plot would be expected a *priori* to bias estimates of the treatment's effectiveness upwards. (A statistical analysis of 25 1990 ULV trial plots did not, however, prove a correlation between a farmer's account of which plot had been manured first and the yield difference between the treated and non-treated plots). Lastly, project staff reported that some farmers were adding millet heads from outside the trial plots to the stacks of millet heads from the trial plots in order to receive more free threshing from the project. If a significant number of such cases has gone undetected, this would affect the validity of the trial results.

This experience provides a useful lesson to agricultural researchers. The inclusion of farmers in the management of agricultural research is usually advocated as a means of increasing its relevance to their needs (Farrington 1988, Merrill Sands 1986). Even setting aside the applicability of the research, however, farmers' lack of interest in the research agenda may compromise the accuracy of the trial data.

FARMER PARTICIPATION IN CROP-LOSS ESTIMATION

Crop-loss estimation programmes for Sahelian millet (Coop, 1991; GTZ 1991; Jago *et al.*, 1991; Pantenius *et al.*, 1991) are usually based upon observations of the millet head just before harvest and require trained technicians to sample and interpret the heads. The Mali Millet Pest Project also used farmer surveys to collect supplementary data upon pest attack. The advantages and dangers of this approach are as follows:

Table 26 Management of ULV trial plots, 1990.

	Treated plot	Control plot	No distinction
Answers to question:			
'Which plot was weeded first?'	46	14	3
'Which plot received most manure?'	25	12	33

Advantages

(a) Observation of the head ignores the stand-reduction effects of grasshopper nymphs, *Spodoptera* spp., rodents and birds;

(b) It is difficult to distinguish by observation alone between damage caused by *Pachnoda interrupta* and grasshoppers, or between abortion of the head due to drought and damage caused by flower-feeding beetles such as *Psalydolytta* spp. A farmer, however, will have observed the damage as it was happening and thus be able to attribute it;

(c) The farmers' perception of different pests is *per se* an important element in the determination of research policy;

(d) Interviews with farmers cover a given area at much lower cost.

Drawbacks

(a) When free pesticides are available, the farmer has a reason to exaggerate losses in untreated fields and understate them in treated fields in order to increase his allocation;

(b) Interview methods cannot establish losses precisely, either in absolute or in percentage terms;

(c) Farmers rarely consider plant diseases to be pests, may confuse different pest species (especially Lepidopteran larvae) or lack the vocabulary to communicate a pest's identity to an untrained interviewer.

The experience of the Mali Millet Pest Project therefore suggests a two-fold approach to crop-loss estimation, with localized direct observation and extensive farmer surveys validating each others' findings.

Section 11

Obstacles to the adoption of ULV spraying

For a technology to be adopted by farmers, it must not only work but must also fit the economic and institutional environment in which farmers work. As the Mali Millet Pest Project's research progressed it became clear that any attempt to encourage farmers to invest in ULV technology would be likely to fail. Malian institutions were not ready to promote the sale of ULV, farmers were too poor to buy it and for those that did the financial return would be too low and risky.

FINANCIAL RETURNS

The financial benefit from each treatment could be obtained by multiplying the average yield increase, expressed as kg of millet per hectare, by the price of millet. The benefit from each treatment was then divided by the treatment's cost to give 'benefit-cost ratio' (BCR). The BCR is a basic indicator of the treatments' profitability. If it is less than 1, then the farmer would have made a financial loss. If it is more than 1, he would have made a profit. For example, BCR of 1.2 indicates a profit of 20% upon the farmer's investment.

Table 27 shows the mean and median BCRs for all pesticide trials producing more than 9 replicates. Within each trial, however, one cannot put an economic interpretation on the variation in yield increases because the treated and control plots would have produced different yields in the absence of a treatment. The pesticide costs are derived from observed prices in Bamako (Lock, 1988; Lock, 1989; Lock, 1990). The applicator, battery and labour costs are based upon a time and motion study (Shah, 1988c; Shah *et al.*, 1988a). Three millet prices are offered, a low price (FCFA 50/kg), a medium price (FCFA 75/kg) and a high price (FCFA 100/kg).

The most important feature of the BCRs in Table 27 is that a recognizable pattern is hard to find because of the tremendous variability between fields and between years. The only firm conclusion to be drawn is that the financial returns are neither high nor predictable. The fact remains that 5 out of the 13 ULV trials with over 9 replicates would have produced negative mean financial returns with millet priced at FCFA 75/kg, a success rate that would repel a western investment banker, let alone a farmer living hand-to-mouth in the Sahel.

On the basis of these results it is therefore unwise to recommend the use of ULV pesticides on millet to Sahelian farmers. Neither is it possible to justify foreign donors' providing free pesticides to the Sahel as emergency commodity aid. The only year when ULV produced good financial returns was 1988, when rainfall was abundant and pests were few – scarcely an emergency environment.

GOVERNMENT SUBSIDY

Mali is a poor country. In 1986 foreign aid funded over two-thirds of its government's expenditure (World Bank, 1988). Civil service salaries have been frozen since 1987 and are often paid two or three months in arrears. A head of section in the national plant protection service, the SNPV (Service de Protection

Table 27 Benefit-cost ratios 1986–90

Year	Zone	Treatment (in 3 litres)	*n*	Costs (US$=FCFA 285) ULV FCFA/ha	Granules FCFA/ha	Apparatus and battens FCFA/ha	Labour FCFA/ha	Cost FCFA/ha	Benefit-cost ratios Mean Millet at FCFA 50/kg	Median Millet at FCFA 50/kg	Mean Millet at FCFA 75/kg	Median Millet at FCFA 75/kg	Mean Millet at FCFA 100/kg	Median Millet at FCFA 100/kg
1987	South	1 Ripcord-36 g: Ripcord granules	16	5 000	3 830	260	1 300	10 390	0.2	0.3	0.3	0.5	0.5	0.6
1987	South	1 Karate -36 g: Ripcord granules	15	2 240	3 830	260	1 300	7 630	0.7	0.7	1.1	1.1	1.4	1.4
1987	South	2 Ripcord-36 g: Carbofuran granules	16	10 000	21 000	520	1 600	33 120	0.2	0.1	0.3	0.2	0.4	0.2
1987	South	2 Karate -36 g: Carbofuran granules	15	4 480	21 000	520	1 600	27 600	0.1	0.1	0.2	0.2	0.3	0.2
1988	South	1 Ripcord- 9 g	15	3 690	0	230	300	4 220	2.0	1.7	3.0	2.5	3.9	3.4
1988	South	1 Ripcord- 9 g	12	3 940	0	260	300	4 500	0.4	0.7	0.6	1.1	0.8	1.4
1988	South	1 Ripcord-30 g	14	4 700	0	260	300	5 260	1.1	0.8	1.7	1.2	2.3	1.6
1988	South	1 Ripcord-36 g	16	5 000	0	260	300	5 560	1.0	0.8	1.5	1.1	2.0	1.5
1988	South	1 Ripcord-52 g	19	5 550	0	260	300	6 110	3.3	2.3	5.0	3.4	6.6	4.6
1988	North	1 Ripcord-30 g	33	4 700	0	260	300	5 260	1.4	1.2	2.1	1.7	2.8	2.3
1988	North	1 Ripcord-52 g	35	5 550	0	260	300	6 110	1.2	1.0	1.8	1.5	2.4	2.0
1989	South	1 Ripcord- 9 g	16	3 940	0	260	300	4 500	0.1	0.2	0.2	0.3	0.2	0.4
1989	South	1 Ripcord-36 g	15	5 000	0	260	300	5 560	0.3	0.7	0.4	1.0	0.5	1.3
1989	North	1 Ripcord- 9 g	13	3 940	0	260	300	4 500	0.7	0.9	1.0	1.4	1.4	1.8
1990	South	1 Ripcord- 9 g	65	3 940	0	260	300	4 500	0.8	0.2	1.2	0.3	1.6	0.5
1990	South	1 Ripcord-36 g	23	5 000	0	260	300	5 560	0.4	0.0	0.6	0.1	0.8	0.1
1990	North	1 Ripcord- 9 g	44	3 940	0	260	300	4 500	0.6	0.4	0.9	0.6	1.2	0.8

des Végétaux) receives a salary of approximately US$ 140 per month. The plant protection service's non-salaries budget is US$ 80,000 per year. Excluding transport and building maintenance, this leaves less than US$ 0.50 per employee per day for running costs. There is obviously no possibility of a general government subsidy for ULV spraying.

Foreign donors are a second possible source of subsidy. Indeed, one legacy of the attacks of *Oedaleus senegalensis* and *Schistocerca gregaria* between 1986 and 1988 was a supply of free pesticides from western countries. Two developed country governments subsequently continued to donate around 100,000 litres of ULV insecticide to the SNPV each year. Whilst donated insecticides give the SNPV a role, they will never protect cereals on a national scale. To give half the country's millet and sorghum single applications of insecticide dust and ULV insecticide would cost 3 times as much as the 1986 *Oedaleus senegalensis* spray campaign in Mali, 12 times as much as the SNPV's 1990 campaign or 1.5% of Mali's GNP. Donors are moreover keen to reduce pesticide subsidies on the grounds that they discourage farmers and plant protection services from seeking alternative solutions. So neither the Malian government nor its donors will provide a generalized insecticide subsidy. This then raises the question of the recovery of costs from farmers.

INSECTICIDE MARKETING

The private sector's participation in pesticide marketing in Mali is extremely limited. Market traders in Bamako sell seed-dressings, herbicides to market gardeners and liquid insecticides for mosquito control. Those foreign agrochemical companies that are represented in Mali concentrate upon sales to Malian government institutions, notably the Compagnie Malienne de Textiles which re-sells ULV formulations to cotton-farmers in the south. At the moment they do not wish to develop the smallholder market, either by direct sales or through private merchants. They are wary of high marketing costs, the public health implications of selling into an unregulated market and the political effects of competing with the state-owned formulation company (Société Malienne de Produits Chimiques). Legislation upon pesticide registration and control has been drafted, but it is doubtful that the SNPV will have the expertise or the manpower to control the pesticide market.

The national extension service is very weak. In the region of Koulikoro in 1988, for example, 35 civil servants with an operational budget of US$ 2800 were responsible for a rural population of 975 000. In some areas, however, the Ministry of Agriculture has been strengthened by foreign aid, creating an Opération de Développement Rural (ODR). ODRs are responsible for 42% of the area under millet and sorghum in Mali. They are comparatively well provided with staff and equipment, and often sell inputs to smallholders for cash or credit. At the time of writing, the Ministry of Agriculture is planning to dissolve the ODRs and to create, with World Bank finance, a unified extension system.

The SNPV's role as a channel for free pesticides lends it high status in Bamako and rural areas. Its skills, with an emphasis on motorized pest scouting and spraying, are more suited to donor-funded spray campaigns than to extension. It is not surprising, therefore, that the SNPV is hostile to the idea that Sahelian farmers should pay for pesticides. This proved an important constraint upon the effectiveness of the Mali Millet Pest Project, whose stated objectives included cost-recovery.

At the moment, therefore, there is little marketing of pesticides to Sahelian smallholders. Whether it becomes a possibility in the future will depend very much upon pesticide registration legislation and the reform of the extension service.

COST OF ULV TO SAHELIAN FARMERS

Table 27 derives the cost of a ULV treatment in Sahelian Mali, US$ 14.80/ha. This is very high in comparison with what farmers are used to spending on their fields (see Figure 11). Mean cash investment in six villages near Mourdiah in 1990 was US$ 36 per family, under US$ 4 per hectare. The distribution of expenditure was extremely skewed with a median of US$ 10.50 per family.

During the growing season 36% of families sold labour out, reducing the resources available for their own fields in order to pay for food or cultivation tools. Mean agricultural expenditure for families selling labour was US$ 15 per family, and 100% of their expenditure went towards cultivation tools – hoes, plough hire or plough repair. For families not selling labour, 62% of expenditure was upon labour hire. The other 38% went towards cultivation tools. Only one family out of 105 bought agricultural chemicals; seed dressing for peanuts.

Set against current investments in agriculture, ULV insecticides are disproportionately expensive. Farmers' investment in cultivation tools and labour shows their commitment to extensive farming, which would conflict with the intensive use of applied inputs such an pesticides.

LABOUR HIRE

Farmers will not pay for ULV insecticides if there is a more profitable alternative. Labour hire is such an alternative, and the circumstances of Sahelian agriculture make it highly attractive.

Land availability is not a constraint upon cereals production in the region. Land use, however, is limited by the availability of labour for weeding during late July and August (see Figure 12). It is common for farmers to plant greater areas than they can weed and to abandon the unweeded part. Farmers have various strategies for reducing the weeding constraint. They spread the sowing of cereals across several weeks in order to extend the weeding period. They buy or hire ploughs to assist with weeding. They clear bush fields where weed populations are less dense. Lastly, where possible, they hire labour (see Figure 11).

A family can expect extremely high financial returns from labour hire. Supposing a family has sown a hectare that would give 500 kg of grain if weeded by hired labour, but would otherwise be abandoned. Given a grain price of FCFA

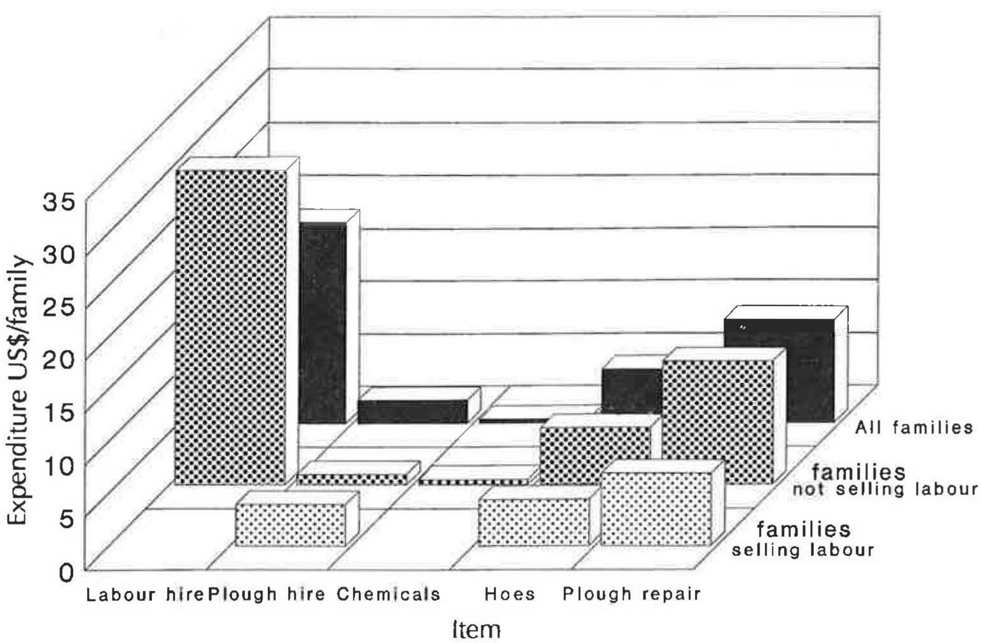

Figure 11 On-farm cash expenditure in six villages near Mourdiah, 1990

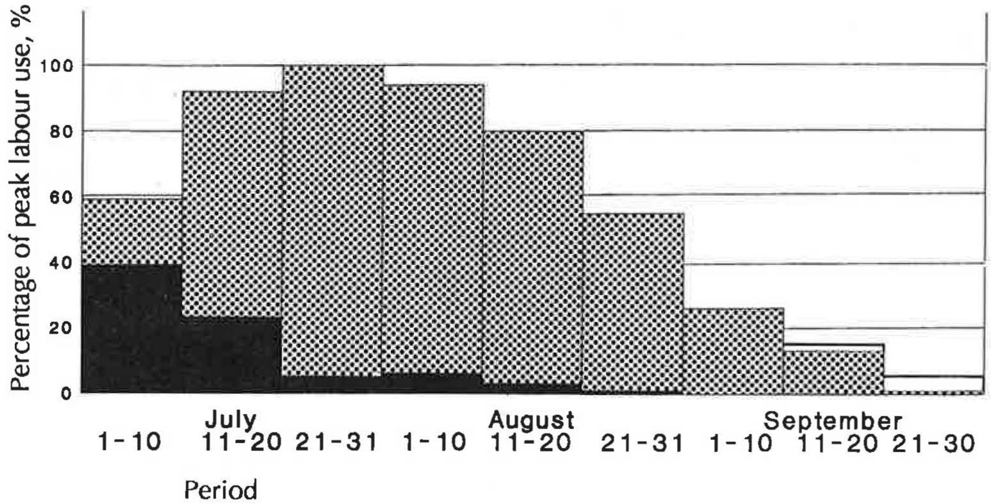

Figure 12 Labour use in six villages near Mourdiah, 1990
■, Preparation; ⊠, Weeding; □, Harvest

75/kg, a daily wage of FCFA 750 and a weeding rate of 21 workdays per hectare, the hirer stands to obtain a financial return of 140%. This is a high target for ULV insecticides to match.

Yield variation in the area is spectacular, between years, between zones and even between families. In 1987, 1988 and 1989 harvests around Mourdiah satisfied the cereal needs of 10%, 77% and under 5% of families respectively. In 1988, average yields around Mourdiah were 900 kg/ha. Around Dilli, less than 100 km to the north-west, they were 300 kg/ha. In three villages near Mourdiah in 1987 the top 25% of families made 348 kg/ha on average whilst the bottom 25% made 45 kg/ha. So it is not surprising that farmers seek to extend their cultivated areas in order to spread risk. Investment in labour meets this goal, whereas investment in ULV insecticides would concentrate more resources into the same area.

PRACTICALITY OF ECONOMIC THRESHOLDS

The economic threshold (ET) is defined as the pest density above which the cost of the treatment is less than the value of the benefits it brings (Headley, 1972). If the economic threshold is known, we can increase the expected financial return by advising farmers to count pests and not to spray when the pest density is below the economic threshold (Norton, 1976).

Unfortunately, ETs would rarely be of use to a Sahelian smallholder:

(a) Because of poor communications, many farmers would be unable to obtain insecticides and sprayers between the pest count and the pest damage. The only alternative would be to stock spray materials, tying up capital;

(b) The millet head-miner is invisible until it has caused the damage;

(c) Farmers must hold cash reserves against the possibility of pest attack. This means refusing to hire labour, which is often a social offence;

(d) Even if farmer-specific intervention thresholds were introduced (Farrington, 1977), they could hardly cope with mixed pest populations, and uncertainty about pest re-invasions and rainfall.

POLICY IMPLICATIONS

ULV technology is too expensive and not profitable enough for Sahelian farmers. Only subsidies could therefore induce Sahelian millet farmers to adopt it. This subsidy would have to come from foreign donors, and could never be large enough to permit adoption of ULV on a national level. Indeed, ULV spraying offers such a low and variable financial rate of return on Sahelian millet that it is hard to justify any subsidy at all.

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