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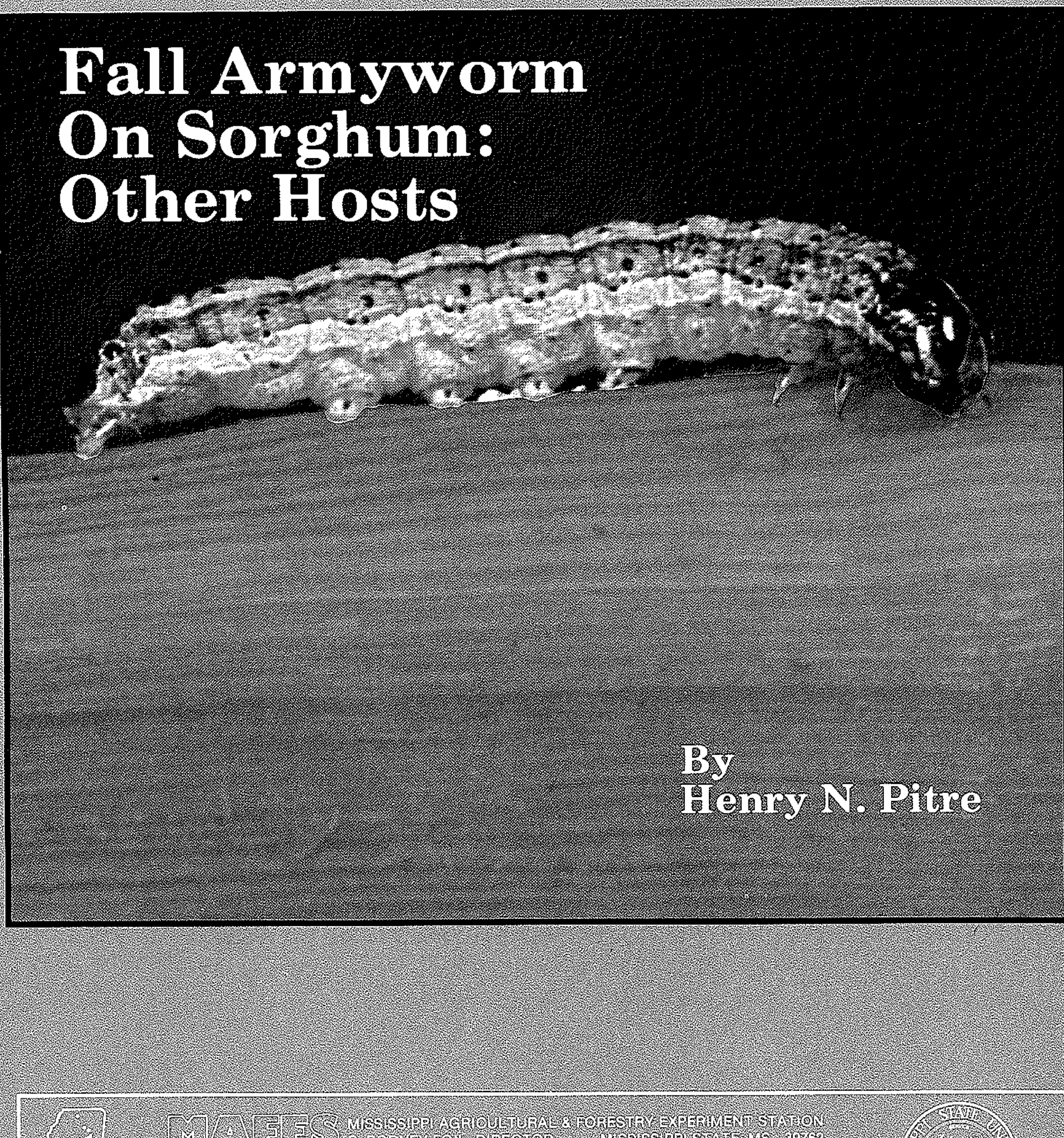

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Summary

Preferred pest management strategies for control of the fall armyworm require minimum use of pesticides to decrease the cost of production, minimize hazards of environmental contamination and protect populations of natural enemies. Recommendations for accomplishing this in sorghum are

(1) planting early to escape large late season populations,

(2) planting, if available, a variety that possesses resistance,

(3) scouting the crop frequently for early signs of fall armyworm infestations (state and federal reports of moth catches indicating armyworm activity can be useful in determining when to begin a scouting program),

(4) applying biological controls,

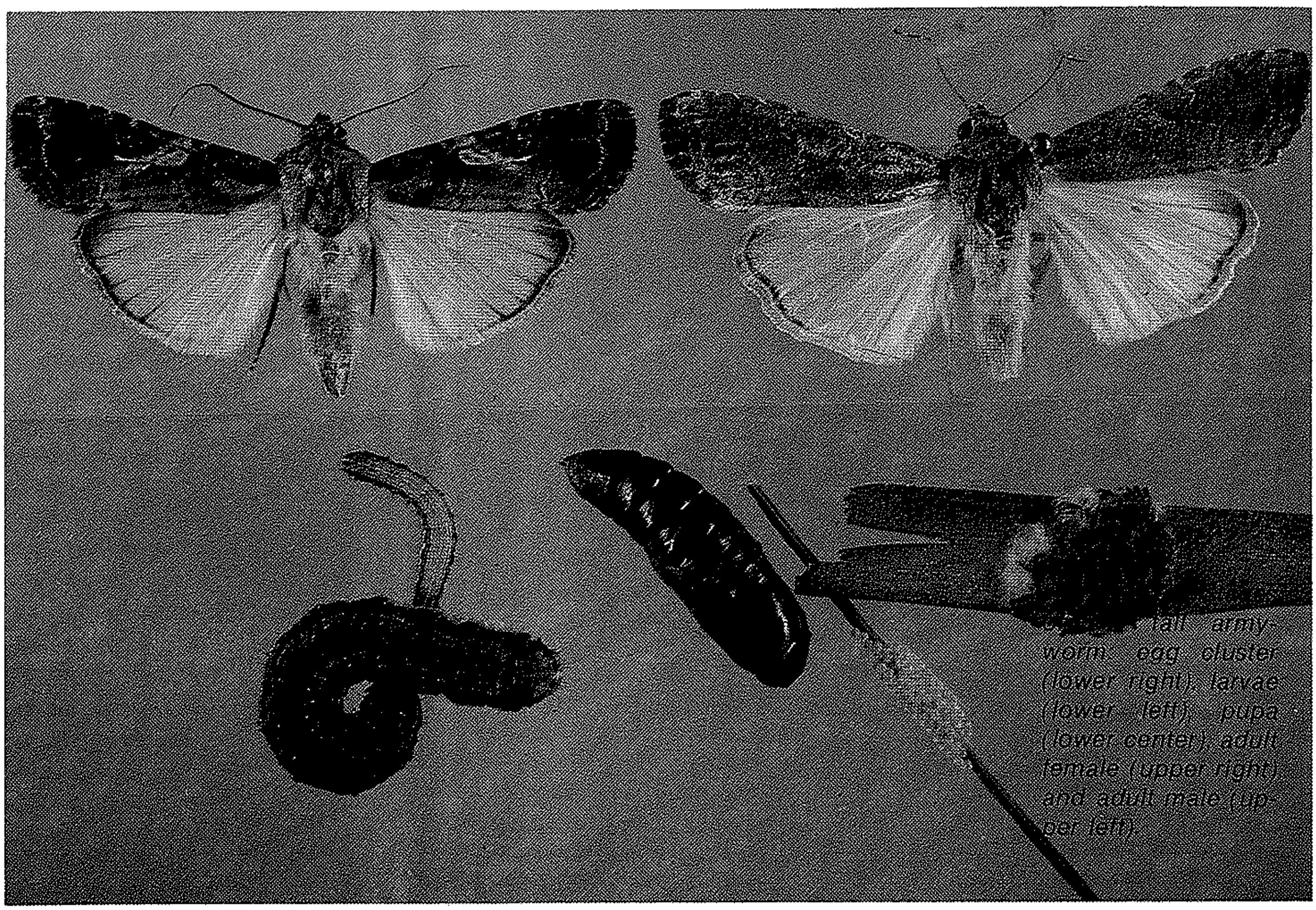
(5) applying insecticides at minimum labeled rates in enough water to obtain complete coverage, including the area deep in the whorl if leaf damage and small larvae are observed on whorl-stage plants and larvae in the whorl average one per plant (ground applications of insecticides in 5 to 10 gallons of water per acre have provided the best control on whorl-stage sorghum), and

(6) examining fields at intervals after insecticide application to determine reinfestation.

Fall Armyworm On Sorghum: Other Hosts

The fall armyworm, *Spodoptera frugiperda* (J. E. Smith), is polyphagous and feeds on both cultivated and uncultivated plants. The adult is an ash-gray moth (Figure 1). The front wings are mottled with white or gray spots near the tips, and the rear wings have a light-brown edge. Adults live two to three weeks.

Females lay eggs indiscriminately on plant foliage in masses of about 50 to several hundred deposited in layers. Eggs are covered with a grayish fuzz (scales from the female moth) and hatch in two to four days depending upon temperature.



[illegible] fall armyworm egg cluster (lower right), larvae (lower left), pupa (lower center), adult female (upper right) and adult male (upper left).

The young larva is whitish at first and has a black head. The body becomes dark with stripes as the larva grows. The fully grown larva may be 1.5 inches long and may be light green to almost black with stripes along the length of the body. The head is dark and shiny and is marked with a light-colored, inverted Y. Color patterns are highly variable within species groups (Levy and Habeck 1976).

Fall armyworm larvae feed in colonies for a short time immediately after hatching, but the small larvae soon disperse to other parts of the initial host plant, or to other plants in the area. Newly hatched larvae move upward on the leaves and usually are found on upper plant parts where they feed on the outer layer of leaf tissue (Figure 2). Young larvae often produce silk-like threads and drop by these to other plant parts. Many that drop to the ground are killed by predators or become infected by soil-inhabiting disease organisms.

Older fall armyworm larvae prefer to feed deep in the whorl of a plant. There they are protected from natural enemies, and insecticides are less effective than when applied to larvae feeding on the surface of upper leaves. However, the plant bud is damaged only occasionally by larvae feeding in the whorl.

Fall armyworms are cannabilistic and usually only one late instar larva will survive in the whorl of a plant. However, small larvae from a different egg hatch may be on the upper leaves while a large larva is in the whorl. These small larvae usually will disperse to surrounding plants, or be killed if they penetrate to where the surviving larger larva is feeding.

Development of the fall armyworm from the egg to a mature larva requires about two to three weeks. The mature larva burrows 1.0 to 2.0 inches into the soil and develops into a reddish-brown pupa that later becomes almost black. The pupal stage may last 10 to 14 days.

The pupal stage is considered to be the overwintering stage in the United States. The fall armyworm apparently cannot overwinter successfully in North America, except in southern Florida and Texas (Luginbill 1928).

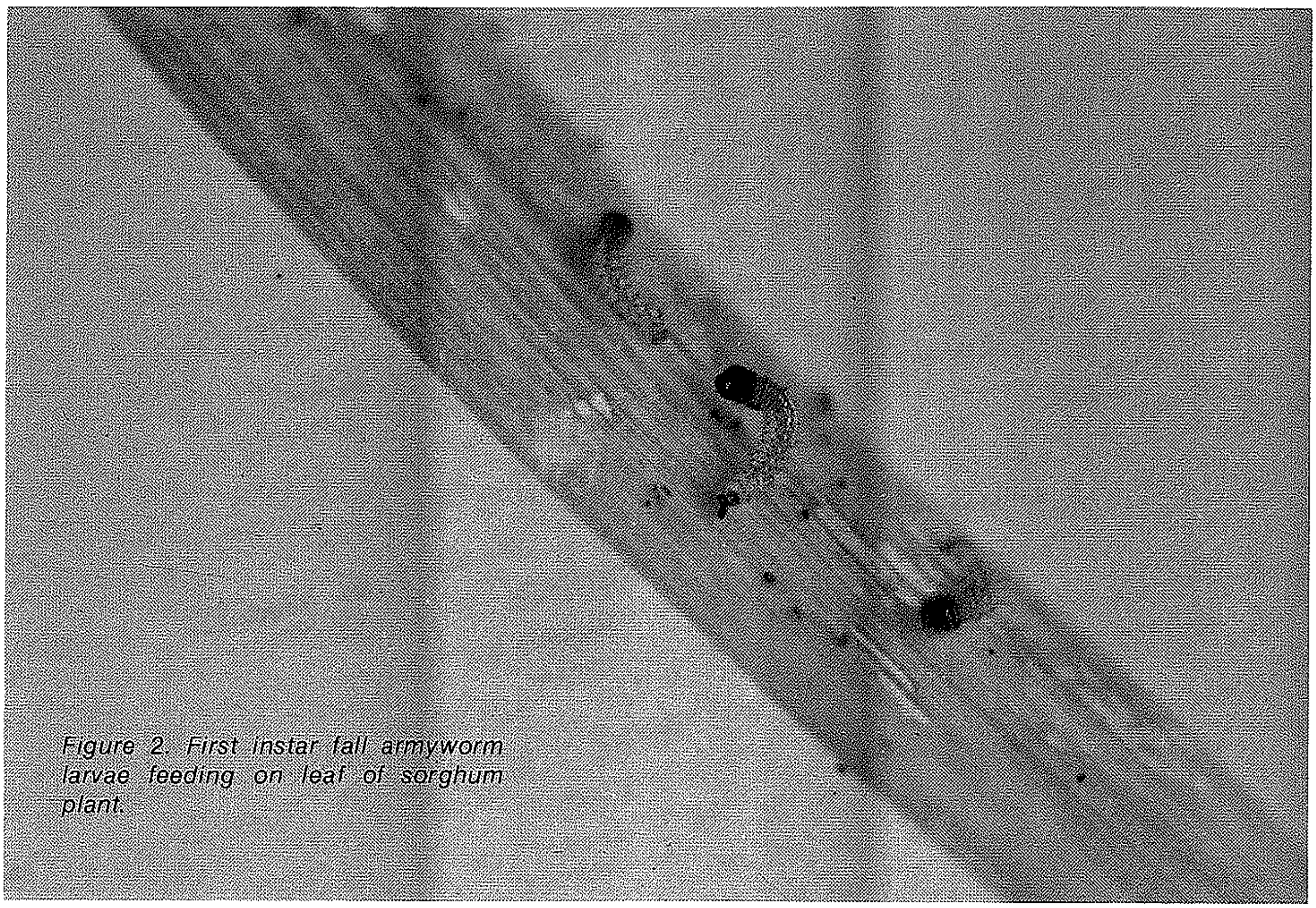


Figure 2. First instar fall armyworm larvae feeding on leaf of sorghum plant.

Figure 3. Sorghum plant damaged by fall armyworm larvae.

Economic Significance of the Fall Armyworm

Agricultural crops attacked by the fall armyworm include corn, sorghum, peanuts, sugarcane, tobacco, cotton and soybeans. Cotton is seldom damaged; however, the fall armyworm caused serious injury to this crop throughout the southeastern United States in 1977. Populations were below normal in 1978 and damage to crops was less than in 1977.

The 36,200 acres of sorghum harvested for grain and the 45,000 acres harvested for silage in Mississippi in 1977 are consistent with the declining trend in sorghum production in the state. The decline in sorghum production in Mississippi and other southeastern states where sorghum is grown can be attributed in great part to the relatively favorable prices for soybeans that have caused a substitution of soybeans for sorghum on some soil types. However, the national average grain yield of sorghum in 1977 was 2,725 lbs per acre compared with 2,074 lbs per acre in Mississippi, and the relatively low yields have contributed to the declining sorghum acreage in the state.

Diseases and insects have contributed to the declining yields, and the fall armyworm causes economic injury to the sorghum crop in some years. The armyworm must be recognized as a serious pest in Mississippi and other southeastern states because of consistently high populations in recent years.

Sorghum and other grain crops (e.g., corn, Navas 1974) can tolerate heavy feeding by the fall armyworm and similar foliage feeders. Sorghum plants are more attractive for egg laying by the armyworm moths during the first few weeks of growth than in later growth stages, and younger plant tissues appear to be most suitable as feeding sites for small larvae. Stand losses may result from heavy feeding of fall armyworms on young seedlings, and large infestations of the armyworm can result in considerable damage that causes plants to appear ragged (Figure 3).

Fall armyworms in whorl stage sorghum have been reported to be responsible for yield reductions of up to 20%. The lower yields appeared to be the result of smaller kernels, rather than fewer kernels per grain head (Henderson et al. 1966). Infestations of larger numbers of worms result in retarded plant growth. Immature heads that have not emerged from the boot may not be seriously damaged, but worms move up and feed on developing seed in the grain heads.

The purpose of this publication is to present results of research designed to develop an integrated pest management program for control of the fall armyworm on grain sorghum. Obviously, the first step in any successful pest management program is identification of the problem.

Identifying the Fall Armyworm Problem

Examination of plants should begin as soon as possible after the expected date of moth arrival in an area. Detection of egg masses is not difficult but takes time. A more practical approach is to look for feeding damage and for young larvae on the upper leaves of plants. Damage by young larvae can be detected by looking for streaks left by removal of the outer layer of leaf tissue (Figure 4). Examinations of the whole plant are required to determine the level of infestation of larvae in the whorls. This is accomplished by pulling a representative sample of plants and examining these to determine the percentage of plants infested with larvae, and the stage of development of the larvae.

Management of the pest is not as difficult when larvae are detected early as when detected at later stages after having caused considerable damage deep in the whorls. Pesticides are more effective when applied at minimum effective rates against young larvae than at the higher rates frequently required when larvae are large.

Recommendations for timing of pesticide applications in the absence of well-defined economic or treatment thresholds on whorl-stage sorghum are "control is needed when you find an average of one worm or more per plant . . . apply the insecticide when you find worms in the sorghum head."[1]

Figure 4. Damage to sorghum leaf by early instar fall armyworm larvae.

[1]*Mississippi Cooperative Extension Service Information Sheet 914. Instructions for producers interested in timing of insecticide applications on small grains are "look for very small worms around the base of plants on spring crops (March and April). Apply insecticides when 5-7 small worms are found per square foot. On fall planting, apply insecticide when you first notice ragging of leaves."*

Managing for Control of Armyworms on Sorghum

Current insect pest management concepts involve one or more practical methods for suppressing pest populations below levels that will cause economic injury to the crop. These include ecological, cultural, biological and chemical control.

Non-chemical methods for control of specific pests are available, but producers continue to rely heavily, or almost entirely in some areas, on insecticides for control of economic pests. The trend, however, is a movement away from total reliance on insecticides, by optimizing use of other strategies in combination with insecticides. For example, insecticides often are applied only after examination of the crop has revealed that pests are present at damaging levels. This procedure maximizes pest control, with minimum harm to the environment and natural enemies of economic pests. However, managing pests in diversified agroecosystems cannot be accomplished satisfactorily without the use of strategies other than observing to determine if and when insecticides are needed.

Cultural Practices

Large populations of fall armyworms in areas where they originate or in areas into which they migrate may be associated closely with cultural practices that encourage the increase of populations to damaging levels. Planting crops at the optimum time increases the probability of higher yields and minimizes the likelihood of insect populations reaching economic threshold levels. Sorghum planted in Mississippi from April 20 to May 20 usually produces higher yields than when planted at later dates, because of better germination and better growth of seedlings. Also, sorghum planted early may escape large fall armyworm population build-ups, or crop damage may be only moderate before the pest reaches peak numbers later in the year. Sorghum planted early (mid-April in the south, early May in the north) in Mississippi will escape serious fall armyworm damage, and the need for applying insecticides will be reduced or possibly eliminated.[2]

Resistant Varieties

Fall armyworm resistance in the form of antibiosis has been reported in pearl millet, *Pennisetum typhoides* (Burn.) Staph and C. E. Hubb (Leuck 1970). The major effect is suppression of the worm population resulting from reduced emergence of adult moths. McMillan and Starks (1966) reported that fall armyworm damage to sorghum differed significantly by variety.

Crop quality is improved and production costs are reduced when varieties resistant to insects are grown. Varieties with high levels of resistance are more effective for control of insects but are not always necessary, because varieties with low levels of resistance can be grown successfully with proper timing of insecticide applications. Yields are considerably higher if insecticides are applied early enough to permit plants to recover from worm damage than if application is delayed until the developing seed heads are damaged.

Fertilization and Mineral Nutrient Content of Soils

Fertilization contributes importantly to production of the lush, dark green sorghum vegetation preferred by the fall armyworm moth. Consequently, producers who fertilize at recommended or higher rates need to examine their fields carefully for evidence of early build-ups of fall armyworm populations.

The relationship of mineral nutrient content of soils to host

[2] *Pitre, H. N. (unpublished).*

plant preference of insects is not well understood. However, it appears that some minerals increase the attractiveness of plants to the fall armyworm moth, resulting in an increase in numbers of eggs laid.

Some compounds sprayed on plants have suppressed natural populations of the fall armyworm, by deterring feeding (Leuck et al. 1974). This suggests that foliar sprays of inorganic compounds (e.g., cupric sulfate and zinc sulfate) may be useful as deterrents to worm feeding and might be used in pest management programs to replace or supplement some pesticides.

Natural Enemies

The fall armyworm is exposed throughout its life cycle to disease organisms, parasites and predators (Luginbill 1928). When other control measures are not employed, populations of fall armyworms can develop to high levels if these natural enemies are absent or present in only limited numbers.

A nuclear polyhedrosis virus (Figure 5) and a fungus appear to be limiting to the development of fall armyworm populations in Mississippi during late season. All worms in a large population may be infected with the virus and/or fungus, resulting in an extremely small subsequent population.

Biological controls (e.g., nuclear polyhedrosis virus) applied to whorl-stage sorghum plants can be effective in control of young larvae, preventing damage to the grain head. Young larvae on the upper leaves are exposed and generally more susceptible; older larvae are less susceptible (Young and Hamm 1966).

Egg and larval parasites are potentially useful in managing fall armyworm populations in the field. However, the role of parasites and predators has not been defined.

Dry weather appears to be favorable for the fall armyworm but detrimental to many of its natural enemies (Carruth 1940).

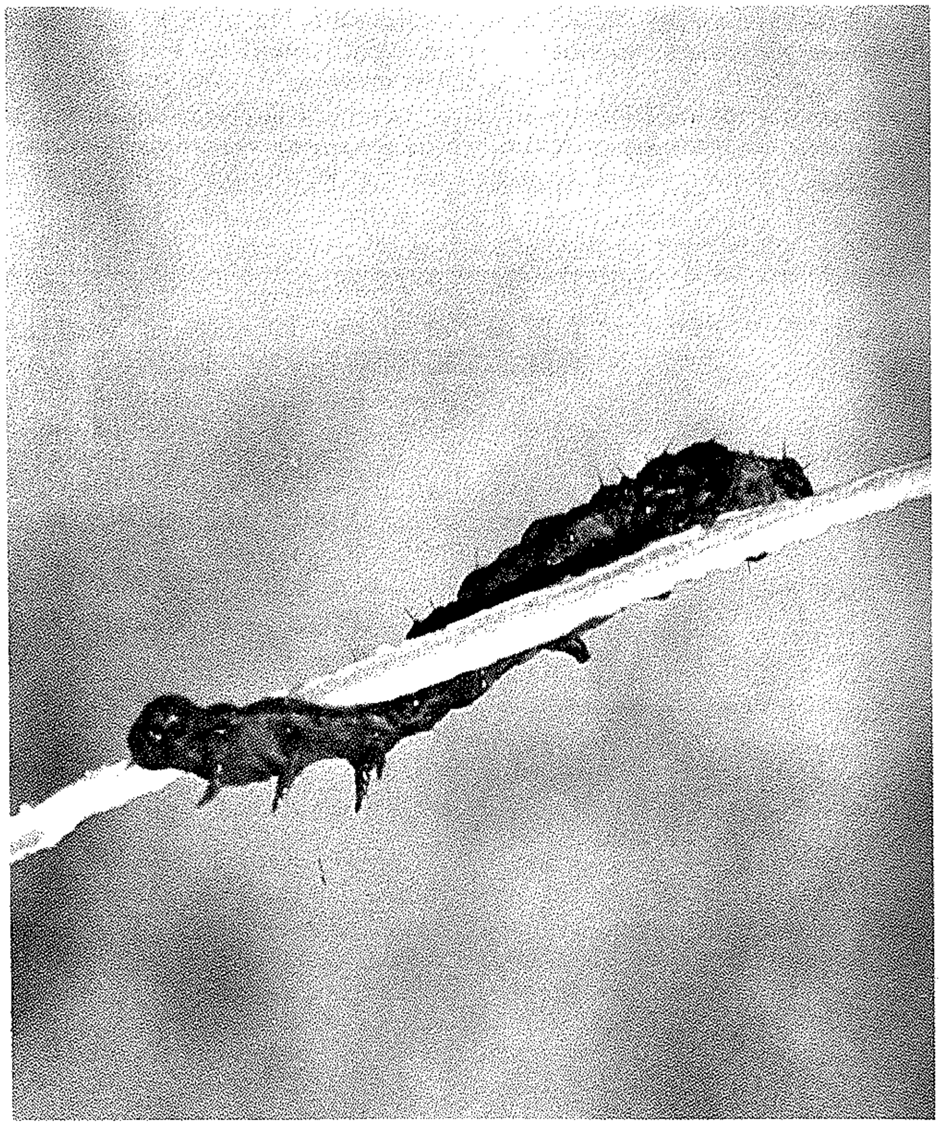


Figure 5. Fall armyworm larvae killed by virus.

Chemical Control

Control of the fall armyworm with insecticides has been considered relatively easy in the past. Nevertheless, producers frequently make more than one insecticide application.

Application of a recommended insecticide at labeled rates often is not sufficient to provide significant

Insecticide Guidelines and Restrictions
(Mississippi)

	Rate	Grazing Limitations
	(Lbs/acre)	(Days)
Sorghum, Corn, Small Grains		
carbaryl (Sevin®)	1.5-2.0	0
malathion*	1.25	7
methyl parathion**	0.75	15
toxaphene***	2.00	28
trichlorfon (Dylox®)**	0.5-1.0	21
Pasture Grasses		
carbaryl	1.50	0
ethyl parathion	0.75	15
malathion*	1.25	7
methyl parathion	0.75	15
trichlorfon	0.5-1.0	0

***No limitations on hay**
****Will burn foliage of some sorghum varieties and sorghum-sudan hybrids**
*****One application after heads are formed; not to be used on crops for silage or forage, for dairy animals or animals for slaughter; only cleared on crops for grain.**

control of the fall armyworm on sorghum and other grain crops, because the growth structure of plants and feeding behavior of the larvae often enable the insect to escape from the insecticide. Effectiveness of an insecticide application often can be related directly to the method of application and the amount of water used. This is particularly true for sorghum in the mid- to late-whorl stage, because the insecticide will not reach larvae deep in the whorl if enough water is not used.

Lannate,® toxaphene, diazion and Sevin® applied at labeled rates in 10 gallons of water per acre to 16-inch tall sorghum plants in Mississippi in 1976 effectively reduced populations of fall armyworm larvae after 24 hours (Table 1). Lannate and toxaphene applied at labeled rates in 10 gallons of water per acre to small (16-inch tall) and large (34-inch tall) whorl-stage sorghum plants in 1977 were effective after 24 hours, but Sevin at labeled rates in the same amount of water was not effective (Table 2). Lannate and toxaphene remained effective through day seven. Plant damage was about equal for all treatment plots 17 days after one insecticide application.

Pesticides applied with ground equipment usually have been more effective against fall armyworm larvae than when applied by air. The small amounts (2-3 gallons per acre) of water applied by air are not sufficient for adequate plant coverage; whereas, larger amounts (10-50 gallons per acre) applied with ground equipment have reduced infestations on whorl-stage sorghum plants.

Lorsban® applied at labeled rates in 5-10 gallons of water per acre to 21-inch tall whorl-stage sorghum

Table 1. Control of fall armyworm larvae with insecticides applied to 16-inch tall whorl-stage sorghum, by treatment, Mississippi, 1976.

Treatment[1]			Infested plants[2]	
Material	Formulation	Rate	Day 1	Day 7
		Lbs/A	--------%--------	
Lannate	1.8 EC	0.25	4 a[3]	10 a
Diazinon	4 EC	1.00	16 c	10 a
Sevin	70 S	2.00	13 bc	15 ab
Toxaphene	6 EC	2.00	8 ab	20 b
Untreated	---	---	33 d	20 b

[1]Insecticides applied on 8/13/76 in 10 gallons of water per acre, using a hand-held, compressed air sprayer at 30 psi.
[2]Days after application: Day 1 (8/14) Day 7 (8/20).
[3]Means followed by the same letter do not differ ($P < .05$) as determined by Duncan's Multiple Range Test.

Table 2. Control of fall armyworm larvae with insecticides applied to 16-inch and 34-inch tall whorl-stage sorghum, by treatment, Mississippi, 1977.

Treatment[1]			Larvae count on				Damage
			Day 1		Day 7		
Material	Formulation	Rate (lb/A)	16-inch[2]	34-inch[3]	16-inch[2]	34-inch[3]	rating[4]
			------------Number/10 Plants------------				
Lannate	1.8 EC	0.25	0.0 a[5]	0.5 a	0.1 a	0.4 ab	5
Lannate	1.8 EC	0.50	0.3 a	0.4 a	0.1 a	0.3 a	5
Sevin	80% S	1.00	3.7 c	1.1 b	0.2 a	1.2 d	6
Sevin	80% S	1.50	3.9 c	1.1 b	0.2 a	1.0 cd	6
Sevin	80% S	1.75	3.1 c	1.3 b	0.2 a	0.8 bcd	6
Sevin	80% S	2.00	1.4 b	1.3 b	0.2 a	0.9 cd	6
Toxaphene	6 EC	1.50	0.6 a	1.1 b	0.1 a	0.4 ab	6
Toxaphene	6 EC	2.00	0.5 a	0.6 ab	0.1 a	0.4 ab	6
Untreated	---	---	1.8 b	1.1 b	0.3 a	0.7 bc	6

[1]Insecticides applied on 8/2/77 in 10 gallons of water per acre, using a hand-held, compressed air sprayer at 30 psi.
[2]Avg. ht. at application = 16 inches.
[3]Avg. ht. at application = 34 inches.
[4]Rating 1 = no damage; 6 = severe damage (17 days after insecticide application).
[5]Means followed by the same letter do not differ (P < .05) as determined by Duncan's Multiple Range Test.

in Mississippi in 1977 was more effective through day seven than toxaphene applied at labeled rates in the same amount of water. Toxaphene also was generally less effective than Lorsban after 24 hours (Table 3). Increasing the volume of water from 5 to 10 gallons per acre did not change effectiveness of Lorsban; whereas the effectiveness of toxaphene was greater when applied in 10 gallons of water per acre. Toxaphene at 2.0 lbs per acre in 5 gallons of water was as effective as at the 1.0 lb per acre rate in 10 gallons of water. Toxaphene at 1.0 lbs per acre in 10 gallons of water was as effective as

Table 3. Control of fall armyworm larvae with insecticides applied to 21-inch tall whorl-stage sorghum, by treatment, Mississippi, 1977.

Treatment[1]				Infested plants[2]		
Material	Formulation	Rate	Water	Day 1	Day 2	Day 7
		Lbs/A	Gals/A	---------------%---------------		
Lorsban	4 EC	0.50	10	8 ab[3]	14 bc	7 a
Lorsban	4 EC	1.00	5	4 a	7 a	27 bc
Lorsban	4 EC	1.00	10	8 ab	6 a	22 b
Toxaphene	6 EC	1.00	5	30 d	21 d	36 de
Toxaphene	6 EC	1.00	10	14 c	23 d	41 ef
Toxaphene	6 EC	2.00	5	12 bc	19 cd	32 cd
Toxaphene	6 EC	2.00	10	16 c	13 b	45 f
Untreated	---	---	---	40 e	18 bcd	33 cd

[1]Insecticide applied on 8/20/77 using a hand-held, compressed air sprayer at 30 psi.
[2]Days after application: Day 1 (8/21), Day 2 (8/22), Day 7 (8/27).
[3]Means followed by the same letter do not differ (P < .05) as determined by Duncan's Multiple Range Test.

at the 2.0 lbs per acre rate in 10 gallons of water. Results of the trial indicate that management of the fall armyworm with insecticides can be accomplished with minimum rates of the selected material applied in 5 to 10 gallons of water per acre.

Distribution of the Fall Armyworm

Fall armyworms disperse and breed throughout the United States (Luginbill 1928). The pest is spectacular because of the apparent sudden appearance of larvae in extremely large numbers and because of excessive feeding damage by the larvae.

Distribution of the fall armyworm is limited to North, Central and South America and the West Indies. It is well known in the United States but has been recognized as an annual pest on many crops in the southeastern United States only in recent years. Previous occurrence of the pest was considered to be cyclic, and economically damaging numbers were reached only occasionally.

Migration of the Fall Armyworm

Occurrence of annual migration by the fall armyworm in North America is generally accepted. Moths may move annually into most of the southern United States from overwintering further south; e.g., south Florida, Mexico and South America. The pest does not overwinter in the northern United States, and populations that develop there probably arise from moths migrating from states in the south (Vickery 1929).

The sudden appearance of the fall armyworm in late season (early September) as far north as Sault Ste. Marie and surrounding areas in Canada is suggestive of long-range migration (Rose 1975). This migration has been found to be associated with large populations of fall armyworms in north Mississippi; i.e., moth flights originating in North Mississippi were moved north on convection winds.

Seasonal Populations of Fall Armyworms

Normally there is only one generation of the fall armyworm in the northern United States. However, there are as many as six generations in the Gulf states. The sudden disappearance of populations indicates the closeness of ages within generations and emphazises the distinctness of generations. Therefore, it is possible to distinguish one generation from another in field populations of the fall armyworm.

Fall armyworm generations also can be distinguished in most years, using moth collections as a basis for delineation. Peak catches of moths have been recorded in different months of the past five to seven years, but the general trend is for populations to increase during June and July and peak in July and/or August. However, moth populations do not always reach a single peak and then decline but may, in any one year, reach about equally high numbers in two or more months.

Flights of fall armyworm moths into Mississippi during June and/or July have been reported consistently. Records of these flights are consistent with the literature on proposed migration of the pest into the Gulf states and are substantiated by the appearance of larvae at successively later dates from south to north. A reasonable assumption is that numbers of larvae on susceptible hosts in an area increase, in the absence of regulating factors, as

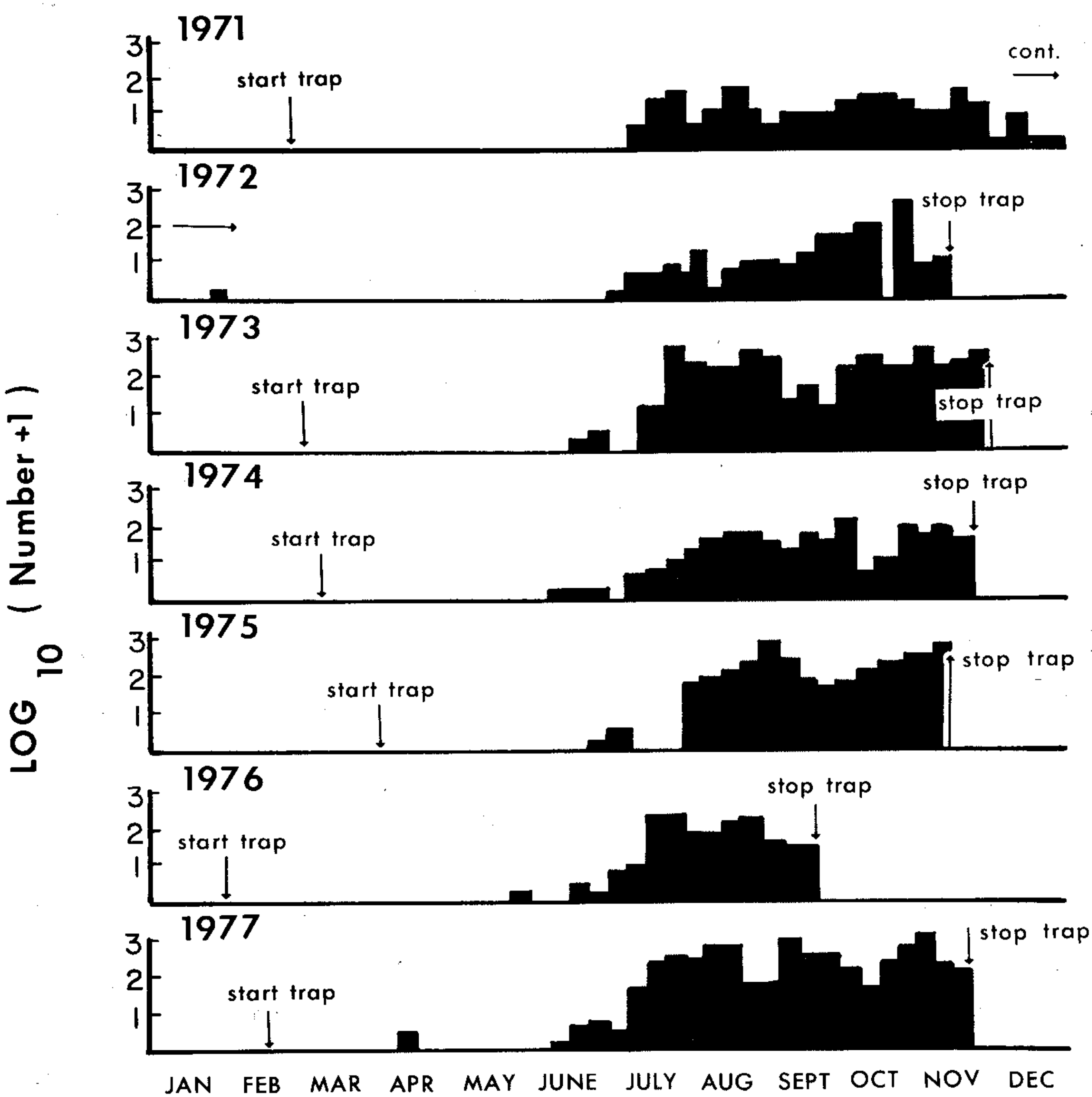


Figure 6. Fall armyworm light trap catches. Stoneville, Miss. 1971 - 77.

T.R. Pfrimmer U.S.D.A., B.I.C.L., Stoneville, MS.

moth populations increase in the area. Populations of fall armyworm larvae in south Mississippi normally reach damaging levels earlier than in central and north Mississippi.

Populations of fall armyworm larvae may not always parallel populations of adult moths. Natural enemies and diseases play an important role in suppressing larval populations, and a favorable environment for these biological control agents can result in the natural decline of the pest. The high infestations of larvae recorded in Mississippi during August and September in 1977 showed a sharp decline during October, principally because of diseases.

Unusually early arrival of fall armyworm moths can be expected to lead to early establishment of larval populations that year, giving the pest the potential of reaching higher populations earlier than if moths arrive later in the growing season. Several moths were collected at Stoneville, Miss. in late January 1972 but not again until early July. The few moths collected in January may have represented early migrants from areas south of Mississippi, and moths collected that early would not be expected to survive in most years because of low temperatures.

The earliest detection of fall armyworm moths at Stoneville in the last five years was in 1977, when moths were taken in light traps during the first week of April (Figure 6). Larval populations in Mississippi were established early that year, the population reached high levels earlier than in previous years when the first moths arrived later, and populations remained at damaging levels longer, with peak moth activity recorded in November.

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Mississippi State University