REVIEW OF LITERATURE

Interest in integrated pest management system has been stimulated by difficulties brought on by the almost total reliance on synthetic organic insecticides in dealing with pest problems. Indiscriminate use of insecticides without regard to the complexities of the ecosystem, especially the fundamental aspects of the population dynamics of pest species and growing health hazards, has led to better knowledge of basic short comings of insecticidal control approaches. Moreover single factor approaches for the control of insects are often inadequate though examples of dramatic control can often be cited for insecticides, pathogens, parasites, predators, release of sterile males or resistant plant varieties. The term "integrate" was first used by Bertlett (1956) and the idea of "managing" insect pest populations was proposed by Geier and Clark (1961). Geier (1970) used "pest management" in preference to "integrated control".

Integrated approach for insect control, which is now accepted as the best strategy, has been defined by Stern et al. (1959) as "the utilization of all suitable techniques and methods, in as compatible a manner as possible to maintain the pest population at levels below those causing economic injury". The more recent and complete definition given by FAO Panel of Experts (1966)
is that it is "a pest management system that, in the context of the associated environment and the population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible and maintains the pest populations at levels below those causing economic injury".

In recent years scientists have suggested that insect control must be extended beyond the all or nothing method to a system based on principles of applied ecology. Such a system has been defined as integrated system of insect management (Bhima, 1972).

The concept of integrated control was originally mooted to bring about compromise between chemical control and biological control (Smith and Allen, 1954; Stern et al., 1956) but the situation since then has changed and the scope of integrated pest control has been widened so as to embrace not only chemical and biological control but also other means of control to keep the pest population below economic injury level (Smith and Reynolds, 1965). Franke (1966), Watson et al. (1965), Seiler (1966), Rabb and Guthrie (1970), Hoyt and Barta (1974), and Panel of Experts (1966, 1969, 1970 and 1972) have discussed in detail the various aspects of integrated control. Apple and Smith (1976) have detailed the progress, problems and prospects of integrated pest management and Bredas (1976) is of the view that future
development in agricultural production will depend largely on integrated pest management system.

As early as 1962, Pradhan and Venkatraman suggested the integration of chemical and biological control of *Chilo partellus* (Swinhoe) by (i) analysis of direct and/or indirect effects of weather and insecticides on host/parasite interaction and (ii) improved control through periodic colonization of parasites and predators, improved strains of natural enemies, use of alternate host plant and/or host insects, changes in insecticidal timings, doses of chemicals, modification of cultural practices and even inoculation of crop plants with the pest when it is scarce to preserve natural enemies. According to Pradhan (1969) the idea of integrated control of insect pests seems to be readily acceptable but the possible techniques of formulating integrated control have not yet received enough attention. The aim of integrated control is to attempt a kind of rational integrated schedule for growing a pest free crop. Pradhan (1969) suggested a cooperative routine schedule of control operations against insect pests of maize and millet crops, which is as follows: (i) the harvested stalk of millet plants should be used up as soon as possible, (ii) stubbles should be dug out and destroyed, (iii) a pest resistant variety should be selected, (iv) higher seed rate should be used to remove affected plants, (v) crop should be
inspected to destroy egg masses and sluggish moth,
(vi) chemical control operations should be carried out
according to the nature and intensity of the pest, and
(vii) if (i) to (v) precautionary operations, somehow,
fail to provide adequate protection then a suitable
persistent insecticide should be applied.

There is strong need of integrated pest management
in crop like sorghum where modern production and protection
practices have often not yet been introduced to a large
extent. Recently Teetes et al. (1960) have given a
scheme as to how individual practices of control may be
fitted together into an operational and comprehensive
integrated pest control programme in sorghum.

The work done on various components necessary for
integrated control of stem borer, Chilo partellus (Swinhoe)
is reviewed in the following pages under separate
sub-headings.

1.

BIOLOGY AND BIONOMICS OF STEM BORER

Before attempting any control operation, it is
essential to know the weak links of the pest so as to
properly select and time the control operations. Detailed
studies on biology and bionomics can only provide such
information.

Biology and bionomics of the stem borer have been
studied by a number of workers (Fletcher, 1919; Fletcher
and Ghosh, 1920; AyyarNemakrishna, 1940; Trehan and

Mating takes place generally during the early hours of the day, oviposition lasts one to three days and each female lays more than 300 eggs in a number of separate clusters in the evening hours. Eggs are laid on the midrib of the underside of the leaves or on the stalks (Issac and Mishra, 1933; Trehan and Butani, 1949). Bhambukar (1956) reported that humidity plays very important role in the life history of this pest. Katiyar (1956) for the first time reported, contrary to common belief, that moths do not show preference for any particular place or part of plant for egg laying. The eggs hatch in 2-5 days. The larval period lasts from 16-50 days in summer to 193 days in winter. Normally there are five moults but over-wintering larvae undergo an extra moult during December and January. The pupal stage lasts 6-15 days and adult emergence generally takes place in the early morning. Moths are nocturnal and usually live for about 2 to 7 days (Trehan and Butani, 1949 and Pant and Kalode, 1964). The total life span of *Chilo partellus* during the period from July to December is reported to range from 29 to 125 days when the average minimum temperature ranges from 4.7°C to 22.8°C and average maximum temperature from 22.7°C to 40.5°C. The life cycle from November to June is reported to extend from 132 to 210 days when average minimum
temperature was 5.0°C to 16.7°C and maximum temperature was 29.1°C to 39.9°C. Young and Teetes (1977) reported that life cycle in the active season is completed in 30-40 days, so two generations may attack a single crop.

2 NATURE OF DAMAGE AND LOSSES CAUSED BY BORER

The damage caused by stem borer has been categorized in four distinct types (Lefroy, 1906; Fletcher, 1919; Ayyanarasakrishna, 1940; Travan and Butani, 1949; Vedamooorthy et al., 1966; Young, 1970 and Guthrie, 1975) viz.,

2.1 Leaf injury:

It results from the feeding of young larvae inside the leaf whorl. The unfolding central leaves show small or big holes on leaf lamina. Appearance of these 'pin holes' can be taken as warning symptom of the start of borer infestation. During severe incidence, the holes coalesce and entire leaves may be shredded into ribbon like pieces.

2.2 Dead heart:

The larvae in young plants bore inside the stem through the leaf whorl and in case of severe damage they cut the central whorl of leaves which causes drying of central shoots. This symptom is also called "dead heart" and its formation generally takes place at early growth stage of plants.
2.3 **Stem tunnelling:**

This type of damage is most serious and results in significant yield losses. The larvae feeding inside stem affect plant growth, resulting in stunting and poor earhead formation. The infested stems also become weak and can break easily.

2.4 **Peduncle damage:**

In recent years severe damage to emerging earheads has been reported from the states of Tamil Nadu and Madhya Pradesh. The larvae bore and feed within the peduncles and if the infestation occurs at an early stage, the earhead may completely dry up and there may be no grain formation.

Starks (1969) studied the extent of damage by stem borer on sorghum in Uganda. He reported that infestation at 20 days led to reduction in plant height, number of heads and stalks and weight of grain and stalks. However, infestation at 40 days resulted in severe stem tunnelling.

Studies on losses to sorghum by the stem borer attack were undertaken by several workers. It has been reported that incidence of sorghum stem borer may range from 10-75 per cent and in severe cases the depredations are so heavy that resowing of the crop becomes inevitable (Bishan, 1940; Trehan and Butani, 1948; Narayana, 1953 and Butani, 1956). Pradhan and Prasad (1955) have attempted to evolve correlation equation for estimating
the losses caused by the stem borer. They have suggested the following equation: 
\[ x_1 = 6.6204, \quad x_4 = 0.9257, \quad x_3 = 27.17 \]
where in \( x_1 \) = yield of jowar grain per plant, \( x_3 \) = percentage of stem length infested and \( x_4 \) = number of earheads per plant. This means that for a unit increase in the percentage stem length infested, the average decrease in the yield per plant will be 0.9257 gm. It is well known that the relationship between pest incidence and the extent of loss it causes to plants is not simple. There are a number of factors involved, one of which is the growth stage of the plant at which the infestation occurs. For example, the infestation of sorghum by the stem borer during earlier stages causes dead heart formation when the central shoot is killed and there is hardly any yield from the damaged plant. However, the occurrence of dead hearts during the late stage is rare (Pradhan, 1964). In general, the perusal of literature reveals that loss due to stem borer in sorghum ranges from 10 to 100 per cent (Anonymous, 1965; Rawat, 1967; Thobbi et al., 1968; Jotwani et al., 1971; Jotwani and Prem Kishore, 1973; Kulkarni and Jotwani, 1976 and Brivestava et al., 1976).

3 ECONOMIC THRESHOLD STUDIES

The concept of economic threshold as the major criterion for formulating any pest management programme has been essentially ignored (Stern, 1973; Van den Bosch and Stern, 1962 and Hoyt and Burts, 1974). The concept,
which was first described by Stern et al. (1959) as the density at which control measures should be initiated to prevent an increasing pest population from reaching the economic injury level, is not so simple, particularly in view of recent models put forward by Hillebrandt (1960), Headly (1972) and Hall and Norgaard (1973). Headly (1972) stated that economic threshold is that population level where the marginal benefit from damage prevented by control programme is equal to marginal cost of realizing that population through a control programme. The basic elements as proposed in his model are (i) a pest population growth function, (ii) a pest damage function, (iii) a yield function and (iv) a pest control function.

Hall and Norgaard (1973) indicated that Headley's model is a static one and gives no information on optimal timing of application of control measures during the season. They showed that the economic threshold varies over time and under certain assumptions, increases with time; so that the closer the harvest time, the higher is the level of pest population that will be tolerated before controls are applied. They suggested following elements in their model: a pest population growth function, a pest population kill function, a pest population damage function, a product yield function, and a pesticide cost function.

Serup et al. (1977) working on economic threshold of Chilo partellus infesting maize crop used endosulfan
insecticide. Economic threshold of borers was determined by manually infesting maize plants at seven different ages viz., 10, 13, 15, 17, 20, 25 and 30 days old plants with variable number of eggs (black-head stage), viz., 5, 10, 15, 20 and 25 eggs per plant. Considering the grain yield obtained from infested plants receiving no chemical treatment as also from those protected by endosulfan showed that maximum reduction in yield and relatively higher damage was caused in between 10 and 20 days old crops, regardless of number of eggs released.

As the economic injury level may vary from area to area, season to season, crop to crop, stage of the crop or with man's changing scale of economic values, the concept of economic threshold will also undergo a change. Thus it can be said that this concept is still in the process of evolution.

4 MOST PLANT RESISTANCE

Among the insect pests, borers as a class, by virtue of their behaviour, are most destructive and pose the greatest problem of control (Ingram, 1958; Nye, 1960 and Harris, 1962). Resistant varieties of crops specially for such insects have, therefore, been most ideal. The differences in the response of plant varieties to insect infestation and phenomena of inter-relationships of plant to insects are known for more than hundred years. Plants
resistant to specific insect pests were discovered as early as 1782, when "Underhill" wheat showed resistance to Hessian fly, *Mavetiola destructor* attack. The use of resistant apple variety 'Winter Majetin' against woolly aphid is also known for a pretty long time, besides this, some outstanding examples of insect resistant varieties developed for several crops are grapes against *Phylloxera* sp. (Painter, 1951); wheat against Hessian fly (Painter, 1966) and stem fly, *Cephus cinctus* Nort. (Lucinbill and Knipling, 1960), rice against plant hoppers, leaf hoppers (Pathak, 1969) and jassids (Parnell, 1935; Krishnamurty, 1972) and a number of corn hybrids to Southwestern corn borer *Zeadiastraea* (Diatraceae) *grandisella* and European corn borer, *Ostrinia nubilalis* (Hubner). Very exhaustive reviews on this aspect of insect control have been given by workers like Guthrie et al., 1960; Beck, 1965; Pathak, 1970; Maxwell et al., 1972; Leunk, 1970 and Sprague and Behms, 1972.

Behms (1943) has emphasized the importance of utilization of host plant resistance in the pest management programme in sorghum in the following words, "the use of resistant varieties to lessen injury from insects that attack sorghum would appear to deserve more attention, because the control of insects on a crop of low value per acre precludes the use of insecticides. Furthermore there is a possibility that growing of resistant variety would
reduce the insect population. It goes to the credit of Painter (1951) who provided the impetus to seriously consider the concept of 'Host Plant Resistance' in the control of crop pests in more methodical ways.

4.1 Screening for borer resistance and selecting sources of resistance

In India the first indication about the existence of resistance to Chilo in sorghum was provided by Trehan and Butani (1949) which was later confirmed by Pant et al. (1961) and Swarup and Chaugale (1962). Systematic screening for borer resistance was started by Singh et al. (1963), who screened 3,053 sorghum varieties from the world germplasm collection. The studies were continued by Jotwani and co-workers who screened additional 6,343 varieties available in the world germplasm collection and finally selected 26 varieties including BP 53, M 35-1, Kerad Local and Aispuri as highly promising (Pradhan, 1971 and Anonymous, 1964-1971). Initially the screening was carried out under high natural infestation conditions and the promising sources were evaluated by artificially infesting with egg masses. An artificial diet was developed so as to get large number of eggs for mass rearing of the borer (Deng et al., 1970, Lakshminarayana and Soto, 1971; Siddiqui et al., 1977; Seshu Reddy and Davies, 1978).

Out of 26 varieties selected for resistance to borer most of them are of Indian origin with the exception of 15-3096 from Georgia, U.S.A., 15-7279 from Nigeria and 15-9136 from Kenya.
Some very important work on host plant resistance has also been carried out on sorghum in Africa by Dogget and Majisa, 1966; and Starks and Dogget, 1970.

4.2 Parameters for determining resistance:

Various workers have adopted different parameters for screening the resistant lines against borer infestation. Pant and Kalode (1964) opined that the leaf injury index values, as calculated on the basis of different gradations, probably are the best means for screening. Chakraborty (1966) also employed the same parameter and classified BP 53 and C 10-3 as less susceptible and B. Negari, Babush and BRYS Milo as highly susceptible varieties. Singh et al. (1966) rated varieties with more than 30 per cent dead hearts as susceptible and those with 30 per cent and less dead hearts as resistant. Some of the criteria (which indicate the component of resistance involved) for evaluating resistance, as described by Behms (1972) are as follows; (i) number of insects attracted to a variety when given a free choice (preference or non-preference for oviposition or feeding), (ii) number of eggs oviposited (preference or non-preference), (iii) grading for insect damage (leaf injury, and stem tunnelling for borer) and (iv) biology of the pest to determine the length of life cycle, number of surviving insects and length of reproductive life of adults.
Earlier workers evaluated the sorghum lines on the basis of dead hearts caused by borer larvae. However, this parameter was found to be unsuitable as under certain conditions even severe borer infestation did not result in the formation of dead hearts. In subsequent work two more parameters, leaf shoring damage grading and stem length tunnelling were used to grade sorghum varieties. However, there is evidence to show that these parameters are acting independently as there is no direct correlation between the two types of damage (Jotwani et al., 1978). Similar situation has also been reported by Guthrie (1975) who has stated that since borers have more than one generation each season and infestation is continuous at various stages of plant growth, the biological relationship between the insect and host plant may not be same for each generation.

4.3 Mechanism of borer resistance:

The information on mechanism of resistance is limited. Kalode and Pant (1967) first reported antibiotics in some borer resistant varieties of maize and sorghum. Tectia and Sharma (1967) reported 12 of 30 sorghum varieties tested by them for resistance to borer seemed to have an antibiotic effect on growth and development of borer. Jotwani et al. (1971) also reported prolongation of larval period and higher mortality of borer on three varieties viz., 13-1151, 13-4764 and 13-4776 as compared to susceptible hybrid CNH-1. Jotwani et al. (1976) observed
that tolerance and antibiosis mechanisms are operating in resistant varieties. During detailed studies on development of stem borer larvae on resistant and susceptible varieties, he found that on resistant varieties like 13-1151, 4263, 4776, 5016, 5072, 5200, 5604 and 5629, mortality in early larval stages was higher and pupation was less as compared to susceptible variety.

4.4 Genetic basis of resistance:

Bana and Murthy (1971) carried out genetic analysis of stem borer resistance and reported that inheritance of borer resistance was polygenic. In their studies F1 hybrids were found to be intermediate for primary damage (leaf injury) but better than mid-parental values for secondary damage (stem tunnelling). They further found that resistance to leaf injury was governed by additive and additive x additive gene-action while additive and non-additive types of gene-action were important for stem tunnelling. Thus according to them, the inheritance patterns of leaf injury and stem tunnelling were different.

4.5 Breeding for borer resistance:

In the programme on breeding for resistance to stem borer, a number of identified sources of resistance have been utilized by crossing them with dwarf exotic types which are highly susceptible to borer attack but are agronomically desirable parents. The identified resistant sources are generally tall, late maturing and poor yielders.
This programme under the All India Coordinated Sorghum Improvement Project has resulted in developing a number of hybrids and varieties which are from exotic x Indian (Temperate x Tropical) crosses combining higher yield and wider adaptability and also possessing moderate level of borer resistance. Four hundred and fifty derivatives obtained from crosses between high yielding and resistant varieties were screened against stem borer. Twenty lines having either M-35-1 or BP-53 as one of the resistant parents, were selected as highly promising for exhibiting desirable level of resistance to stem borer (Kundu et al., 1977). E-302, E-303 and 447 have proved to be good yielders and were introduced in yield trials. Rao (1972) suggested that the process of continuous screening of resistant types under artificial infestation conditions should be continued since the plant may eventually evolve an immunity mechanism. House (1972) on the basis of literature, suggested that inter-generic crossing can also help in building up resistance. Jotwani et al. (1977 and 1978) in a series of trials with 3-302, E-303, F-333, U-380, P-97, P-151 and 447 reported that the extent of borer resistance acquired by these advanced derivatives is fairly high. The yield potential of these derivatives was also good. Taley and Dhurve (1976) reported SPV-100, SPV-138, SPV-165, SPV-167 and E-303 as resistant to borer while Sadakathulla et al. (1976) reported CSN-78, Aispuri, E-332, SPV-99, SPV-110, BJ-107-1
as significantly less damaged by borer out of a large number of derivatives (Crosses between exotic and Indian sources) received from Sorghum breeders as entries in advance yield trials.

5 CHEMICAL CONTROL

Satisfactory control of the stem borer with insecticides was first reported by Trehan and Butani (1940). They observed hundred per cent mortality of the larvae in 30 hours by spraying 0.1% DDT. Shi (1957) conducted laboratory bioassay tests and reported that on the basis of LD50 values parathion, lindane malathion, endrin, diazinon, isodrin and aldrin were about 124.4, 14.4, 11.8, 11.1, 9.3, 5.6 and 3.0 times more toxic than DDT.

Putterudriah (1958) suggested repeated applications of 5 per cent BHC dust for the control of borer.

Seini (1959) studied the residual toxicity of endrin, lindane and parathion on the leaf surface of maize against just hatched larvae of the borer and found that all the insecticides became ineffective after one to two days.

Pradhan et al. (1956) gave three sprays of DDT 0.1 per cent, gamma BHC 0.1 per cent, endrin 0.05 and 0.1 per cent and systox 0.025 and 0.05 per cent for the control of borer, first on the 25th day after sowing, second on 26th day of the first spraying and the third on 24th day
after the second spraying. They reported significant reduction in the larval population in 1st and 2nd sprayings but the 3rd spraying was found to be ineffective. They also obtained more yield from BHC and endrin treated plots as compared to systox.

Latif et al. (1960) reported that spraying with endrin, trichlorphon and diazinon @ 0.25, 0.5 and 1.0 lb/acre (0.113, 0.227 and 0.45 kg a.i./ha) either three times at an interval of two weeks or twice at an interval of three weeks were effective against the borer.

Butani (1961) suggested that the borer can be effectively controlled by spraying with 0.125 per cent DDT or 0.04 per cent ethyl parathion or 0.04 per cent endrin @ 60-100 gallons/acre (273-455 l/acre) depending upon the growth of the plant. Kushwaha et al. (1961) tried three sprays of 0.02 per cent endrin and 0.25 per cent DDT on hybrid maize against borer. The percentage of infestation in endrin and DDT treated plots and untreated control was 5.6%, 12.92 and 15.92 respectively. Difference in the infestation between DDT and control was not significant.

Grivestava and Gupta (1961) observed that 0.025 per cent endrin + 1 per cent ovicide @ 80 gallons/acre (364 l/acre) was effective against the borer in U.P.

Wheatley (1961) in Kenya recommended three applications of 0.1 per cent DDT emulsion against borer at 10 days interval starting from 10th day after germination.
Lele et al. (1962) tried finely ground BHC and lindane as seed treatment on maize. Gum arabic paste was used as sticker. They reported BHC used @ 5 gm/100 gm of seeds gave protection from borer damage up to 11 days. The higher concentrations used were phytotoxic.

In trials on the control of borer, conducted at Delhi during July and August 1961 on Red bine 58, four applications of carbaryl spray applied @ 1.5 lb a.i./acre at weekly interval, starting 15 days after planting reduced dead heart injury to 2.6 per cent as against 41 per cent in control. Endrin spray (0.2 lb), endrin granules (0.24 lb), parathion spray (0.5 lb), BHC spray (0.2 lb gamma), BHC dust (0.5 lb) and phorate granules (0.5 lb) a.i./acre reduced dead heart injury levels by 10 to 15 per cent (Anonymous, 1961–62). Probably this is the first report from India about the use of granular formulation for the control of stem borer.

Sandhu (1962) attempted to evolve an economical spray schedule for the control of stem borer on maize. He found Tripterax (trichlorphon) to be the best insecticide followed by diazinon + endrin, endrin, diazinon, parathion and DDT. In another trial conducted at Coimbatore during 1962, carbaryl (1-2 kg a.i./ha) applied as spray for four times at weekly interval gave him effective control by significantly reducing the borer population.

Young (1962) suggested spraying of BHC 50 per cent WP @ 25 gm/gallon (25 gm/4.55 l) or endrin 20 per cent.
EC 7 cc/gallon (7 cc/4.55 l) at the rate of 25.50 gallon/acre (116.02 l/acre), depending upon plant growth for protecting maize crop from borer. He suggested complete drenching of whorl with the insecticides, giving 2-4 applications at an interval of 10 days starting 10-20 days after sowing.

Sivagami and Sulochana Bai (1965) conducted field trials at Coimbatore from 1958 to 1963 to compare the efficacy of 0.025 per cent parathion, 0.02 per cent endrin and 0.1 per cent of aldrin, dieldrin, azinophos-methyl, BHC, carboaryl and diazinon (all applied as sprays) as also dusts of 10 per cent BHC, 5 per cent chlordane and 5 per cent DDT. Each insecticide was applied twice. BHC 0.1 per cent and parathion 0.025 per cent sprays gave highest yield. They concluded that BHC being cheaper may be preferred.

A field trial (Anonymous, 1964-65) was conducted for the control of stem borer with foliage application of endrin 2 per cent granules (imported on clay base), endrin 2 per cent granules (local on clay base), carboaryl 10 per cent granules (imported on clay base), endrin 2 per cent granules (local on clay and coconut shell base), BHC 10 per cent granules (local on clay base) and lindane 1.3 per cent granules (local on clay base). Comparison between treated plots with the untreated control showed that in all the insecticidal treatments there were significantly less dead hearts and leaf injury. Green and green fodder yields were considerably higher in the treatments as compared to control.
Systematic and planned studies on the control of sorghum pests were started under the All India Coordinated Sorghum Improvement Project (AICSIP). A number of trials were conducted at different locations for the control of borer. In the initial trials endrin (2% granules) was applied into whorls and on the upper leaves at the rate of 15-25 kg/ha according to the size of the plants. A total of 6-7 weekly applications were made during the season. Applications were discontinued when the earheads emerged from the boot. This schedule of endrin applications reduced damage to very low levels when compared to untreated plots (Anonymous, 1965-67).

Thobbi et al. (1966) reported that three to six applications of 2 per cent endrin granules applied at the rate of 10-15 kg/ha in leaf whorls at weekly to fortnightly intervals, gave effective control of the borer and increased the grain yields by about 1,000 to 3,000 kg/ha at different locations. There was no significant difference in yields between three and six applications.

Butani (1968) studied efficacy of various insecticides using different formulations and concentrations as also frequencies of application and observed that only endrin and isobenzene granules gave significantly higher grain yields. Frequency of application (fortnightly or triweekly) had no effect on yield whereas there was a gradual increase in yield with increase in concentration.
Kulshrestha et al. (1968) studied relative efficacy of different granular insecticides and observed that none of the insecticides tested (endrin 2G, lindane 1.3G, dimethoate 10G, Carbergal 10G and malathion 10G) gave highly satisfactory control of the borer. Plots, given six applications of endrin, gave the highest yield. Ahmed and Young (1969) obtained satisfactory control of the borer with 4 applications of carbergal (1.0 and 1.5 kg a.i./ha), endrin (0.2 and 0.3 kg a.i./ha), lindane (0.13 and 0.20 kg a.i./ha) and BHC (1.0 and 1.5 kg a.i./ha). The grain yields from treated plots ranged from 1005 to 1624 kg/ha in 1963 and from 3063 to 4212 kg/ha in 1964 as compared to 199 and 336 kg/ha from untreated plots.

Perusal of the results of trials conducted by different workers reveals that in majority of the field trials, endrin granules applied in whorls gave satisfactory control of the borer. However, studies on residues of endrin applied at the rate of 2.016 kg a.i./ha before earhead emergence resulted in the recovery of 2.83 ppm to 5.0 ppm in the grain at the time of harvest (Kathpal et al., 1960). Thus, this insecticide cannot be recommended for borer control as tolerance limit fixed by F.I.A. of U.S.A. on feed and fodder crop for this insecticide is zero.

Under AICRP (1966) a trial was conducted at different locations for the control of stem borer using the granules of endrin (2%), lindane (1%) dimethoate (10%), monocrotophos (5%) and endosulfan (4%). The granules
were sprinkled over the whorl and upper leaves at the rate of 10-15 kg/ha per application, starting on the 20th day after germination and repeating the application two and three times at 10 day intervals. Three applications of all the insecticides significantly reduced stem borer dead hearts and leaf whorl injury when compared to plots without any treatment (control). During kharij 1969, a uniform trial, similar to that conducted in 1968, was carried out at different locations. The insecticides used were same as in 1968, except that trithion was used in place of endrin granules. Results indicated that stem borer injury was significantly reduced by all insecticides at all the locations. Endosulfan gave better protection among all other insecticides. Yield of both green fodder and grain generally followed the pattern of insect injury, showing negative correlation. The result of this experiment further confirmed the earlier results that insecticidal control of stem borer is essential to achieve maximum yield. In the next year (1970) another trial was planned under AICLIP at different locations to determine the number of applications required for the control of borer with the granular formulation of three promising insecticides viz., carbaryl, lindane and endosulfan. The granules of different insecticides were applied in one, two and three applications schedule. The insecticides were applied at the rate of 8 kg/ha on 25th day after
germination, 8 and 10 kg/ha on the 20th and 35th day after germination and 8, 10 and 12 kg/ha on the 20th, 30th and 40th day after germination respectively. The percentage of dead heart and leaf injury due to stem borer were significantly lower in all the insecticidal treatments when compared to control. The yield of grains from plots given two applications of endosulfan did not differ significantly from plots given three treatments of lindane and carbaryl granules. The highest yield of grain was obtained from three applications of endosulfan (Anonymous, 1966-70).

From 1967 to 1970, a number of other insecticides were tested in the form of sprays and granules. In 1967, it was observed that three applications of endrin, BHC, dimethoate, carbaryl and malathion granules given at fortnightly interval significantly reduced borer injury. In 1968 and 1969 trials, two insecticides viz., endosulfan and monocrotophos were found to be effective against the borer. In 1970 comparison was made between spray and granular formulations of four different insecticides viz., monocrotophos, lindane, endosulfan and carbaryl. Considering the two criteria of borer damage viz., leaf injury and stem tunnelling, as well as grain and fodder yields, it was concluded that the granules gave better control of the borer than the sprays. Maximum grain yield obtained was 56.9 Q/ha in plots treated with endosulfan.
4 per cent granules, applied in whorls at the rate of 0.32, 0.46, 0.6 kg s.i./ha on 20th, 30th and 40th day after germination. The next in the order was monocrotophos granules which gave grain yield of 52.3 q/ha (Jotwani and Young, 1972).

Jotwani (1969), based on the results from a preliminary trial, indicated the feasibility of controlling the sorghum stem borer by side-dressing 20 days old crop with mephosfolan and carbofuran. Further trials with mephosfolan were conducted in India against the stem borer during Kharif 1968 and 1969. When used at the time of sowing in soil at the rate of 1.5 gm/metre row length and again after 25 and 35 days after germination it gave effective control of the stem borer (Anonymous, 1972). However, this treatment may not be economical.

Baskaran (1971) investigated efficacy of fourteen granular insecticides against shoot fly and stem borer. For borer control the insecticides were applied as side dressing. He found that out of 14 insecticides tested, carbofuran, mephosfolan, disulfoton and phorate gave effective control of the two pests resulting in better grain and fodder yields. As compared to carbofuran, mephosfolan gave better control of the stem borer but it was relatively less effective against shoot fly. The maximum grain yield of 74.82 q/ha was obtained from mephosfolan treated plots.
Chatterjee et al. (1972) studied the efficacy of seven insecticides, including mephosfolan and carbofuran granules, against the stem borer on maize. Insecticides were applied at the rate of 2 kg a.i./ha in the soil as side dressing on 15 and 30 days old crop. The plots treated with mephosfolan and carbofuran showed significantly less damage.

Marwaha (1973) studied relative efficacy of the laboratory prepared granular formulations of different insecticides by using 4 diluents and 2 binders. The granules were prepared by different methods and applied on maize crop against Chilo partellus. The granules were applied by two methods viz., side dressing of 10.0 per cent granules at the rate of 1.875 kg a.i./ha in the soil on 16 days old crop and 2.0 per cent granules at the rate of 0.30 kg a.i./ha in the whorls of 15 days and 28 days old crop. All the laboratory prepared granules and the commercial formulation of mephosfolan granules showed significantly less borer injury than the control. In the case of granules applied in whorls on 15 days old crop, mephosfolan based on bentonite proved to be more effective.

Jotwani and Prem Kishore (1973) conducted a trial to evaluate the relative efficacy of granular formulation of endosulfan, carbaryl + lindane and fenitrothion for the control of stem borer. Out of three insecticides tried, fenitrothion proved to be much less effective than the other two, while endosulfan was better than carbaryl +
lindane. The grain yield (Q/ha) was maximum in endosulfan treated plots followed by carbaryl + lindane and fenitrothion.

Venugopal et al. (1975) reported that two applications of four per cent Sevidol (carbaryl + lindane) granules were effective for controlling the borer. Kulkarni and Jotwani (1976) conducted trials on borer control at Bharwad. They used granules of four insecticides viz., Sevidol (carbaryl + lindane), endosulfan, carbofuran and quinalphos. The granules were applied in the leaf whorls at 5 and 7.5 kg/ha on 25th and 35th day of germination. All the insecticides gave satisfactory control of stem borer. The loss of grain yield due to borer damage was found to range from 12.56 to 42.02 per cent and the increase in yield due to borer control in the insecticidal treatments ranged from 14.36 to 72.48 per cent.

Sethu et al. (1977) found that 2 to 3 applications of dust of 4 per cent endosulfan gave better control of borer than the dusts of 10 per cent DHC, 10 per cent carbaryl, 5 per cent malathion and 2 per cent phenthroate.

Sadakathulla and Mani (1976) tested six different insecticides as dust and compared them with standard carbofuran 3G and untreated check. They found that 2 per cent phenthroate dust and 4 per cent phosalone dust effectively controlled the borer but their efficacy was relatively less than carbofuran 3G.
Sadakuthulla et al. (1976) reported that carbofuran 3G treatment was significantly superior to micro granular formulation of fenitrothion, dimethoate formulations and six different insecticides used as dust.

Vaishampayan and Veda (1976) evaluated nine insecticides for the control of stem borer applied at the rate of 1.5 kg a.i./ha at 5 weeks after germination. Endosulfan 4G proved to be highly effective treatment while fenitrothion 0.05 per cent and monocrotophos 0.05 per cent spray were found to be highly and moderately phytotoxic to plants.

Jotwani (1979) reported that effective control of borer can be obtained by giving 2 applications of endosulfan 4 per cent or carbaryl 4 per cent or lindane 2 per cent or BHC 6 per cent granules in areas where borer causes serious damage.

6 CULTURAL CONTROL

Lefroy (1906) reported that large number of borer larvae remained inside the stems during ripening period of crop. After the grain was harvested the caterpillars remained in the dry stems and especially in the stumps which were left in the field. The caterpillars hibernated during the cold and dry weather in the sorghum stems and stubbles. Fletcher (1919) observed that the seasonal history of this pest was most irregular. Many larvae were found resting in May and July. Trehan and
Butani (1949) reported that in sorghum 86 per cent larvae hibernate in stems and 12 per cent in stubbles. Singh et al. (1975) stated that borer is active from March to November and over winters as larvae in stalks, cobs and stubbles of maize, sorghum and some grasses. Taley and Thakare (1977 and 1978) reported that traditional storage of sorghum stalks is a main source of carry over of the borer from one season to next season in Maharashtra. Chundurwar (1978) also studied the role of sorghum stubbles in carry over of the stem borer.

Prior to insecticidal era, Lefroy (1906) recommended ploughing of the land after the harvest to bury the stubbles; undertaking timely cultural operations to keep the pest under check, exposure of the jowar stalks and stubbles to sun rays for killing the hibernating larvae, storing the stalks in storage structures well plastered with cowdung and mud during winter, chaffing the stalks into small pieces and feeding it to cattle and destroying the dead hearts at the time of thinning. Trehan and Butani (1949) reported that stubbles buried at 3" (12-13 cm) depth resulted in 100 per cent mortality of the larvae after about 6 weeks, whereas at shallower depths, a relatively longer time was required. Various research workers (Fletcher, 1914; 1918; AyyarRamanavrama, 1940; Kadam and Patel, 1955 and Nayar et al., 1979) have recommended the use of increased seed rate in areas where the pest is of regular occurrence.
Fletcher (1914) recommended the use of light traps for the control of maize and sorghum stem borer in the field. Troyan and Butani (1949) used 250 candle power petromax lamp in the field to collect *Chilo zonellus* moths but this yielded no results. Narayanan (1953) also recommended setting up of light traps to attract the moths of *Chilo zonellus* in the case of severe infestation. Fletcher (1919) and Rahman (1944) reported that the pest is positively phototropic.

Laxminarayana and Rao (1975) studied the relative incidence of stem borer on 146, 392, 926 and CSII-5 sown in plots under different levels of nitrogen fertilization (0, 40, 60 and 120 kg N/ha). The data revealed that there were significant differences between the varieties with reference to percentage of dead hearts and leaf injury.

Relative incidence of stem borer under different levels of nitrogen on CSII-1 sorghum was undertaken by Shrivpleja et al. (1976). The doses of nitrogen were 0, 10, 20 and 30 kg N/ha. The data revealed that plots with 20 kg N/ha had fewer (3.10%) dead hearts caused by stem borer than those fertilized with 0 or 10 or 30 kg N/ha.

Starks et al. (1971) from their studies on the influence of soil fertility (levels of nitrogen and phosphorous fertilizer) on the damage caused by *Chilo zonellus* to grain sorghum concluded that both fertilizers contributed to increased yield of grain, but borer prevented a maximum response to soil fertility.
BILOGICAL CONTROL

Considerable emphasis has been laid to utilize potential of biological agents in the control of stem borer (Sharma et al., 1966; Milner, 1967). Fletcher (1919) observed hymenopterous (including chalcid, braconida and ichneumonida) and dipterous parasites attacking Chilo. Carabid grubs (species of Chlaenius) were also observed preying upon the larvae in affected stems. AyyarRamakrishna (1940) observed two parasites on sorghum stem borer viz., red and black braconid, Microbracon chilocid parasitoid, and large ichneumonid, Xanthopimpla orator. Trehan and Butani (1949) reported Stenobracon daseae Cam. and Stenobracon nicavillei. Bingham emerging during winter from infested stems and stubbles and Xanthopimpla orator and Xanthopimpla aurata Cam., as pupal parasites. Butani (1957) observed tachanid flies and phorid flies parasitising Chilo zonellus in the then Bombay State (Maharashtra).

Sharma et al. (1966) have completely reviewed the information available on parasites of Chilo zonellus. A total of 35 primary and secondary parasites have been recorded from this pest of which three are dipterous and 32 hymenopterous. According to them Anacteles flaviceps seems to be the commonest primary parasite of C. zonellus in India. Katiyar (1966) recorded Staphylid larvae feeding on 3rd instar to full grown caterpillars of the borer.
Studies on bionomics and mode of over wintering of parasite *Anastelles flavipes* Cam. were undertaken by Rao *et al.* (1969) from June 1967 to March 1968. They observed that *A. flavipes* is most dominant and widely distributed parasite of *Chilo zonellus* in India and the parasite hibernates as second instar grub within hibernating *Chilo zonellus* caterpillars. It was also observed that a part of parasite population passes the winter in the cocoon stage.

Field release of five batches of *A. sesamae* Cam. was not sufficient to establish the parasite on *Chilo* population in Uganda (Starks, 1969). Verma and Bindra (1974) in their laboratory studies on *A. flavipes* and *A. chilonea* took constant number (5) of *Chilo* larvae and exposed them to variable number (1, 5, 10, 15, 20 and 25) of parasitizing females of two species of *Anastelles*. In each case parasitisation did not exceed 90 per cent unless the parasitizing females out numbered the host larvae by 4 times. The death of host occurred before the completion of development of the parasite larvae. Rao and Hamid Ali (1976) found that eggs of sorghum stem borer were parasitized by *Trichogramma* sp. Besides this, larval parasite *A. flavipes* Cam. was found to be very effective, affording 5.3 to 5.70 per cent parasitisation. *Chaeius* sp. and *Xanthopimpla* sp. were also recorded.

Nayyar *et al.* (1970); Anonymous (1975-77); Jotwani Verma (1966) and Jotwani *et al.* (1972) also given a list

Mathur *et al.* (1966) recorded a fungus *Neurospora danae* parasitic on *Chilo zonallus*. Atwal *et al.* (1973) observed mortality of *Chilo* larvae owing to the fungus *Asperillus flavus* and *Fusarium* sp.

Biological control agent *Bacillus thuriniensis* has been reported to be effective against 137 insects of different orders including Lepidoptera (Heimpel, 1967). Efficacy of granular formulation of *Bacillus thuriniensis* for the control of sorghum stem borer was studied by Jotwani *et al.* (1977-78). The treatment consisted of 2 and 3 applications of *B. thuriniensis* alone and two applications of *B. thuriniensis* followed by one application of endosulfan 4 per cent granules. All the treatments were found to be effective as compared to control.