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CONTROL OF SORGHUM SHOOTFLY *ATHERIGONA SOCCATA* RONDANI THROUGH TRAPPING AND BAIT SPRAYS

THESIS SUBMITTED TO THE ANDHRA PRADESH AGRICULTURAL UNIVERSITY
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD
OF THE DEGREE OF MASTER OF SCIENCE IN AGRICULTURE

by

CORNELL ODHIAMBO OMONDI

Department of Entomology
College of Agriculture
Andhra Pradesh Agricultural University
Rajendranagar, Hyderabad 500030
Andhra Pradesh, India

June 1984

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CERTIFICATE

This is to certify that the thesis entitled "Control of Sorghum Shootfly *Atherigona soccata* Rondani Through Trapping and Bait Sprays" submitted in partial fulfilment of the requirements for the degree of Master of Science in Agriculture of the Andhra Pradesh Agricultural University, Hyderabad, is a record of the bonafide research work carried out by Mr. Cornell Odhiambo Omondi under my guidance and supervision. The subject of the thesis has been approved by the student's Advisory Committee.

No part of the thesis has been submitted for any other degree or diploma or has been published. Published parts have been fully acknowledged. All the assistance and help received during the course of the investigations have been fully acknowledged by him.

1/6/84

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ABSTRACT

Title : Control of Sorghum Shootfly (*Atherigona soccata* Rond.) through trapping and bait sprays

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1984

Field trials were undertaken to explore the possibility of controlling sorghum shootfly, *Atherigona soccata* Rondani, by mass trapping of the flies in fishmeal-baited traps and by using bait sprays of fishmeal and a synthetic pyrethroid, decamethrin. Soil application of carbofuran 3G at the rate of 40 kg/ha and an untreated check were used as a basis for comparison.

The use of fishmeal-baited traps, while useful for monitoring and assessing shootfly populations, was of little practical value in control of shootfly. A cage experiment showed that fishmeal is a food attractant for hungry flies. Less hungry flies were less attracted in the morning and remained in the sorghum seedlings. Flies did not react to fishmeal attractiveness in the absence of sorghum seedlings.

Fishmeal baits and decamethrin sprayed in a strip 5 m wide around the field produced effective control during December-January, February-March, and March-April when the fly population was low. Bait sprays of fishmeal and decamethrin only gave moderate control during October-November and failed to provide effective control during July-August due to the continuous heavy rainfall.

Carbofuran 3G applied in the seed furrow at the time of planting was very effective in reducing fly injury during July-August. The performance of carbofuran was not uniform. The amount of rainfall during the seasons was an important factor influencing the efficacy of carbofuran. The relative ineffective control obtained in October-November, December-January, February-March and March-April, seems to be related to a depeleting moisture situation and reduced rate of growth of the seedlings.

There was a distinct preference of the shootfly for oviposition on seedlings emerging from carbofuran treatments. This has been attributed to the dark green colour and healthier growth of these seedlings.

1. INTRODUCTION

Sorghum (*Sorghum bicolor* Moench) is one of the main staple food crops of the world's poorest people, particularly in the semi-arid tropics. Over 55% of the world's sorghum production is in this ecological zone (Davies, 1980). Generally, sorghum grain yields on peasant farms are low, ranging from 500 to 800 kg/ha (Seshu Reddy, 1982) and one of the major factors that affects these yields are insect pests.

Sorghum is attacked by over 150 species of insect pests from sowing to the final crop harvest (Seshu Reddy and Davies, 1979). The sorghum shootfly, *Atherigona soccata* Rondani, is one of the more serious pests reducing grain yields and is widespread in Asia, Africa and Mediterranean Europe. It is a seedling pest and attacks the crop up to 4 weeks after emergence. White elongated eggs are laid singly on the undersurface of leaves. The larva, after hatching, crawls down the leaf sheath and up into the whorl where it reaches the growing point. It cuts the growing point resulting in the drying of the central leaf causing the characteristic 'deadheart' symptoms.

With the introduction of high-yielding sorghum hybrids in India in 1964 (Rao and House, 1965), shootfly damage became a major yield-limiting factor. Up to 100% damage was reported in the northern districts of Karnataka during July and August by Usman et al. (1967). It became evident that a practical solution to the shootfly problem would be essential for the success of the sorghum improvement programmes. Research efforts were intensified to find an effective control method against shootfly by undertaking short and long-term programmes. Under the short-term programmes, chemical control was given more emphasis as it was expected to give immediate results, while the long-term programme was mainly aimed at host plant resistance.

Earlier attempts to control the shootfly with conventional foliar sprays and dustings of the available contact insecticides generally failed to give an effective control. Work carried out in the early sixties showed that the application of systemic insecticides like phorate, disulfoton and carbofuran granules in soil at the time of sowing was effective in controlling the shootfly. Recently, two more insecticides, isofenphos and fensulfothion have been found to be equally effective (Sukhani and Jotwani, 1980). However, the cost of applying these insecticides is rather high. Seed treatment with carbofuran at 5 parts a.i. per 100 parts of seed proved to be effective and economical (AICSIP, 1971), but it requires technical knowledge to handle this extremely toxic chemical and during heavy incidence it may not give satisfactory control.

An integrated approach to the management of the shootfly has also been a major thrust of sorghum research workers during the last 15 years. The necessary foundation has been laid by detailed studies on the biology of the pest and an understanding of the effect of different ecological factors on the shootfly populations. Based on seasonal incidence, for instance, early sowing has proved to be effective for avoiding shootfly damage.

Cultural control coupled with host plant resistance has some role to play in checking this pest, but this again has some limitations since all the farmers in a defined area do not plant their crop at the same time nor do they use the same cultivar.

One of the alternative methods to control this pest may be mass trapping of flies in fishmeal-baited traps. Fermented fishmeal has been shown to be attractive to *Atherigona soccata* and has been used in traps for monitoring shootfly populations at ICRISAT Center (Seshu Reddy and Davies, 1978). The high catching capacity of these traps offers a great potential for utilization in shootfly management. There is also the possibility of baiting an area around the sorghum field with fishmeal sprayed with insecticide rather than treating the field itself, since the flies tend to come out of the field borders each day (Young, 1972b).

The present study was, therefore, undertaken to explore the possibility of controlling the shootfly by:

1. Mass trapping of the flies in fishmeal-baited traps.
2. Attracting and killing the flies by spreading fishmeal bait around the field and spraying it with insecticide.

2. REVIEW OF LITERATURE

Sorghum, though an important cereal crop, especially in the developing countries of Asia and Africa, did not receive adequate attention of the agricultural scientists till the sixties, when some planned effort was made in India to improve its yields. This effort resulted in high-yielding hybrids, but it soon became apparent that the hybrids developed from exotic parents were highly susceptible to insect pests of which the shootfly, Atherigona soccata (Rond.) was the major one (Rao and House, 1965).

Although shootfly continued to be a major factor limiting the production of improved grain sorghum, some efforts in developing management strategies were made during the seventies (Sepsawadi et al., 1971; Barry, 1972; Singh and Jotwani, 1975). Several reviews and book chapters providing descriptions on the pest biology, nature of damage and control in recent years reflect the increase in attention to the shootfly problem (Jotwani, 1981; Meksongsee et al., 1981; Shie et al., 1981; Srivastava and Jotwani, 1981; Young, 1981; Seshu Reddy, 1982). Current control strategies for shootfly management include integration of cultural methods, insecticide, resistant cultivars, attractant traps and biological control reinforced by a knowledge of supportive tactics of the pest biology and population dynamics. Although the present study does not deal with all these aspects, the following review provides the present state of knowledge with respect to shootfly management.

2.1 Cultural Control

Use of cultural methods is considered to be of importance in the pest management programme. The following methods have been found to reduce the shootfly populations to some extent.

2.1.1 Time of Sowing: Time of sowing has been found to be of great significance in reducing the level of damage by shootfly in the monsoon season. This observation is generally related to the fact that shootfly populations remain very low during the hot and dry season and the beginning of the following rainy season (Starks, 1970). Available knowledge on the biology and ecology of the fly has been useful in understanding the seasonal occurrence of fly populations. The annual fly distribution pattern is closely related to the rainfall pattern and the cropping season of its sorghum host.

Many workers have reported seasonal occurrence of the shootfly; Ponnaiya (1951), Jotwani *et al*., (1970), Kundu *et al*., (1971a) in India; Deeming (1971) in Northern Nigeria; Clearwater and Othieno (1977) in Kenya. In general on rainfed sorghum, the fly activity begins to increase at the onset of the rains coinciding with planting of the crop in June. The population is held at a low level during the preceding dry season due to high temperatures and low humidity and the absence of host plants. As the first crop begins to grow, low populations of flies migrate to it, depositing the eggs that produce the following generation. Three to four weeks later, a second generation begins to emerge so that later plantings are severely attacked (Clearwater and Othieno, 1977). As the last crop of sorghum matures, the fly population drops to a low level since there are no seedlings to support larval development (Kundu *et al.* 1971a).

Narayan and Narayan (1967) reported that maximum shootfly damage was on the crop sown during August-September but the incidence was less on the crop sown during January-February and June-July at Warangal in Andhra Pradesh, India. Rao and Gowda (1967) suspected that the fly attack is positively correlated to lower temperatures, high humidity and also the existence of sorghum crop which is already attacked by the pest.

Shootfly damage remained very low in those areas where a single crop of sorghum is grown per year and planted right at the beginning of the rainy season (Deeming, 1971; Breniere, 1972; Rao, 1975; Clearwater and Othieno, 1977). Wheatley (1961) reported that losses in yield were negligible in early sown sorghum in Kenya while the late sown crop suffered moderate losses. Continuous cropping over several months, through irrigation, definitely favours population buildup and damage by flies on later plantings. Under Indian conditions it has been found that in most of the traditional sorghum growing areas the crop sown up to the first week of July generally escapes shootfly damage (Vidyabhushanam, 1972). The efficacy of this cultural control practice is now an established fact and is being applied in Israel and other countries (Young, 1981) either deliberately, or as a result of already established cropping patterns as in Thailand (Meksongsee, 1972).

2.1.2 High Seed Rate and Removal of Affected Plants: Numerous field trials have been conducted to test the efficacy of the age-old recommendation of using a higher seed rate and removal of shootfly-damaged seedlings to destroy the larvae (Vedamoorthy *et al.*, 1965). Infested plants should be well buried after they are removed. This may reduce fly population buildup and attack on the crop planted later. This method, however, failed to reduce shootfly damage in trials conducted at Delhi under heavy shootfly infestation (Jotwani, 1981). There was no significant difference in damage and grain yield when untreated seed was used at 8, 10 and 12 kg/ha.

While the benefit of this procedure in reducing the fly population on the existing crop is doubtful, Ponnaiya (1951) demonstrated its effectiveness in maintaining a good stand of healthy seedlings after planting with a seed rate of 10-15 kg of seed per hectare and thinning infested plants about 4 weeks after germination. This was also proved by Breniere (1972) and has been recommended for Africa. It is presumed that this control practice can possibly succeed where infestation levels are low and when the operation is carried out by a majority of farmers in a large sorghum growing area and labour is available for thinning. Davies and Seshu Reddy (1981b) found that a higher plant density increased the numbers of shootfly adults, eggs laid and plants attacked. They also reported that reduction in potential stand losses by shootfly was possible by sowing thickly and roguing out infested plants prior to development of the second generation of shootfly within the crop.

2.1.3 Destruction of Alternate Hosts: Several wild graminaceous plants have been reported as hosts of the sorghum shootfly in various parts of Africa (Deeming, 1971). *Sorghum verticilliflorum* was reported as a common wild host of *A. soccata* in Eastern Africa. Starks (1970) noted that, in Uganda, S. verticilliflorum was infested by sorghum shootfly early in the season, but substantial number of flies could be found only after emergence of the cultivated crop. He suggested that population buildup was not possible on wild sorghum. In Kenya, Sorghum arundinaceum was found to be preferred for oviposition to a highly susceptible sorghum hybrid CSH-1 (Delobel and Unnithan, 1981) and remains the main or only host of the sorghum shootfly in areas where sorghum is not grown.

In India, sorghum shootfly has been reared from 17 wild and 5 cultivated graminaceous host plants (Davies and Seshu Reddy, 1981a) but species other than the wild sorghums support only very low populations. Sorghum halepense and S. verticilliflorum were the most important alternate hosts while S. almum and S. sudanense proved to be less important. Other graminae members that appeared to be potential sources of carryover in the summer were Echinocloa colonum and E. crusgalli, both very common weed grasses in Andhra Pradesh. But very few of these appeared to be significant host plants for carryover or for multiplication of the fly in India.

Granados (1972), in Thailand, found that shootfly populations could not build up on any of the three wild hosts, Digitaria ascendens, Eleusine indica and Brachiara reptans. When the relative preference of the fly for the three grasses was compared with Sorghum bicolor, the fly showed distinct preference for the cultivated sorghum. In China, however, Shie et al. (1981) reported that damage by shootfly on the two wild hosts

Digitaria sanguinalis and Sorghum propinquum ranged from 10 to 20%. During the dry season, volunteer or irrigated sorghum appeared to be the principal source of carryover (Davies and Seshu Reddy, 1981a) and attempts should be made to discourage growing summer sorghums and if possible to remove wild hosts to reduce the buildup of shootfly attacking the main crop.

2.2 Chemical Control

Three different methods of application of chemical that have been tested for the control of sorghum shootfly are: use of sprays and dust formulations as foliar applications; soil application of granules of systemic insecticides; and seed treatment.

2.2.1 Foliar Spraying and Dusting: The first report on the control of shootfly with insecticides is by Harris (1934) in Africa, who used derris preparations with some success. After the introduction of synthetic organic insecticides, Swaine and Wyatt (1954) in Tanzania reported five applications with 2.5% DDT in combination with 1.5% gamma-BHC dust (1:1) at weekly intervals starting 9 days after sowing, to be a promising treatment. Ingram (1959) failed to control the fly with DDT at Serere, in Uganda. Clinton (1960) also found that DDT sprays failed to give control in the Sudan. Wheatley (1961) in Kenya obtained control with DDT-BHC dusts applied in late plantings but the results were not consistent. Davies and Jowett (1966) in Uganda, found spraying with DDT at the rate of 1 lb/acre (1.84 kg/ha) or carbaryl at 2 lb/acre (3.68 kg/ha) resulted in increased levels of shootfly damage over the untreated control. They attributed this effect to a reduction of parasites and predators in treated plots. Fenitrothion at 1 lb/acre (1.84 kg/ha) also failed to decrease shootfly injury. At the same location, Doggett and Majisu (1966) obtained only partial control with endosulfan sprays.

In India, Rao and Rao (1956) obtained partial reduction in infestation in one year by spraying with 0.05 and 0.1% BHC, while DDT sprays at the same rates and a BHC 5% dust failed to give effective control. Vedamoorthy et al. (1965) reported that foliar applications of carbaryl and endrin were much less effective in controlling shootfly than the seed and seed-furrow application of phorate and other insecticides.

Seventeen insecticides were tested in the form of emulsion concentrate or wettable powder sprays applied 4 days after germination and repeated 8 days later at Delhi during summer (March-April) and Kharif (August). None of these sprays was effective in reducing shootfly damage (AICSIP, 1968-69). In another trial conducted at Coimbatore, sprays of bidrin, phosphamidon, dimethoate, thiometon, methyl demeton and menazon, all applied at the rate of 0.375 kg/ha (four applications at 5-day intervals) failed to effectively control shootfly. Many of these insecticides were phytotoxic to the seedlings.

Chachoria (1972) carried out a large number of trials with endrin and dimethoate sprays. In these trials, the use of different insecticides, their concentrations, addition of a surfactant and directing the spray towards the undersurface of the leaves provided significant control. However, the improvement, while significant, was not sufficient to provide a practical level of control under severe shootfly population pressure during the late kharif or rabi season in Maharashtra. The results indicated that under conditions of high shootfly incidence, endrin did not give control even when the interval between sprays was reduced to 7 days, with the insecticide concentration trebled to 0.15% or a surfactant used to spread the endrin more directly into the whorls of the plants.

In Israel, Yathom (1967) reported failure to control shootfly with the contact and systemic insecticides, formithion and sumithion, applied at 0.3 to 0.5% as foliar sprays at intervals of 3-4 days. Foliar applications of dimethoate diazinon, endrin, dieldrin, gusathion and dursban at weekly intervals also failed to give control of the fly in Thailand (Meksongsee, 1972). The majority of the sprayed chemicals were phytotoxic causing burning of the leaves. Gusathion and dursban, however, gave partial control as 0.1% foliar spray applied at 3-day intervals.

It is evident that the use of conventional foliar sprays or dusts for the control of sorghum shootfly is not likely to give satisfactory results. Spraying is also too laborious because of the frequent applications needed which adds to the cost of labour and insecticides. The sorghum shootfly is probably not effectively controlled with sprays and dusts due to the characteristic of the plant to grow fast. Thus the chemical which adheres to the leaf surface is diluted in quantity per surface area in proportion to the growth and expansion of leaf surface (Meksongsee, 1972). Also satisfactory spray coverage of the underside of leaves is not possible through conventional spraying equipment. The newly hatched larvae migrating to the whorl do not come in contact with sufficient levels of insecticide. Frequent applications are needed to kill the larvae before they penetrate into the shoot of the plants.

Certainly in the semi-arid tropics where water is in short supply, some of the recommended spray require too much water causing severe transport problems. Simpler application techniques involving either no water or at least only minimal quantities have to be investigated.

2.2.2 Soil Application of Granular Insecticides: During the early sixties a number of granular systemic insecticides were marketed and reported to be highly effective against soil and seedling pests. Phorate 10G at the rate of 1.5 to 2.0 kg a.i./ha applied in the seed furrows at the time of sowing was the first of such insecticides which gave satisfactory control of the shootfly (Vedamoorthy *et al.*, 1965). They noted that plants receiving phorate as a soil application appeared to have more eggs deposited on them but showed less survival of larvae, indicating the effectiveness of this systemic insecticide in preventing the larvae from penetrating the plants and causing deadhearts. Sufficient amounts of this toxicant are apparently taken up by the plants to protect them from the fly during the first month of growth when the plants are most susceptible. Disulfoton was also found to be equally effective. However, there were reports about failure of these chemicals to control shootfly in some locations and causing reduced germination (Everly and Pickett, 1960; Rao *et. al.*, 1968). In Hyderabad, phorate reduced germination of the seed especially in the lighter soil types. Singh and Jotwani (1975) demonstrated that the method of application of phorate and disulfoton granules played an important role in determining the germination of the seed. Phytotoxic effects were noted only when the seeds came into direct contact with the insecticide and even then, they did not give economically effective control of the shootfly. They concluded that the insecticides uptake was not sufficient during the critical seedling stage. Either the development of the root system was not enough to cover the area where the insecticides were applied or other factors like absorption, adsorption, leaching, etc., might have affected the availability of the insecticides.

A number of other granular insecticides were tested under the All India Coordinated Sorghum Improvement Project (1965-67; 1968-69) and disulfoton 5G and carbofuran 3G were found to be as effective as phorate. The dosage required for carbofuran was 1.0 to 1.2 kg a.i./ha (Barry, 1972; Meksongsee, 1972). Moreover, carbofuran did not impair the germination of the seeds even when in direct contact. Carbofuran, phorate and disyston have been reported to be effective when applied directly in the seed furrow with fertilizer (Kundu and Sharma, 1975). Recently, granules of isofenphos 5G, fensulfothion 5G and chlorfenvinphos 10G have also been found to be effective for shootfly control (Sukhani and Jotwani, 1980; Srivastava and Jotwani 1981). Thus a number of granules are now available by which shootfly damage can be successfully checked. The major drawback is the cost of these insecticides which is rather prohibitive for the average sorghum grower and therefore will not be favoured by them.

2.2.3 Seed Treatment: Realizing that most farmers would be reluctant to adopt the costlier granular insecticides, investigations were continued to develop cheaper and effective methods for shootfly control. It was felt that by a seed treatment technique the insecticide doses and consequently the cost could be reduced. Jotwani and Sukhani (1968) obtained successful control of shootfly by the use of carbofuran 75WP as seed treatment. This finding was later confirmed by other workers (Jotwani *et al.*, 1972; Usman, 1972; Balasubramanian *et al.*, 1976). Sepsawadi *et al.*, (1971) reported that plants grown from seed treated with selected rates of carbofuran showed significantly less shootfly damage than untreated ones. The 5% a.i. rate of carbofuran was the most effective in the test locations in Thailand. Sukhani and Jotwani (1980) conducted trials to compare the efficacy of carbofuran formulations to develop a suitable technique of seed coating to reduce the dosage. They concluded that the flowable 5% seed treatment was as effective as the SP formulation and that carbofuran 3G seed coating at the rate of 30 g per 100 g of seed provided satisfactory protection only up to 2 weeks.

Carbofuran 75WP has since then been withdrawn from the market due to the high mammalian and human toxicity and the hazard in application due to inhaling its fluffy dust during the mixing process.

Carbofuran seed treatment has been found to be as effective as some of the granular insecticides in which 3-4 times more active ingredient is used (Meksongsee *et al.*, 1981). Carbofuran treated seeds are now being widely used, especially in the State of Maharashtra, which is a major sorghum growing area of India. Due to the high mammalian toxicity of carbofuran and hazards involved in handling the formulation, the treatment is done by trained plant protection staff of the government and only treated seed is supplied to the farmers (Srivastava and Jotwani, 1981).

To further reduce the cost of application of carbofuran, various mixtures of treated and untreated seeds had been tried. It was found that even under a high level of shootfly incidence, a 60:40 mixture of treated:untreated seed can effectively protect the crop from shootfly damage (Sukhani and Jotwani, 1980). By using this method, the cost of the insecticide can be further reduced by about 40%.

One interesting observation reported by different workers is that there is a definite preference by the shootfly for oviposition on the seedlings emerging from carbofuran treated seed. This is attributed to the dark green colour and healthier growth of these seedlings. A preliminary trial conducted in a limited area has shown that by sowing treated and untreated seeds in alternate rows, the fly can be induced to oviposit on treated seedlings which protects the untreated seedlings (Srivastava and Jotwani 1981). Further trials are necessary to prove the efficacy of this method. The flies have also been noted to migrate into the sorghum field and then back to the borders of the field each day. Therefore, it may be possible to control them by treating an area around the field rather than the field itself (Young, 1972b).

2.3 Host Plant Resistance

Resistance to the shootfly in sorghum was first demonstrated by Ponnaiya (1951) who screened 214 sorghum types subjected to a high infestation level. He selected 15 varieties which showed relatively less damage by the shootfly. In this pioneering work, Ponnaiya recognized the presence of host plant resistance to shootfly in sorghum and suggested its possible value to reduce fly damage. He noted that shootfly oviposition was almost equal in both the susceptible and resistant varieties, but the resistant types showed less percentage deadhearts than the susceptible ones. The resistant plants possibly contained a factor which slowed penetration by first instar larvae to the growing point. In more detailed studies he determined that the third and fourth leaf sheaths of resistant types M-47-3 and T-1 contained irregularly shaped silica bodies that were not present until the fifth and sixth leaf sheaths of susceptible sorghum varieties AS 2095 and AS 1093. He concluded that these silica bodies were the mechanism of resistance (antibiosis) in sorghum. This finding was later confirmed by Blum (1968) who found that resistant cultivars were characterized by a distinct lignification and thickness of cells enclosing the vascular bundles of young leaves at the three leaf stage. Also the resistant varieties possessed a much greater density of silica bodies in the abaxial epidermis at the base of the first, second and third leaf sheaths. Subsequently Rao and Rao (1956) found that out of 42 varieties they screened, 14 exhibited a fair amount of resistance to shootfly attack. They also did not notice any oviposition preference by the fly on susceptible varieties.

Evidence for existence of an antibiosis mechanism has also been provided by trials conducted under glasshouse conditions (Jotwani and Srivastava, 1970). The resistant lines were artificially infested with two eggs per seedling, thus excluding the nonpreference mechanism. The results showed a significantly lower damage in resistant lines compared to the susceptible lines. Further evidence was provided by Roshan Singh (1973) who found that survival and larval development of the shootfly were adversely affected when reared on resistant varieties. More recently, Raina et al. (1981) observed that some cultivars possessed strong antibiosis for the shootfly in which mortality among the first instar larvae was very high and growth of the surviving larvae was significantly lower. The longevity of the female was also reduced. The high mortality of the first instar larvae coupled with a reduced growth among the survivors in resistant types is a clear indication of a post-oviposition factor contributing to resistance.

Nonpreference for oviposition has also been observed to be a mechanism of shootfly resistance in sorghum. Jain and Bhatnagar (1962) were the first to observe that oviposition on some South Indian resistant lines was significantly less than on susceptible lines which showed relatively less damage by the fly. This was also reported by Jotwani et al., (1971). More recent work has confirmed that nonpreference for oviposition is a major mechanism of resistance to the shootfly. Jotwani et al. (1974) demonstrated the utility of nonpreference for oviposition by growing three selected resistant lines in multi-row blocks in isolated areas. Nonpreference was generally found to be associated with pale green coloured and glossy leaves. Similar observations have been made by Soto (1974). There also appears to be a definite link between nonpreference for oviposition and the presence of minute hairs or trichomes on the leaf lamina (Maiti et al., 1980). These trichomed cultivars have distinctive characteristics, which are evident only in the first 3 weeks. The leaves tend to be more erect and narrower, with a yellowish green glossy appearance which is referred to as 'glossy trait'. The correlation between the presence of trichomes and oviposition nonpreference was observed to be nearly r = -0.8, which is high enough to make this trait an important selection criterion (ICRISAT, 1979/80). At ICRISAT, the use of the trichome and glossy trait and the identification of resistant plants in the seedling stage has proved to be a very effective and reliable system leading to development of several agronomically elite lines with a high level of resistance. It has also been demonstrated that this nonpreference mechanism is operative and deters oviposition even in the absence of a susceptible variety where the flies have no choice (Jotwani et al., 1974).

Tolerance or recovery resistance is yet another mechanism which has been observed in sorghum (Doggett and Majisu, 1966). The killing of the early main shoot results in rapid tillering in some cultivars and subsequent survival of heads produced by the tillers so that yield is not significantly affected. Tolerance represents a type of resistance that puts no selection pressure on the shootfly since there is no inhibition of the insect's establishment and development. However, tolerance can be greatly influenced by the growth conditions of the plant and thus may not always be predictable in various locations (Starks, 1972). Also tillering delays the plant maturity and, in some areas, the sorghum may run out of soil moisture before producing a satisfactory crop. In Uganda, Doggett (1972) reported that a resistant plant must produce its crop within 2 weeks of the harvesting of the undamaged shoots. In a very short rainy season, this delay of a fortnight may be sufficient to prevent a good yield being realized. Doggett (1972) also noted that the synchronous tillers of resistant varieties are few, but most of these bear a head. Susceptible varieties may produce numerous tillers after shootfly attack, but no profitable heads are obtained from them.

A systematic and extensive screening programme for identifying sources of shootfly resistance was undertaken under the All India Coordinated Sorghum Improvement Project (AICSIP) in the sixties. More than 10,000 varieties from the world germplasm collection were screened at different locations under natural and artificial infestation conditions. None of the varieties tested exhibited immunity, however, some lines showed significantly lower damage not only at different locations in India, but also in other countries, viz. Thailand, Israel, Uganda and Nigeria where screening programmes were undertaken and their resistance has been stable over the area of distribution of the fly (Young, 1972a)

Starks (1970) found that the application of fishmeal increased the sorghum shootfly infestation in experimental plots.

Using this finding ICRISAT (1978) developed a cheap and reliable field screening technique by utilizing a combination of sowing dates, spreader rows and fishmeal on the materials under test to identify sources of resistance. It has been established that shootfly resistance can be transferred from the donor parents and maintained in successive segregating generations. Some of the highly promising lines selected which provided the most stable source of shootfly resistance are IS Nos. 1054, 1055, 1151, 3541, 5469 and 5490 (Young, 1972). These lines in general are poor agronomic types; they are tall and therefore susceptible to lodging, are photosensitive, late maturing and low yielding. They have been utilized in breeding programmes in an attempt to transfer the resistance to new high-yielding cultivars. A number of varieties and hybrids released recently for commercial cultivation have been developed by using the resistant lines as one of the parents (Young, 1981). These cultivars possess low to moderate levels of resistance to the shootfly. The results so far obtained are highly encouraging and it is hoped that commercial cultivars possessing better levels of resistance will be available to sorghum growers in due course. Some progress has been made in this direction and the change can be seen from the susceptibility level of the first released hybrid CSH-1 as compared with CSH-5, CSH-7R and CSH-8R.

Resistance is important when planting is delayed or when drought or other factors delay seedling development, and during the rabi season when shootfly levels are moderate. For high levels like in July it may not be adequate. If resistance will hold under no-chance conditions in farmers' fields, then a 60% population reduction factor has probably a cumulative effect on the population depression over several years provided a larger area is planted with the same variety (Leuschner, 1982). Rana *et al.*, (1981) reported that the shootfly resistance was polygenic in nature and was governed by additive genes. They suggested that the resistance showed partial dominance under low to moderate shootfly infestation and this relationship could shift under heavy infestation. The present level of resistance to shootfly combined with the ability to tiller may be sufficient to control shootfly in farmers' fields during the kharif season. Rao *et al.* (1978) have stated that due to superiority of hybrids over the parents and the additive nature of the inheritance of the shootfly resistance, it can be advantageously utilized in hybrid breeding as well as in line development. To make further progress in increasing the level of resistance to shootfly in case the level is not satisfactory for the kharif or rabi season, there is need to improve the techniques to identify more diverse resistant sources for the breeding programmes.

2.4 Biological Control

A relatively small number of hymenopterous parasites have been reported from eggs, larvae and pupae of the shootfly in Africa (Deeming, 1971) and Asia (Pont, 1972). Deeming (1971) observed the following parasites reared from the pupae: *Alysia* sp. (Braconidae), *Pachyneuron* sp. (Pteromalidae) and *Exoristobia deemingi* (Encyrtidue). He further observed some solitary hymenopterous pupae on a number of occasions on third-instar larvae but these could not be successfully reared.

From a series a plantings, Kundu et al., (1971b) noted the emergence of two parasites; Aprostocetus sp. (Eulophidae) was identified as the predominant parasite while only a few specimens of Callitula bipartitus (Pteromalidae) could be found. Parasitism was found to be 16% in August, 25% in September and 6% in October. No emergence of any parasite was observed from material collected in other months. This was the first record of these species as parasites of Atherigona soccata.

Prem Kishore et al. (1977) systematically investigated the identification and utilization of natural enemies of the shootfly under the AICSIP at Delhi. It was found that in addition to the two parasites recorded by Kundu et al. (1971b), the shootfly larvae was also parasitized by Ganaspis sp. (Eucoilidae), Psilus sp. (Diapriidae), Hemiptarsenus sp. (Eulophidae) and Diautnopsis sp. (Eulophidae). The observation on parasitism during different periods showed that except for 2% parasitism by Ganaspis sp. in April, these parasites were recorded only in the infested seedlings collected during the months of September and October. Even in these months the extent of parasitism ranged from 1 to 4%. Also Aprostocetus sp. and C.bipartitus could be found. Parasitism of Aprostocetus sp. was higher than with any other parasite and ranged from 4% (October) to 15% (September).

Seshu Reddy and Davies (1979) have reported an Erythraeid predator, Abrolophus sp. on the eggs and early larvae at ICRISAT Center, India. They have also listed Crataepiella sp. (Eulophidae) and Tetrastichus nyemitawus as parasites attacking pupal stages, and larval stages respectively.

In Kenya, shootfly eggs are parasitized by *Trichogramma kalkae*. Second and third-instar larvae are parasitized by *Tetrastichus nyemitawus* but the rate of parasitism remains lower than 10%. In Nigeria, the numbers of parasites and predators of the shootfly recorded were insignificant and probably played no role in reducing the population of shootflies (Adesiyun, 1981).

2.5 Use of Attractants for Insect Control

The use of attractants offers a great potential for the control of insect pests. Indeed attractants have been used in a wide variety of pest species but this review will concentrate only on dipteran flies.

The potency and specificity of a good attractant makes it a useful tool in monitoring pest movements and in assessing the population density. Attractant baited traps that reduce the numbers of one or both sexes of a species would be excellent control tools if they could be used effectively and economically.

There are examples in which pheromone or attractant traps have been used successfully for insect suppression and some which show potential for incorporation into an integrated pest management programmes. A classic example of using attractants in the control of flies is the use of methyl eugenol to lure male oriental fruitflies, *Dacus dorsalis* (Hendel) to toxic baits. This insect was eradicated from the Mariana islands through the aerial distribution of fibreboard blocks soaked in a solution of the male lure, methyl eugenol and 3% naled insecticide (Steiner *et al.*, 1965; 1970).

Similarly, almost total eradication of the population of the melon fly, *Dacus cucurbitae* (Coquillett) was obtained over a large area of the island of Hawaii by one such fibreboard block (5 x 5 x 2.5 cm) per acre placed 0.5 - 1.5 m above the ground, each treated with 95% cue-lure and 5% naled insecticide (Cunningham and Steiner, 1972). Bateman et al., (1966), however, found that cue-lure and 5% naled insecticide could not control the Queensland fruitfly, D. tryoni, in a large plot in Australia.

Earlier, Steiner (1952) found that protein hydrolysates of soybean or yeast greatly increased the attractiveness of bait sprays containing sugar and toxicant to the oriental fruitfly D. dorsalis and the Mediterranean fruitfly, Ceratitis capitata (Wied).

Bait sprays of yeast protein and malathion applied at 1.2 lb of toxicant per acre (2.18 kg/ha) successfully controlled the Mediterranean fruitfly in Florida (Steiner et al., 1961). In small-plot tests, bait sprays containing protein hydrolysate, sugar and parathion gave 93% control of Ceratitis capitata on bananas, 89% on mangoes and 98% on guava.

McLeod (1964) found that adult flies of the onion maggot, Hylemya antiqua (Meigen) aggregated on various proteins and amino acids probably caused by both an attractant and feeding stimulant. Of the substances tested, brewers' yeast caused the largest aggregation of flies.

Two distinct types of traps have proven effective in attracting and capturing apple maggot flies, Rhagoletis pomonella; a perforated box containing insecticide baited with an ammonia-type compound or protein hydrolysate and a baited sticky-coated sphere (Prokopy 1973, Reissig 1974). It was felt that such traps could be used in orchard pest management programmes.

The attractiveness of fermented fishmeal to *Atherigona soccata* has been demonstrated by Starks (1970). Since then, fishmeal has been used as a bait in square pan galvanized metal traps for monitoring shootfly populations at ICRISAT Center (Seshu Reddy and Davies, 1978). More recently, the metal traps have been replaced by a dry plastic trap (ICRISAT, 1982) which is very simple and easy to operate. These traps have mostly been used in surveying or studying population densities of the shootfly and their high catching capacity is impressive.

The use of fishmeal attractant traps for shootfly control has been overlooked. However, preliminary work carried out at Navasari in Gujarat, India, has shown that poisoned fishmeal bait applied in leaf whorls of young plants can attract and kill large numbers of adult flies (Jotwani, 1982).

Experiments carried out in Liu Chou, China show that an average of 22 flies were killed every hour by using fishmeal which had undergone fermentation and was spiked with insecticide (Shie et al., 1981). Remarkable results were obtained by using the fishmeal attractant at LuTan Farm in Gung Xi Province. In a highly shootfly infested field (9.2 eggs/100 plants), insecticide plus fishmeal application resulted in only 6.7% deadhearts and 3.6 eggs/100 plants while in another field with 5.2 eggs/100 plants, insecticide control alone showed 32.8% deadhearts and 28.4 eggs/100 plants. These findings indicate that percent deadhearts and density of eggs can be reduced more effectively by applying attractant plus insecticide rather than insecticide alone (Shie *et al.*, 1981).

The finding of fishmeal acting as a strong attractant for shootfly adults has a great potential for utilization in control operations. Collaborative work by ICRISAT and the Max Planck Institute, Munich, on the isolation of active shootfly attractant component of fishmeal resulted in an extract FM 134 which was eight times more attractive than raw fishmeal (ICRISAT, 1981).

3. MATERIALS AND METHODS

In order to utilise the shootfly traps for control and population monitoring effectively, trap height, choice of insecticide and the changing frequency of insecticide in the trap had to be standardized.

3.1. Description of the Attractant Traps

The plastic shootfly trap developed at ICRISAT (ICRISAT, 1982) has been used in all the experiments. It consists of a 1-litre capacity plastic jar with three rows of small holes (4 mm diameter) near the open end to allow the entry of shootflies (Fig. 1).

The base of the jar has a hole for the insertion of the fishmeal dispenser. The fishmeal dispenser is perforated around the upper part while the lower unperforated part contains the fishmeal. The inner part of the jar lid is cut in such a way that only a small rim is left on which the edge of the plastic funnel can rest. The jar lid ring is screwed on to the plastic jar such that the funnel and lid fit tightly. The collection jar is mounted on to the funnel outlet by means of a hole in its plastic lid to collect the dead flies. The dispenser is filled with 25 g of fishmeal saturated with water. After 24-hr fermentation of the fishmeal, the dispenser is inserted into the trap.

Fishmeal fermented in such a way remains attractive for 7 days. This trap is selective for flies of less than 3 mm in width as the size of the entry holes restricts larger flies. The following experiments were conducted for the trap

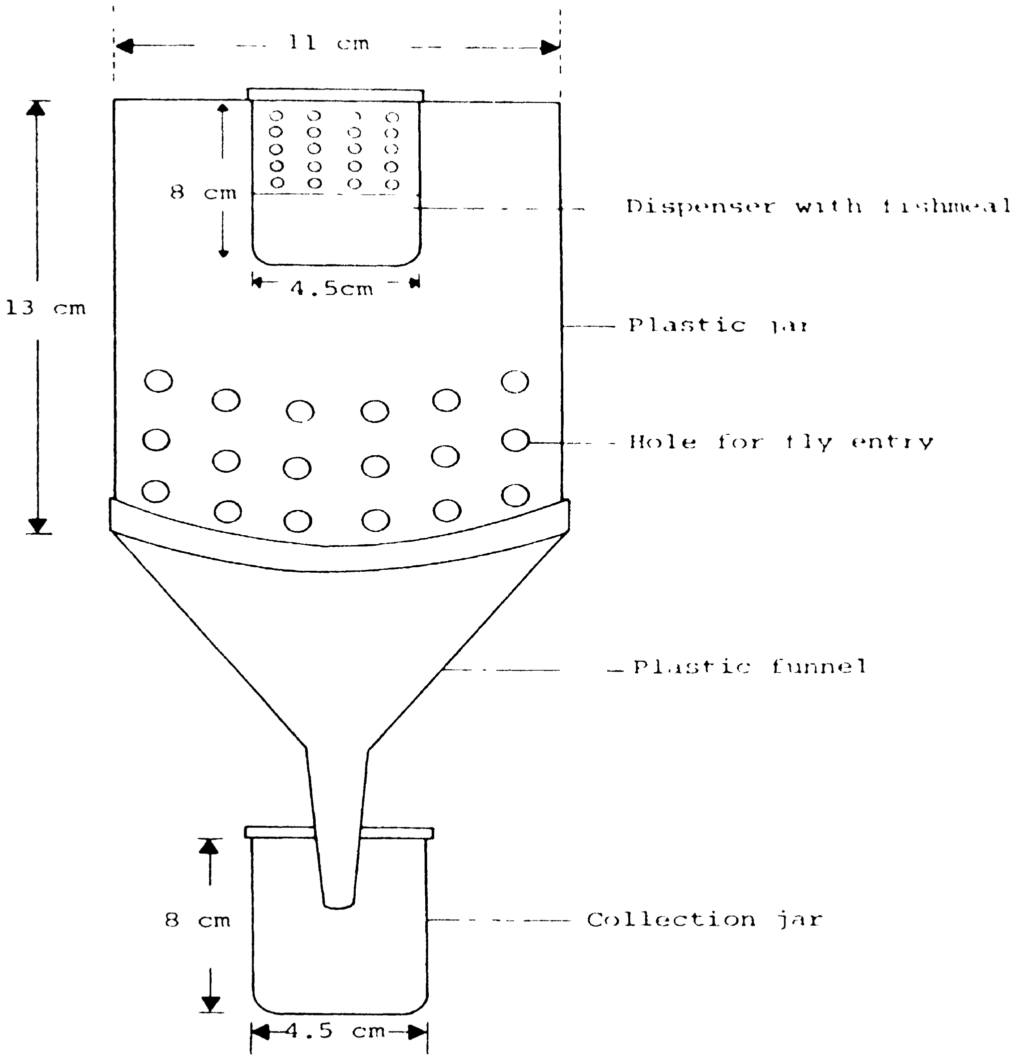


Fig. 1. Shootfly trap

standardization.

3.1.1. Height of Traps

A preliminary trial was conducted to evaluate the response of shootflies to traps set at different heights in order to find the most suitable trap height for maximum capture of adult shootflies. Traps were placed in a sorghum field during 10 February to 12 March 1983.

Four trap heights were tested for trapping efficiency:

a. At ground level
b. Crop canopy-level
c. 0.5 metre above crop canopy
d. 1.0 metre above crop canopy

Traps were arranged in a 4x4 latin square design in a sorghum field with four replications and the treatments were rearranged after every 7 days for a period of 4 weeks. The fermented fishmeal was replaced after every 7th day. Trapped flies were collected and counted twice a week for the entire period of the experiment.

3.1.2. Choice of killing agent

This trial was undertaken to test the efficacy of Sumicidin (fenvalerate) as a killing agent following observations that dichlorovos, which had earlier been used in these traps, reduced the trap catches (Taneja, Pers. comm.).

The following methods of application of the two toxicants were evaluated:

i. Dichlorovos (volatile) in a small plastic vial
ii. Sumicidin (contact action) sprayed in the plastic container
iii. Sumicidin sprayed in the collection bottle
iv. No insecticide

Traps were similarly arranged in a 4x4 latin square design in a sorghum field with four replications, with the treatments being rearranged weekly, and the fishmeal changed as in the previous experiment. Trap catches were collected and counted twice a week for a period of 4 weeks.

3.1.3. Optimum Replacement Frequency for Insecticide

This experiment was run over a period of 4 weeks, from 29 March to 23 April 1983 to examine the optimum replacement frequency of the insecticide used as killing agent in the fishmeal traps. Both dichlorovos and sumicidin were tested at various intervals.

Treatment: As in the previous experiment, dichlorovos was placed in a perforated plastic vial in the trap while sumicidin (0.005%) was sprayed around the inside of the plastic container of the trap. A third method of dipping the fishmeal dispenser in a soluation of 0.005% sumicidin was also included in the study. After dipping in the insecticide solution, the dispenser was left to dry before being fitted into the trap. Traps were installed at the crop canopy level.

Frequency of insecticide change:
P1 = Weekly
P2 = Every 2 weeks
P3 = Every 3 weeks
P4 = Every 4 weeks

All the possible combinations of insecticide and application frequency were tested. Thus there were 12 treatment combinations with three replications each.

Fishmeal was changed every week when the positioning of the traps was also rearranged within the sorghum field. Shootflies caught in the traps were collected and counted twice a week.

3.1.4 Fishmeal Trap Catches in Relation to Nutritional Status of Shootfly Females

A preliminary effort was made, in a cage experiment, to look into the effect of the hunger status of shootfly in a competitive situation of fishmeal bait and sorghum seedlings.

CSH-1 sorghum was sown in three seedbeds measuring 3.4 x 2 m, with 15 cm between plants in rows. The beds were covered with a 3.4 x 2 x 1 m screened cage 8 days after germination. One fishmeal trap was kept in each cage and 100 freshly caught shootflies were released into each of the cages at 9.00 am.

The number of flies recaptured were counted at 3-hr intervals - at 12.00 noon, 3.00 pm and at 6.00 pm. This experiment was run for 2 days.

On the 10th and 11th days, the whole procedure was repeated using flies which had been collected from fishmeal baited traps but kept overnight without food in small cages. One hundred such hungry flies were released into each of the caged beds and trap catches taken at 3- hr intervals. As a control, similar 3-hourly fly catches were taken from two traps under natural field conditions.

In a third experiment, 100 field-collected flies were released into cages with only traps inside but no seedlings to test the influence of sorghum seedlings in relation to trap catches. This was also done with flies which had been kept overnight without food. The test was run with three replications for days and recording of fly catches was done in the same way as mentioned above.

3.2 Control of shootfly

All field experiments were conducted with CSH-1 sorghum which is highly shootfly-susceptible. Although it was planned to plant the experiment at monthly intervals from July to December 1983, this was not possible during August and September due to continuous rains.

Five sowings were done on 22 July, 28 October, 12 December 1983, 1 February and 14 March 1984. For each sowing date, the material was planted in four big plots measuring 40x40 metres, and receiving the following treatments (Fig. 2):

T1 : Mass trapping of shootflies
T2: Spraying 5 metres around the crop with decamethrin 0.005% and fishmeal bait
T3 : Carbofuran 3G soil application at 40 kg/ha
T4 : Untreated control

Seeds were sown in furrows, 75 cm apart, with a tractor-mounted planter. Thinning was done 8 days after crop emergence to keep a distance of 10 cm between plants. The mass trapping treatment was located at least 500 metres away from the rest of the treatments. The fishmeal-baited traps were placed 10 m apart, at crop canopy level, all around the field. The fermented fishmeal was replaced every 7 days.

In the second treatment (T2), fishmeal was uniformly spread in a strip 5 m wide around the field and then sprayed with 0.005% decamethrin insecticide. This application was repeated at weekly intervals for 3 weeks.

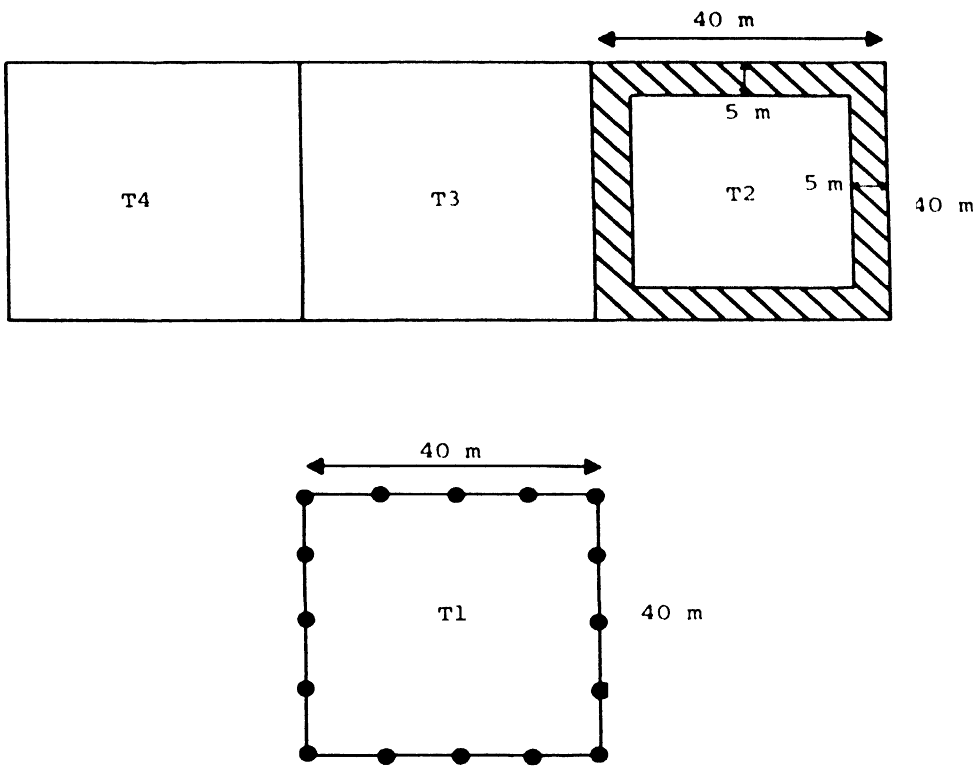
In the third treatment (T3), carbofuran was applied in the seed furrows at the time of planting.

Observations taken:

1. Number of shootflies trapped twice a week
2. Egg laying count 14 days after crop emergence
3. Deadheart count 28 days after crop emergence

For egg laying and deadheart counts, nine spots in each plot were marked (Fig. 3) and 150 plants at each spot observed.

The meteorological data on maximum and minimum temperatures, relative humidity and rainfall were also recorded during the entire period of these studies.



● Position of fishmeal baited traps

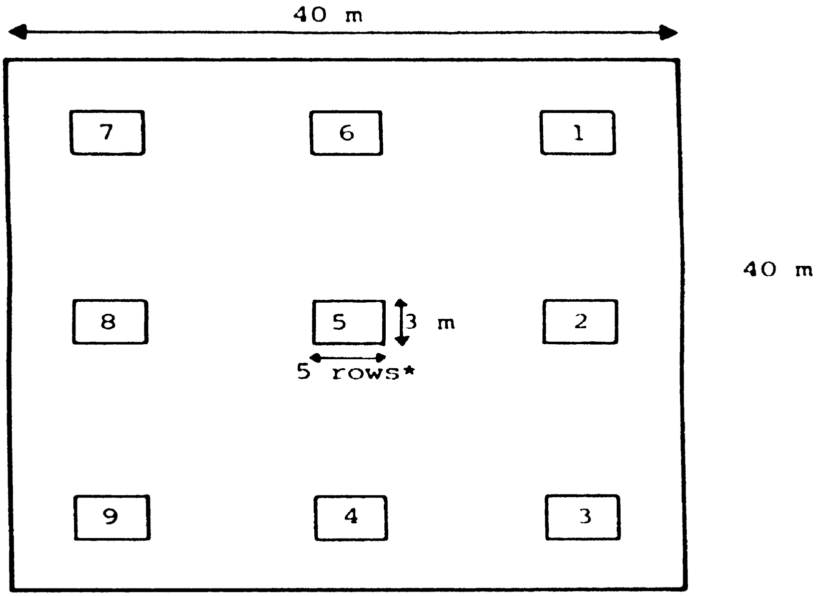
T1 Mass trapping of shootflies

T2 Spraying 5 m around the crop with decamethrin and fishmeal bait

T3 Carbofuran 3G soil application @ 40 kg/ha

T4 Untreated control

Fig. 2. Field layout plan of the experiment



* Each spot had 5 rows of 3 m length (Ca 150 plants)

Fig. 3. Observation spots within a treatment

4. RESULTS

4.1 Trap Height

Results of the experiment to test the effect of trap height on shootfly catches are presented in Table 1. Fly catch was significantly influenced by the trap height. Traps placed at the crop canopy level proved to be suitable as it caught the highest number of flies per trap and significantly more flies than traps placed at either 0.5 m or 1.0 m above the crop canopy. However, there was no significant difference in fly catch between traps placed at crop canopy and ground level.

Table 1. Effect of trap height on catch of shootflies.

Trap height	Weekly shootfly catches				Mean
	1	2	3	4	
Ground level	440 (20.4)*	299 (16.6)	497.8 (21.6)	174.5 (12.9)	352.8 (17.9)
Crop canopy level	294.3 (16.9)	360.8 (18.9)	719 (26.2)	359.5 (18.4)	433.4 (20.1)
0.5 m above crop	227.5 (14.4)	190 (13.2)	385 (18.8)	194 (13.9)	249.1 (15.1)
1.0 m above crop	86 (8.6)	153.8 (11.9)	438.3 (20.7)	175.5 (12.6)	213.4 (13.5)
SE ±					(2.00)
CD at 5%					(4.52)
CV %					(20.99)

*Figures in parentheses are transformed values $=\sqrt{catch}$.

Though the analysis of data indicated that there was no significant difference in shootfly catch between traps placed at the crop canopy and those placed at the ground level, there is a distinct advantage of placing the traps at the crop canopy level rather than at the ground level, particularly in an irrigated field. Traps placed at the ground level were flooded with water and there was an accumulation of debris around the plastic jar.

Differences in trap catches were also noted with respect to time (weeks). Trap catches at all trap heights, during the 3rd week were relatively higher than catches during the 1st, 2nd and 4th weeks, coinciding with the time when the fields were irrigated.

At ground level, trap catches during the 3rd week were significantly higher than catches during the 2nd and 4th weeks, but there was no significant difference with catches in the 1st week. Trap catches during the 2nd and 4th weeks were similarly not significantly different nor were there differences between the 1st and 2nd weeks.

Catches of flies in traps placed at the crop height level during the 3rd week were significantly higher than catches during the 1st, 2nd and 4th weeks. There were no differences in trap catches in the 1st, 2nd and 4th weeks. A similar trend was observed with traps placed 1.0 m above the crop level.

At 0.5 m above crop level, 3rd week trap catches were significantly higher than 2nd week catches but not different from catches in the 1st or 4th weeks. Catches in the 1st, 2nd and 4th weeks were also not significantly different.

Based on these results, canopy-level position of the trap was used in all field experiments.

4.2 Choice of Insecticide in the Trap

Observations on the influence of insecticides and method of application on the shootfly catch in fishmeal baited traps are presented in Table 2. Sumicidin was by far the best toxicant for use in the traps when sprayed around the inside of the plastic container. Traps with this treatment caught significantly higher numbers of shootflies than Nuvan placed in a vial inside the trap. Similarly, spraying Sumicidin inside the plastic container was similarly significantly more efficient than applying this insecticide to the collection bottle or applying no insecticide at all.

Traps in which Nuvan was used as the killing agent caught significantly more flies than either traps with Sumicidin sprayed in the collection bottle or traps with no toxicant.

While the lower catches in traps with Nuvan could be attributed to a masking effect, the low catches in traps with no toxicant or with Sumicidin sprayed in the collection bottle could probably be due to some flies finding their way out and escaping through the entry holes, since positive phototactic behaviour of flies will only allow few flies to end up in the collection bottle.

In this second trial, differences in trap catches were also noted with respect to time (weeks) exhibiting a similar trend as was observed in the first experiment. It is apparent from Table 2 that during the 3rd week (this field was also irrigated in the 3rd week on 26th February 1983) trap catches were significantly higher in traps with Sumicidin sprayed inside the plastic container than any of the other treatments. The catches were also significantly higher in the 3rd week than in the 1st, 2nd and 4th weeks within the same treatment.

Table 2. Influence of insecticides on shootfly trap catches.

Treatment	Weekly shootfly catches 1	2	3	4	Mean
Dichlorovos in vial	292.3 (16.9)*	195 (13.5)	360.8 (18.8)	175 (13.1)	255.8 (15.6)
Sumicidin sprayed into plastic container	489 (21.9)	355.5 (18.8)	718.5 (26.6)	237.5 (15.1)	450.1 (20.6)
Sumicidin sprayed in collection bottle	36.3 (6.0)	61.3 (7.5)	131.3 (10.7)	48.3 (6.6)	69.3 (7.6)
No insecticide	23 (4.7)	48.3 (6.9)	101.8 (10.1)	103.8 (9.9)	69.2 (7.9)
SE ±					(1.17)
CD at 5%					(2.64)
CV %					(20.48)

*Figures in parentheses are transformed values $=\sqrt{catch}$.

It appears that trap catches increased with increase in shootfly population and diminished with lower fly population but in each case, traps suspended at the level of the crop height, and with Sumicidin sprayed inside the plastic container as the kiling agent, consistently caught higher numbers of shootflies.

4.3 Replacement Frequency for Insecticide

Results of this trial are summarized in Table 3. The application frequency of the insecticide did not influence the number of shootflies caught in the traps.

Table 3. Effect of insecticide replacement frequency on shootfly catch.

Treatment	Changing frequency (weeks) 1	2	3	4
Dichlorovos in vial				
1st week	87.7(8.7)*	53.3(6.8)	48.7(6.2)	103.3(9.8)
2nd week	21.3(4.2)	73.0(8.3)	27.0(4.8)	57.8(6,8)
3rd week	30.3(5.3)	48.7(7.0)	37.0(5.9)	42.7(6.1)
4th week	7.7(2.9)	9.3(2.9)	1.7(1.5)	10.7(3.1)
Mean	36.8(5.3)	46.1(6.2)	28.6(4.6)	53.6(6.4)
Sumicidin sprayed in plastic container				
1st week	136.7(11.2)	65.7(8.1)	46.0(6.8)	18.0(3.9)
2nd week	100.0(9.8)	32.7(5.7)	20.7(4.6)	3.0(1.7)
3rd week	126.0(10.1)	33.0(5.7)	35.0(5.9)	13.7(3.2)
4th week	58.7(7.7)	45.0(6.4)	38.7(6.2)	4.7(2.1)
Mean	105.3(9.7)	44.1(6.5)	35.1(5.9)	9.8(2.8)
FM dispenser dipped in Sumicidin				
1st week	74.3(7.9)	23.7(4.5)	31.0(5.6)	7.7(2.7)
2nd week	18.0(4.3)	24.3(4.4)	26.0(4.9)	5.0(2.3)
3rd week	88.3(8.4)	26.3(4.2)	18.7(4.1)	11.0(2.6)
4th week	92.3(8.5)	15.3(3.8)	14.7(3.8)	7.3(2.5)
Mean	68.2(7.3)	22.4(4.2)	22.6(4.6)	7.8(2.5)

SE comparing 2 levels of frequency at same level of treatment ±(1.53)
SE comparing 2 levels of frequency at same level of frequency ±(1.38)
SE comparing 2 levels of treatment at same level of week ±(0.97)
SE comparing 2 levels of weeks at same level of treatment ±(1.02)

*Figures in parentheses are $\sqrt{n+1}$ transformations.

The treatment effects were significantly different. Sumicidin sprayed in the plastic container resulted in higher catches than when the fishmeal dispenser was dipped in the insecticide solution. There were no differences in shootfly catches in traps which had dichlorovos in a vial and those with the fishmeal dispenser dipped in Sumicidin.

The treatment x week interaction was significant and the largest numbers of flies were caught during the 1st week, and this was significantly higher than the catches in the 2nd, 3rd, and 4th weeks.

The 2nd and 3rd week catches were similar but were both significantly higher than the catches during the 4th week.

4.4 Fishmeal Trap Catches in Relation to Nutritional Status of Shootfly Females

The experiment was done to test if shootflies can pass the protective trap border line and insecticide-fishmeal strip around the field. It was postulated that fishmeal is a food source.

Fly catches increased with time in the case of less hungry flies with a mean catch of 13 flies at 12.00 noon, 18 flies at 3.00 pm and the highest mean catch of 32 flies at 6.00 pm (Table 4).

Table 4. Fishmeal trap catches in relation to nutritional status of shootfly females.

Time	No.of flies recaptured in treatment without seedlings		No.of flies recaptured in treatment with seedlings		Field catch
	Less hungry flies	Hungry flies	Less hungry flies	Hungry flies	
9 am-12 noon	5	8	13	33	24
12-3 pm	0	2	18	26	42
3-6 pm	1	0	32	10	120

A similar trend was observed with 3hourly trap catches under field conditions with the lowest number of flies caught at noon and maximum catches in the evening.

The hungry flies behaved differently. Maximum catches were observed at noon and diminished towards the evening. An average of 33 flies were caught at 12.00 noon. This decreased to 26 flies at 3.00 pm and 10 flies at 6.00 pm.

The treatment with no plants caught very low numbers of flies.

4.5 Control of Sorghum Shootfly

A preliminary analysis of the data was done to find out if there were any differences between the border plots and the centre plots, for all sowing dates. Difference between the border and centre plots were worked out for both percent deadhearts and egg laying, and subjected to analysis of variance. The results are presented in Tables 5 and 6.

Table 5. Analysis of variance of shootfly deadhearts forthe differences between border and centre plots.

Source of variation	df	SS	MS	F cal	F tab 0.05
Sowing dates	4	58.15	14.54	0.762	3.26
Treatments	3	13.42	4.47	0.235	3.49
Error	12	228.93	19.08		
Total	19	300.50			

Table 6. Analysis of variance ofshootfly ovipositionforthe difference between border and centre plots.

Source of variation	df	SS	MS	F cal	F tab 0.05
Sowing dates	4	132.18	33.04	0.871	3.26
Treatments	3	84.86	28.29	0.745	3.49
Error	12	455.43	37.95		
Total	19	672.47			

It was found that there were no significant differences between the border and centre plots for all treatments and sowing dates (nonsignificant F values).

July-August 1983 Trial

Results on the effect of the different treatments on shootfly oviposition and deadheart injury are presented in Table 7. During this period, maximum percent deadhearts was observed in plots where the fishmeal traps were installed for mass trapping of the flies and in the control plots receiving no treatment, recording shootfly damage of 99.8% and 97.8%, respectively. The rate of oviposition was also very high in both plots, averaging between 98.2% and 97.4%, respectively.

Table 7. Effect of different treatments on shootfly incidence on CSH-1 during July-August 1983.

Treatment	Egg laying (%)	Deadhearts (%)
Traps	98.2±0.89	99.8±0.11
Fishmeal + decamethrin	81.4±3.58	86.3±1.71
Carbofuran	97.9±0.82	27.5±3.46
Control	97.4±0.99	97.8±0.55

Plots in which fishmeal bait was spread in a 5 m band around the field recorded a fly injury of 86.3% deadhearts with an oviposition rate of 81.4%.

Plots treated with carbofuran 3G as soil application had significantly less deadhearts than all the other treatments, showing a fly damage of only 27.5% deadhearts. Shootfly oviposition was also very high (97.9%) in the seedling emerging from carbofuran treated plots.

The high rate of oviposition on all plots indicated a very high shootfly population pressure during July-August as is evident from Fig. 4. Maximum numbers of shootfly were caught in traps during this period. A mean maximum temperature of 34.9°C and mean relative humidity of 80-90% during this time appear to be a very favourable condition for the activity of the shootfly, giving rise to the high number of flies caught in the traps, high oviposition rate in all plots and high fly damage.

Though the incidence was high during this period, carbofuran 3G applied in the seed furrow at the time of planting was effective in reducing deadheart injury due to shootfly. There were no significant differences in deadheart injury in plots where traps were installed and in plots with fishmeal bait sprayed with decamethrin with the untreated check.

<u>October-November 1983 Trial</u>

The results of the test are summarized in Table 8. The results of this trial were not encouraging. None of the treatments gave good control as the percentage deadheart injury in all plots were above 50%. Even carbofuran which gave good results in July-August showed damage of up to 63.9% deadhearts. Up to 78.9% deadhearts were observed in control plots while the mass trapping of flies could not reduce the fly injury below 70.7%. Bait sprays of fishmeal and decamethrin resulted in an average of 51.9% fly injury which was lower than that observed during July-August. But this was not low enough as to be considered an effective control.

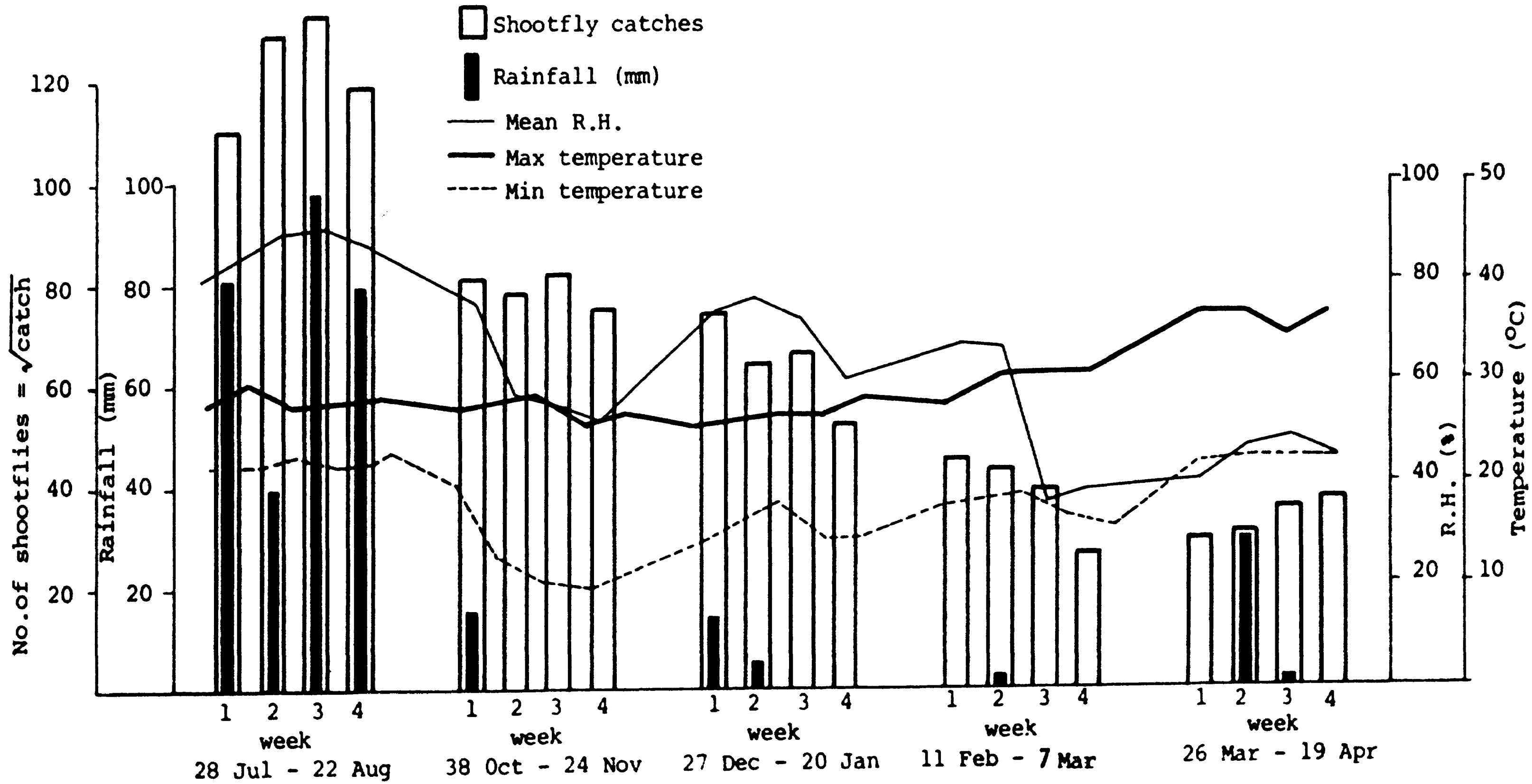


Fig. 4. Numbers of shootflies recovered from 16 fishmeal traps in 5 sowings of CSH-1 in relation to rainfall, temperature and relative humidity

Table 8. Effect of different treatments on shootfly incidence on CSH-1 during October-November 1983.

Treatment	Egg laying (%)	Deadhearts (%)
Traps	38.4±5.64	70.7±2.73
Fishmeal + decamethrin	41.5±3.01	51.9±2.90
Carbofuran	71.1±4.08	63.9±4.07
Control	60.1±6.81	78.9±3.98

It can be seen from Fig. 4 that the shootfly population during October-November was moderate. The maximum temperature during this time was 29°C with a mean relative humidity of 60-70%.

Shootfly oviposition was also markedly lower than that observed during July-August, with the highest rate of oviposition recorded on seedlings emerging from carbofuran treated plots being 71.1%. An average oviposition of 60.1% was recorded in control plots while the plots with bait sprays of fishmeal and decamethrin showed 41.5%. The lowest rate of oviposition was observed in plots in which traps were installed. These plots had an average of 38.4% egg laying and the general rate of seedling growth was also very poor.

<u>December 1983-January 1984 Trial</u>

The results obtained in the December-January tests were encouraging with respect to the bait sprays of fishmeal and decamethrin. It can be seen from Table 9 that plots which received bait sprays of fishmeal and decamethrin showed a significantly lower fly injury of only 23.7% deadhearts and also a low oviposition rate of only 28.3%.

Table 9. Effect of different treatments on shootfly incidence on CSH-1 during December 1983-January 1984.

Treatment	Egg laying (%)	Deadhearts (%)
Traps	90.0±2.09	51.9±1.26
Fishmeal + decamethrin	28.3±4.08	23.7±1.70
Carbofuran	86.8±2.41	42.0±1.45
Control	75.2±3.01	58.4±1.94

The soil application of carbofuran did not prove to be very effective during this period and showed damage of up to 42.0% deadhearts and a high oviposition rate of 86.8% plants with eggs.

The fishmeal traps again proved to be ineffective in reducing shootfly injury. These plots showed an average damage of 51.9% deadhearts and a mean oviposition rate of 90%.

An average of 58.4% deadhearts were observed in the untreated control plots with egg laying of 75.2%.

Shootfly densities during December-January were moderate (Fig. 4), the mean maximum temperature being 23.9°C and a mean relative humidity of 60-75%.

February-March 1984 Trial

In this trial, a marked drop in shootfly damage was observed in plots in which traps were installed as can be seen in Table 10. A very low rate of oviposition of only 1.0% and fly injury of 8.4% deadhearts were observed in these plots, which was significantly lower than in all the other treatments.

Table 10. Effect of different treatments on shootfly incidence on CSH-1 during February-March 1984.

Treatment	Egg laying (%)	Deadhearts (%)
Traps	1.0±0.28	8.4±1.71
Fishmeal + decamethrin	56.9±3.16	36.9±1.95
Carbofuran	85.3±2.45	56.3±2.07
Control	67.9±3.48	87.8±1.91

Bait sprays of fishmeal and decamethrin reduced fly injury to only 36.9% deadhearts and an average of 56.9% plants with eggs which was significantly lower than in the carbofuran-treated plots which exhibited 56.3% deadheart injury. The highest number of plants with eggs (85.3%) was recorded in the carbofuran-treated plots. The untreated control plots showed a mean deadheart count of 87.8% and an oviposition rate of 67.9%.

The traps caught relatively fewer flies indicating a decrease in shootfly populations during this period when the mean maximum temperature was 30°C. There was a considerable drop in relative humidity to only 40% which may have accounted for the decline in shootfly populations and subsequent low catches in the traps (Fig. 4). Humidity influences hatching and subsequent deadheart formation (Leuschner, Pers. Comm.).

The low percentage deadhearts and egg laying in the plot with fishmeal traps, however, presents a deceptive picture. The apparent relatively low incidence may be explained on the basis of the locational and environmental factors rather than the treatment effects. In general, the seedlings showed very slow or poor growth and development. Moreover, there was an abundance of sorghum crop all around the plot which was also in the seedling stage and may have presented a wide choice of food sources for the shootfly. It may be pointed out that it was not possible to use the same plots for all planting dates on account of the cropping patterns of the Institute and also the availability of irrigation facilities.

March-April 1984 Trial

Results of this test are presented in Table 11. Shootfly activity was at its lowest ebb as can be seen from Fig. 4. Trap catches were very low which could be related to the climatic conditions prevailing during this time. Mean maximum temperatures were as high as 36°C and a mean relative humidity of only 40-45%.

Table 11. Effect of different treatments on shootfly incidence on CSH-1 during March-April 1984.

Treatment	Egg laying (%)	Deadhearts (%)
Traps	41.6±3.16	75.1±1.60
Fishmeal + decamethrin	8.3±1.67	26.8±2.20
Carbofuran	23.9±4.72	55.9±2.48
Control	11.1±3.23	53.5±1.84

The low shootfly activity was further reflected by the very low oviposition rate in most plots. As low as 11.1% plants with eggs were observed in the untreated check with a resultant deadheart count of 53.5%.

Bait sprays of fishmeal and decamethrin gave an appreciable control with an egg count of only 8.3% and 26.8% deadhearts which was significantly lower than all the other treatments. An average of 55.9% deadhearts and 23.9% egg laying were observed in carbofuran-treated plots.

Results of the mass trapping treatment again deviated from the general trend observed in other plots. Whereas the shootfly oviposition was markedly low in all other plots, egg count in the mass trapping plot was comparatively higher (41.6%) with a resulting high deadheart count of 75.1%. It may be significant to note that this plot was surrounded by a large area of an older crop of sorghum and as the seedlings emerged, they offered an attractive choice for the shootflies. The very hot and dry climatic conditions also resulted in the rapid drying up of the fishmeal with a subsequent rapid loss in attractivity and efficiency of the traps.

Since there was an apparent influence of locational effects during the last two trials, it was decided to analyse the first three trials separately from the last two.

Data on both deadheart counts and egg laying for the July-August, October-November, and December-January tests were analysed separately and the results are presented in Tables 14 and 15. These results are consistent with those presented in Tables 12 and 13 when the results from all the five trials were analysed together. The results from the February-March and March-April tests showed that spread of fishmeal around the field border sprayed with decamethrin proved to be significantly more effective in reducing shootfly injury if we consider the mass trapping treatment during Februay as an artifact.

The analysis of the data on the efficacy of the different control methods tested with respect to sowing dates have been given in Tables 12 and 13 and illustrated in Figs. 5, 6, 7, and 8. It is apparent from Fig. 5 that mass trapping of shootflies was not effective in reducing deadheart injury in sorghum. The drastic drop in shootfly incidence observed during February-March was, however, attributed to locational and environmental factors rather than the trap effects.

Table 12. Effect of different treatments on shootfly damage in CSH-1 planted on different dates.

Sowing date	Percent deadhearts*				
Treatment:	Trap	Fishmeal + decamethrin	Carbofuran	Control	Mean
22-7-83	88.9*	68.6	31.9	82.0	67.9
28-10-83	57.4	46.1	53.5	63.2	55.1
12-12-83	46.2	29.0	40.1	49.8	41.4
31-1-84	16.4	37.4	48.6	69.9	43.1
14-3-84	60.2	31.0	48.4	47.0	46.7
Mean	53.8	42.4	44.6	62.4	

* Angular transformed values.

SE ± Sowing date = 1.03
Treatments = 0.92
Treat x sowing = 2.06
CV% = 8.6

Table 13. Effect of different treatments on shootfly oviposition on CSH-1 planted on different dates.

Sowing date	Treatment: Trap	Fishmeal + decamethrin	Carbofuran	Control	Mean
	Percentage of plants with eggs*				
22-7-83	83.9	65.3	83.7	82.1	78.7
28-10-83	38.1	40.1	57.9	50.9	46.7
12-12-83	72.2	31.8	69.3	60.4	58.4
31-1-84	5.1	49.0	68.0	55.7	44.5
14-3-84	40.1	16.2	28.4	18.1	25.7
Mean	47.9	40.8	61.5	53.4	

* Angular transformed values.

SE ± for sowing dates = 1.60
Treatments = 1.43
Treat x sowing = 3.19

CV% = 13.3

Table 14. Effect of different treatments on shootfly damage on CSH-1 in the first three sowings.

Sowing date	Treatments:	Percentage deadhearts*				
		Traps	Fishmeal + decamethrin	Carbofuran	Control	Mean
22-7-83		89.0	68.6	31.9	82.0	67.9
28-10-83		57.4	46.1	53.5	63.2	55.1
12-12-83		46.2	29.0	40.4	49.8	41.4
Mean		64.2	47.9	41.9	65.0	

*Angular transformed values.

SE ± sowing dates = 1.12
Treatments = 1.29
Treat x sowing = 2.23

CV% = 8.6

Table 15. Effect of different treatments on shootfly oviposition on CSH-1 during the first three sowings.

Sowing date	Treatment:	Percentage plants with eggs*				
		Traps	Fishmeal + decamethrin	Carbofuran	Control	Mean
22-7-83		83.9	65.3	83.7	82.1	78.7
28-10-83		38.1	40.1	57.9	50.9	46.7
12-12-83		72.1	31.8	69.3	60.4	58.4
Mean		64.7	45.7	70.3	64.5	

* Angular transformed values.

SE ± for sowing dates = 1.68
Treatments = 1.94
Treat x sowing = 3.36

CV % = 11.6

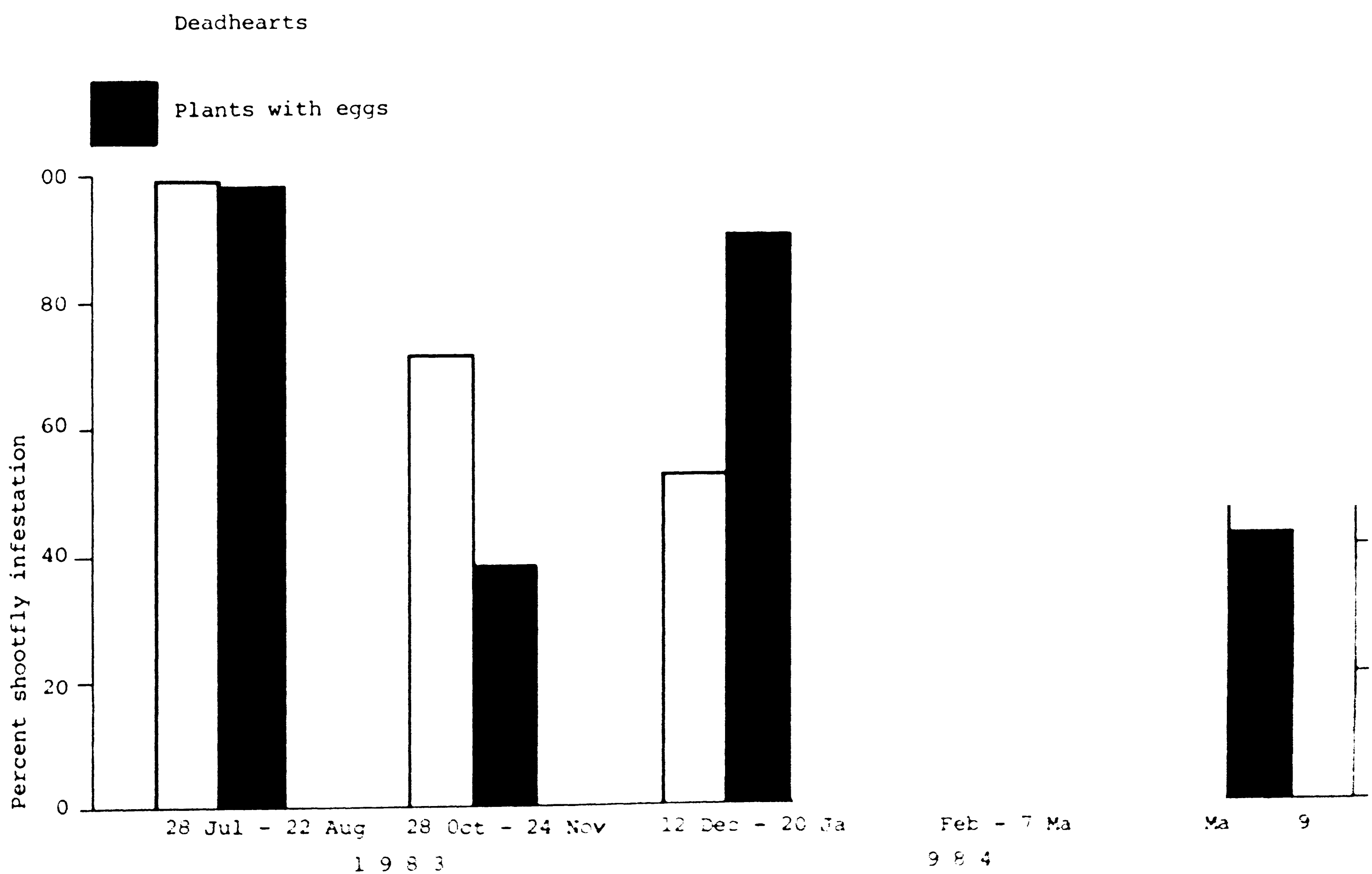


Fig Effect of mass trapping on shootfly incidence on CSH nted on dif ere

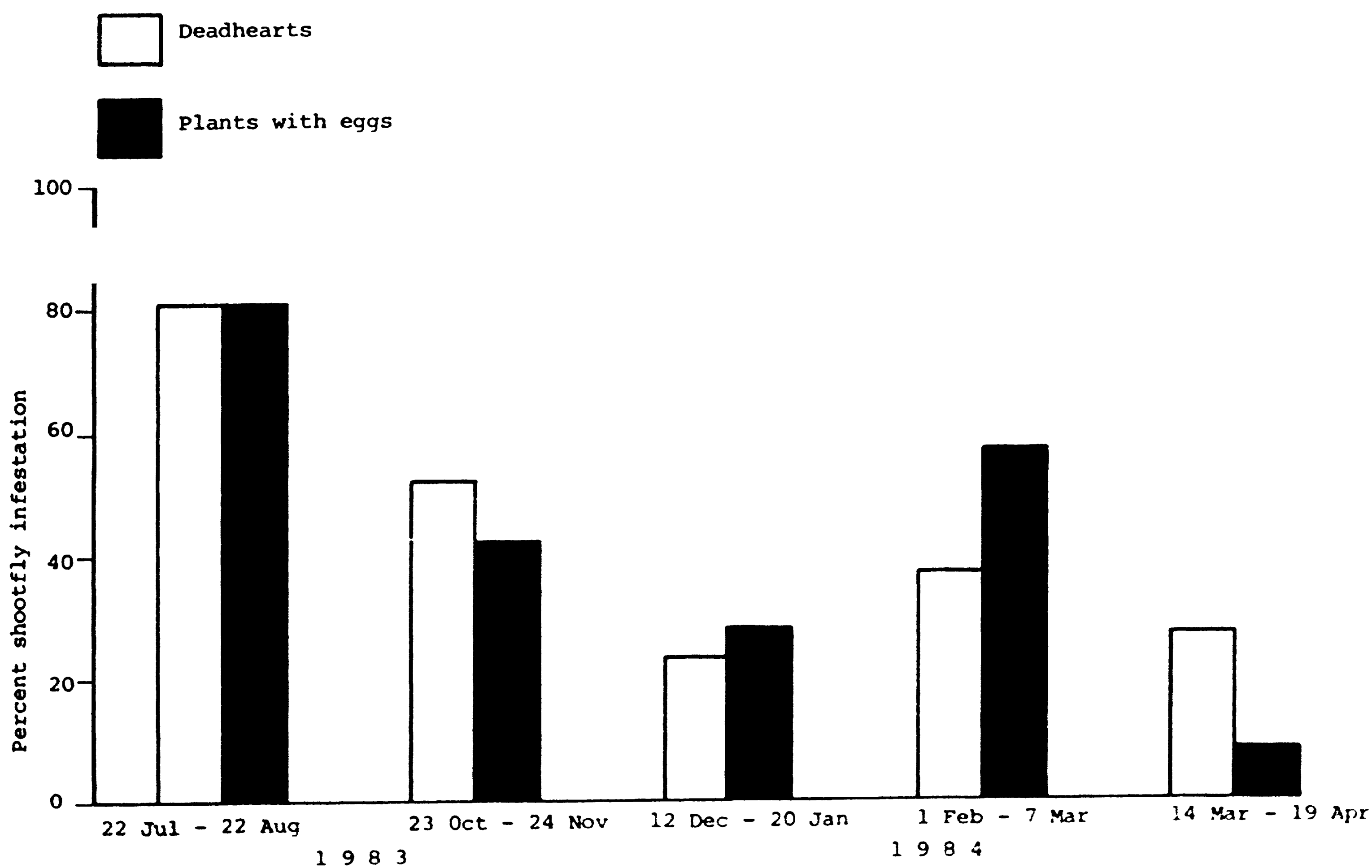


Fig. 6. Effect of fishmeal bait and decamethrin on shootfly incidence on CSH-1 planted on different dates

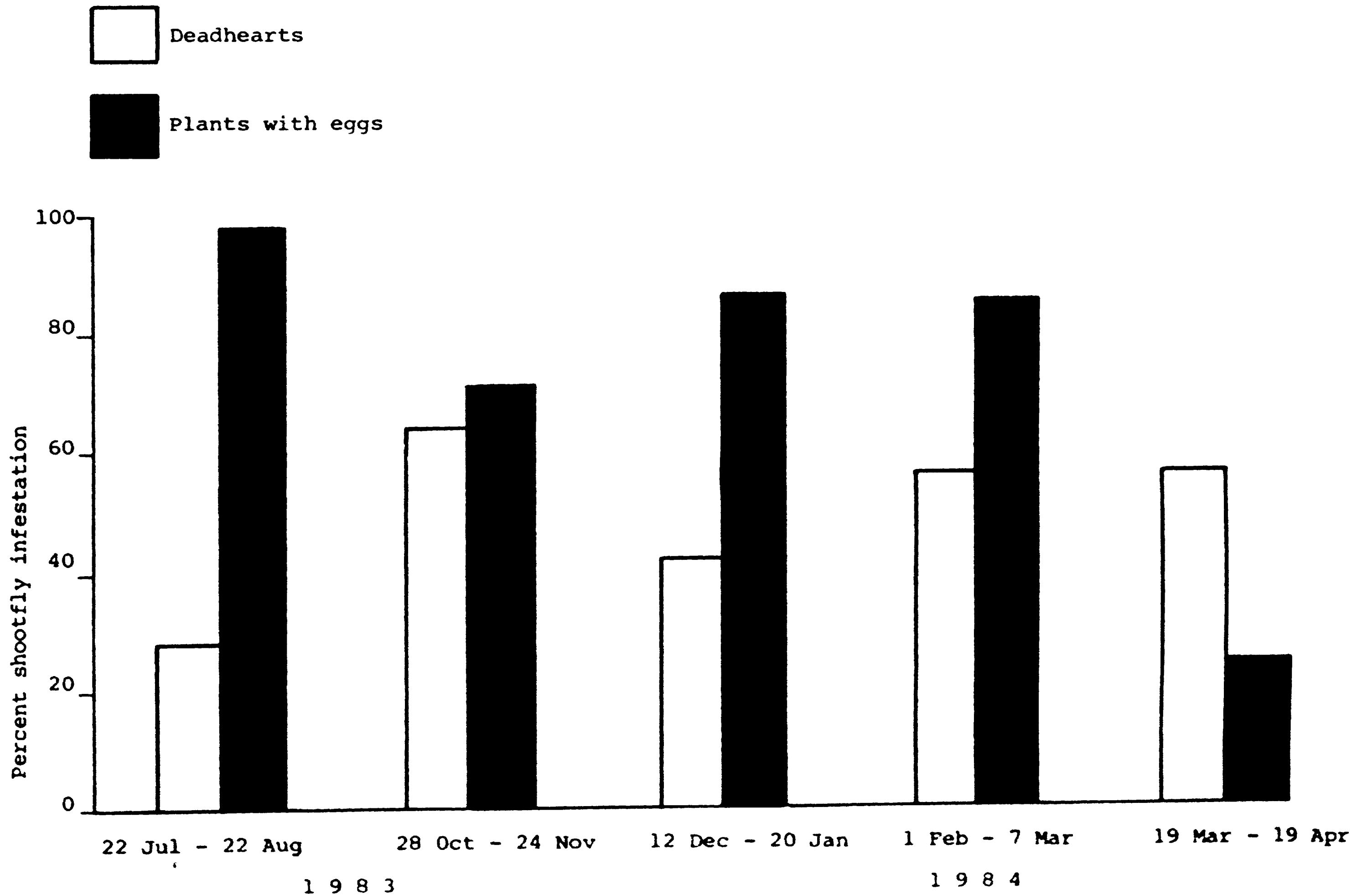


Fig. 7. Effect of carbofuran on shootfly incidence on CSH-1 planted on different dates

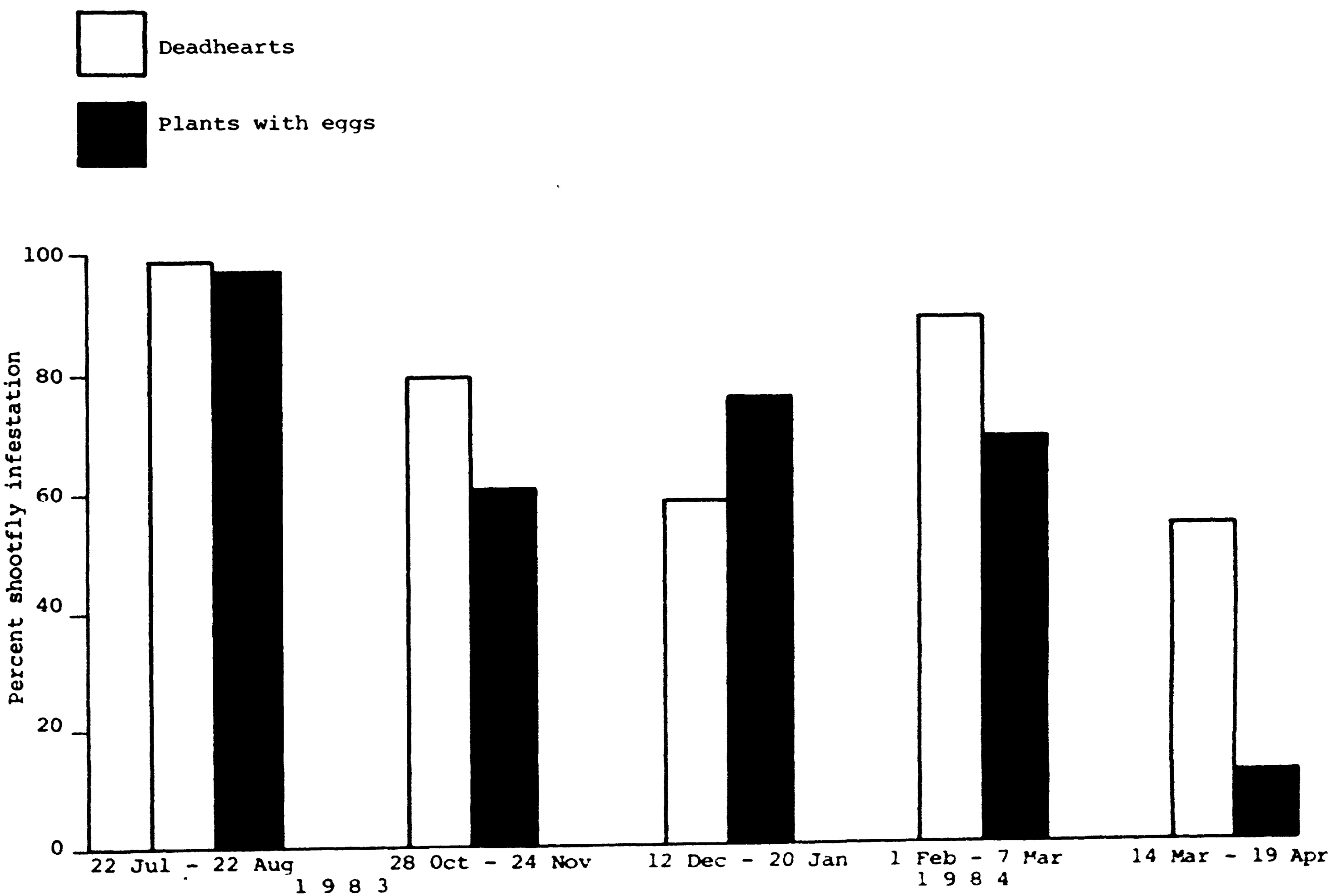


Fig. 8. Percentage of plants showing deadhearts and rate of shootfly oviposition on untreated CSH-1 sown on different dates

DISCUSSION

The control of the sorghum shootfly Atherigona soccata Rond. is an important component of the sorghum improvement programmes. Different methods of shootfly control have been tested and recommended, including cultural practices, chemical control and the use of resistant varieties. Every method has its limitations. While some progress has been made in research aimed towards the reduction of shootfly damage, more efforts are needed to improve on the existing control practices.

Field trials were undertaken to explore the possibility of controlling shootfly by mass trapping of the flies in fishmeal-baited traps and by using bait sprays of fishmeal and a synthetic pyrethroid, decamethrin. These were compared with the currently recommended method of soil application of granular carbofuran and with an untreated check.

The performance of the different treatments with respect to different sowing dates have been illustrated in Figs. 5, 6, 7, and 8.

Mass trapping experiments showed that this technique was of little practical value in control of Atherigona soccata, but may be useful for monitoring and assessing shootfly populations.

The experiments on the hunger status of the fly in relation to fishmeal attractiveness showed that fishmeal is indeed a food attractant for hungry flies. Nonhungry flies were less attracted in the morning and remained in the sorghum seedlings. The interesting thing was the experiment in which no sorghum seedlings and only fishmeal was presented. Flies did not react to fishmeal attractiveness in this situation.

For the field experiments, this could mean that fishmeal is not only a food source, but may act also as an oviposition attractant which will only work in the presence of sorghum seedlings. There may be a possibility that the fish smell of deadhearts acts as an attractant to lure more females into the field which means that there is stronger competition between seedlings (infested) and fishmeal than expected. This could be an explanation for the relatively poor results of control by trapping under field conditions.

The dependence on the sorghum seedling is also demonstrated by the finding at ICRISAT that the preoviposition time of females is prolonged in the absence of seedlings. Females exposed to sorghum seedlings during the preoviposition period began laying eggs on the 5th day while females not exposed did not reach full egg-laying capacity even after 9 days (ICRISAT, 1982). This is another example of the strong interrelationship between host plant and insect.

Knipling (1979) contends that the density of the pest population may have little or no influence on the efficiency of food attractants, but the density or amount of the competing natural food attractants should be a major factor governing the efficiency of attractant traps. If this is a valid premise, a given number of traps should capture the same proportion of the pest population in a given area, whether the population is high or low but the number and rate of capture of flies in baited traps would obviously be influenced by the amount of competing sorghum crop to which the flies respond for food and oviposition.

An experiment using fishmeal traps on a larger scale or area than was tested could probably achieve better results. Adequate numbers of traps suitably distributed need to be tested to assure spatial competition to achieve appreciable control. When traps are placed on borders as in these trials, spatial distribution of the fishmeal attractant to the spatial distribution of the sorghum seedlings could have been a major limiting factor in the efficiency of the traps. Further studies on the suitable trap density and arrangement could be useful to improve on this practice as a control tool.

Deciding on the distance between traps could, however, be a problem because it is difficult to estimate the effective distance of the attractant trap. The amount of attractant emitted, wind direction and velocity are some of the parameters that influence the decision on the minimum distance between traps. Since the spatial relationship of traps to the sorghum seedlings is important it seems logical to assume that traps would be more efficient if they were operated within the field rather than on the borders.

Fishmeal bait containing decamethrin sprayed in a strip 5 m wide around the field produced effective control during December-January, February-March, and March-April when the fly population was low. The reduction in the amount of insecticide and volume of spray has economic and environmental advantages.

Bait sprays of fishmeal and decamethrin gave only moderate control during October-November and failed to provide effective control during July-August. The continuous heavy rainfall during this period may have accounted for the poor results due to the spray deposits being rapidly washed off. A higher concentration of the insecticide coupled with more frequent application would probably have given better results. It would be interesting to test this proposition.

Carbofuran 3G applied in the seed furrow at the time of planting at a rate of 40 kg/ha was very effective in reducing deadheart injury due to shootfly during July-August. A comparison of the data for the entire experimental period showed that the performance of carbofuran was not uniform. The efficacy of carbofuran diminished rapidly after August. This seems to be related to a depleting moisture situation.

The number of eggs laid in the carbofuran treated plots was high in all plantings but the resulting injury to the seedling was as low as 27.5% indicating a high mortality of the larvae. Indeed several earlier workers have reported that there is a distinct preference by the shootfly for oviposition on seedlings emerging from carbofuran treatments and attributed this to the dark green colour and healthier growth of these seedlings.

Seasonal conditions, particularly the amount of rainfall during the seasons, may have been the most important factor influencing the efficacy of carbofuran. It is presumed that the relatively ineffective control obtained in October-November, December-January, February-March, and March-April may be due to insufficient moisture in the soil when the plants may not be able to pick up sufficient quantities of this systemic insecticide. The rate of growth of the seedlings may also have influenced the performance of carbofuran. Slow-growing plants may still be susceptible to the shootfly after the insecticide is not active any more about 30 days after germination.

CONCLUSION

Field trials were conducted at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Center, Patancheru, from July 1983 to April 1984 to find out whether mass trapping of shootflies and spraying of a synthetic pyrethroid insecticide around the borders of the field in combination with fishmeal helps to reduce the shootfly incidence.

The current recommendation of soil application of granular carbofuran and an untreated check were used as a basis of comparison.

Total plant counts and counts of plants with eggs and of plants with the main central shoots damaged by the shootfly 14 and 28 days after emergence provided percentage egg laying and deadheart data for comparison of the treatments.

On the basis of the five trials, the following conclusions can be drawn:

1. Mass trapping of flies was not effective in reducing shootfly incidence under conditions of high or low population densities.
2. Bait sprays of fishmeal and decamethrin provided adequate control during periods of low rainfall or drought from December to April but were ineffective during periods of high rainfall and when shootfly populations were high.

3. Carbofuran 3G applied in the seed furrow at the time of planting at a rate of 40 kg/ha was very effective in reducing deadheart injury during periods of heavy rainfall in July-August but it did not give sufficient control under drought conditions.

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