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13

Insect, Mite, and Nematode Pests of Oat

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Various arthropods and nematodes cause damage to oat (*Avena sativa* L. and *A. byzantina* K. Koch.) plants throughout their life. No stage is free from damage. Crops can be affected from the seedling stage until the grain is harvested. Pests of oat are either polyphagous (damaging a wide range of plants) or oligophagous (feeding on only a few plant species). Few, if any pests, are truly specific to oat crops.

The presence of various pest species in oat fields does not necessarily imply that yield reduction will result. Hundreds of arthropod species feed on oat cultivated in the USA and other countries. Low infestations of certain pests in cereals may stimulate growth and tillers, and actually increase yields (Southwood & Norton, 1973). The population density of a particular pest species at which economic damage will occur is termed the *economic injury level*. This level is a quantitative indicator useful in control strategies. The economic injury level, however, needs to be accurately determined for each pest species and such determinations are complicated by factors such as plant genotype, growth stage, growth conditions, the market price of the commodity, and the cost of the control.

Only a few oat pests are key pests, that is, those that cause yield loss nearly every year over a large geographical area (Young & Teetes, 1977). Examples of such pests are the greenbug [*Schizaphis graminum* (Rondani)], the chinch bug [*Blissus leucopterus leucopterus* (Say)], and the cereal cyst nematode (*Heterodera avenae* (Wollenweber)]. Most oat pests are only occasional pests and cause economic damage sporadically when climatic conditions are favorable for outbreaks. Examples of occasional pests in the USA are the armyworm [*Pseudaletia unipuncta* (Haworth)], cutworms [*Agrotis orthogonia* Morrison, *Apamea amputatrix* (Fitch), *Chorizagrotis auxiliaris* (Grote), *Crymodes devastator* (Brace), *Euxoa ochrogaster* (Guenée), *Peridroma margaritosa* (Haw.)], cereal leaf beetle (*Oulema melanopus* L.), and grasshoppers [*Melanoplus* spp. and *Schistocerca americana* (Drury)]. Secondary

pests are those that are present, but normally do not cause economic damage unless the agroecosystem is upset. Mites [*Penthaleus major* (Dugès), *Petrobia latens* (Müller), and *Oligonychus pratensis* (Banks)], which are present in undamaging numbers may, for example, reach an economic injury level after the use of insecticides eliminates their natural enemies.

For this chapter, the most important insect, mite, and nematode pests of oat occurring in North America will be discussed. Information on oat pests in other countries has been included. Two insect pests have entered the USA since Dahms (1961) wrote his chapter on oat pests for the previous oat monograph in the Agronomy series. The cereal leaf beetle was identified in 1962, and the Russian wheat aphid [*Diuraphis noxia* (Mordvilko)] was detected in 1986. In addition to the pests discussed here the reader should consult both Dahms (1961) and Hatchett et al. (1987). The latter chapter includes wheat (*Triticum aestivum* L.) insects, but many wheat pests cause damage to many graminaceous plants. Postharvest pests will not be discussed, although oat in storage and processed oat (steel-cut or rolled groats) are infested by pests of stored grains.

13-1 FOLIAGE PESTS

Insects of the foliage and those that cause damage aboveground include some of the most important oat pests. Some consume the leaves, panicles, and stems, while others suck sap from the plants.

13-1.1 Aphids (Homoptera: Aphididae)

Pests that puncture plant tissues and feed on cells or phloem sap are among the most destructive. In addition to the damage caused by their direct feeding, they can elicit toxic responses in the host plant and inoculate the plant with disease agents such as viruses. Often these pests are small and reproduce rapidly (Araya et al., 1986).

Insects of the family Aphididae are among the most important oat pests from an economic viewpoint. They are small, delicate insects with piercing and sucking mouthparts and often complex life cycles. The largest species are not more than 5.5-mm long. Many winged (alate) and wingless (apterous) individuals can occur at the same time. Antennae and legs are generally long and most aphids have a pair of tubes (cornicles) involved in secretion projecting upward and backward from the dorsal surface of the abdomen.

Much variation can be found in the biology of aphids; however, there are certain general facts that apply to the entire group. Aphids usually reproduce asexually by parthenogenesis and give birth to living young (viviparous reproduction). In southern states, sexual forms, such as males, sexual females, and eggs, often do not occur. In northern regions, aphids reproduce in the spring and summer as they do in the warmer climates. But with most species, a sexual generation with males and females appears in

the fall. These mate and the females lay a few dark, shining eggs that overwinter and hatch the following spring.

In general, wingless individuals are found when the food supply is adequate and no overcrowding occurs. With deterioration of the host plant or overcrowding, winged forms develop that migrate to other plants. Most aphids are usually restricted in their host plants, feeding on a group of related plants. Some species, however, have alternate hosts on which they are found at different seasons.

Aphids have a high reproductive potential. Many species may complete 20 or more generations a year with each adult female producing 50 to 100 young (nymphs). Normally, aphid populations are held back by natural factors such as adverse weather (i.e., low temperature), predators and parasites, and various disease agents.

13-1.1.1 Aphid Species Damaging Oat

Several aphid species may damage oat plants (Araya et al., 1986); however, the greenbug is the most destructive. Other aphids often found in oat fields in the USA are the English grain aphid [*Sitobion avenae* (Fabricius)], the bird cherry-oat aphid [*Rhopalosiphum padi* (L.)], the corn leaf aphid [*R. maidis* (Fitch)], the rose grain aphid [*Metopolophium dirhodum* (Walker)], (Little, 1972; Araya & Foster, 1983), and the Russian wheat aphid (RWA) [*Diuraphis noxia* (Mordvilko)] since 1986 (Araya et al., 1990). The primary host plants of all of these aphids are cereals and other Gramineae; however, the primary host plants of the bird cherry-oat aphid are bird cherry trees (*Prunus* spp.) and secondary host plants are cereals [oat, wheat, and barley (*Hordeum vulgare* L.)] and grasses. Because of the importance of the greenbug and RWA, this chapter provides more detailed information on them than on other aphids affecting oat crops.

13-1.1.1.1 Greenbug. The greenbug is probably native from Europe and was first described from Italy in 1852. It occurs in Europe; Asia; Africa, and North, Central, and South America. The English grain and the bird cherry-oat aphids are found throughout the USA and Europe and often become abundant on cereal crops. Although these aphids cause less direct feeding damage than greenbugs, they are important as vectors of barley yellow dwarf virus (BYDV), which is the most widespread and damaging virus of cereals.

Some damage from the greenbug occurs every year and several severe outbreaks have occurred since 1882 when it was first reported in the USA from Virginia (Fenton & Dahms, 1951a, b). Atkins and Dahms (1945) estimated the loss in oat in the 1942 outbreak at almost 624 000 t in Texas and Oklahoma alone. The average yearly loss in cereals due to greenbug infestation as reported by the USDA-ARS is 4 to 10%.

Winged greenbugs are distinguished from other aphids infesting oat by the presence of a single-branched media vein in the forewing. The English grain aphid and the bird cherry-oat aphid have the media vein with two branches. The body of the bird cherry-oat aphid is olive green to almost black with distinct blotches around the base of the cornicles, while the English grain aphid usually has a green body (that can also be reddish brown) (Araya

& Foster, 1983). Since the greenbug also has a green body, the wingless aphids are sometimes confused with the English grain aphid; however, the cornicles are entirely black in the English grain aphid and only tipped with black in the greenbug. The adult greenbug usually has a clear dark green stripe along the back that is not present in any other aphid infesting oat.

Sexual forms of the greenbug occur north of central Kansas. The egg-laying female is from 2- to 2.25-mm long and yellowish green. The males are also yellowish green, but only 1.3-mm long. The eggs are broadly elliptical, pale yellow when first laid, changing to green and later to black. Stem mothers, or those derived from the overwintered eggs are clay-yellow, greenish yellow, or apple-green.¹ Sexual forms of the English grain aphid occur north of the 35th parallel and at high altitudes further south. The males are a deep pink and the oviparous females yellowish (Phillips, 1916).

In the northern states, sexual forms of the bird cherry-oat aphid lay pale-green eggs that later change to a glossy black. The males are similar to the viviparous females, except that they are smaller and the body is dusky green. The oviparous female is pale yellowish green often with an orange tint. Rather conspicuous orange or reddish areas are present on the abdomen at the base of the cornicles (Davis, 1914).

Aphids that do not go through a sexual cycle, but overwinter viviparously are often not well protected against cold conditions, and are likely to suffer a much higher mortality in severe winters than are species that produce overwintering eggs (Dixon, 1985). Thus, the number of cereal aphids flying in early summer is correlated with the severity of the previous winter, as observed for the English grain (Dixon, 1985) and bird cherry-oat aphids (Leather, 1981) in England.

13-1.1.1.2 Russian Wheat Aphid. The RWA is a major cereal pest indigenous to southern Russia, USSR (Commonwealth of Independent States) (Grossheim, 1914; Rushowsky, 1914; Walters, 1984), where it has been a pest of wheat and barley since 1900 (Durr, 1982; Walters, 1984). It is present in Iran, Afghanistan, the Yemen Arab Republic, and the countries bordering the Mediterranean Sea (Alfaro, 1947; Stary & Erdelen, 1982; Araya et al., 1990), South Africa (Walters et al., 1984), Mexico (Gilchrist et al., 1984), and Chile (Zerené et al., 1988). The RWA was first collected in the USA in the Muleshoe area of Bailey County, Texas in late March 1986 (Valiulis, 1986). Now, it is found throughout the western USA, and southern parts of British Columbia, Alberta, and Saskatchewan, Canada (Araya et al., 1990). This insect is capable of traveling many miles by using air currents (Walters et al., 1984). Strong prevailing winds may have enabled winged specimens to cross the drylands of northern Mexico and enter Texas or New Mexico in the USA (Fereses et al., 1986).

The RWA is a small green aphid with an elongated body that can be easily distinguished by a prominent supra-caudal process that gives it a double-tail appearance. A summary of the taxonomic characteristics of the RWA

¹ Further details of the biology of the greenbug are provided in section 13-1.1.2 (pages 434-436).

and key for identification have been given by Stoetzel (1987). It has short antennae, and small, globular cornicles (Mier Durante & Nieto Nafria, 1974; Araya et al., 1990). Winged forms have black heads and thorax (Ilharco et al., 1982).

The preferred feeding site of the RWA is the base of the leaf. The feeding action of the aphids curls the borders of the leaves (Stary & Erdelen, 1982; Fouché et al., 1984), forming a protected microenvironment for the colonies (Erdelen, 1981). As the host plant matures, the RWA migrates upwards and eventually colonizes the upper leaves (Kriel et al., 1984) and heads (Alfaro, 1947), where they can be found under the glumes living directly on the forming grains. This protected habitat enables the RWA to survive and reproduce under dry weather conditions, similarly to the corn leaf aphid. For example, the RWA is capable of surviving in many arid localities of the Yemen Arab Republic with relative humidity under 20% during daytime (Stary & Erdelen, 1982).

The development of winged females depends on environmental conditions and the physiological stage of the host plant. Alates are produced under adverse environmental conditions and when the food supply becomes unsuitable for aphid development (Walters et al., 1984). Data from central Spain indicate that the RWA is present on wheat particularly in very dry years (Castañera & Gutiérrez, 1985). To date, the RWA has been capable of surviving the summer in most of the wheat-growing areas where it has been detected in the USA, living on grasses (Kindler & Springer, 1989) and volunteer wheat plants as alternate hosts.

An important consideration is the overwintering capability of the RWA in the USA. Studies in central Spain indicate that this insect survives winter temperatures down to -10°C (A. Fereres, INIA, Spain, 1988, personal communication). Thus, the RWA may be able to survive the winter in many U.S. areas.

Wheat, barley, and oat appear to be the major hosts of the RWA in the USA, although it can also damage sorghum [*Sorghum bicolor* (L.) Moench] and triticale ($\times$ *Triticosecale* Wittmack). Rye (*Secale cereale* L.) appears to be a less preferred plant host. Feeding action of the RWA causes longitudinal chlorotic (white, yellow, and purple) streaks and a convolute curling of the leaves, severely affecting yields (Alfaro, 1947; Stary & Erdelen, 1982; Walters et al., 1980; Pakendorf, 1984; Du Toit, 1986). Damage was initially thought to be caused by a toxin injected during the feeding process (Hewitt et al., 1984; Walters et al., 1984). The RWA causes a severe water imbalance on the affected plants, instead of being affected by such a toxin as with the greenbug (J. Burd, 1989, personal communication). Plants infested with RWA for short periods recover after these aphids have been removed. Under field conditions in South Africa, the RWA reportedly has caused yield losses as high as 35 to 60% in winter wheat (Du Toit & Walters, 1984). The RWA is capable of transmitting brome mosaic virus (BMV) and the *R. padi* virus (RhPV) affecting colonies of this aphid (Rybicki & von Wechmar, 1982), but cannot transmit barley yellow dwarf virus (Araya et al., 1990).

13-1.1.1.2.1 *Biological Control of the Russian Wheat Aphid*

Biological control agents of the RWA have been studied by Aalbersberg et al. (1984). The parasitoid *Aphidius colemani* (*A. platensis* Brethes, Hymenoptera: Aphidiidae) and the ladybird beetle *Adonia variegata* (Goeze) (Coleoptera: Coccinellidae) are the species most frequently observed controlling the RWA naturally in South Africa. The RWA parasitized by *A. colemani*, a species probably of Indian origin (Stary, 1972), die forming characteristic brown mummies from which the adult parasitoids emerge. This hymenopteran has been accidentally and purposely spread over a wide area including South America, Africa, Israel, and Australia. It has a wide host range of aphid species and, therefore, is not entirely dependent on, and hence not affected by, the population dynamics of just one or a few host species. Stary and Erdelen (1982) led the analysis of climatic conditions, parasitoid habitats, and host range to conclude that the Yemen Arab Republic could be a promising place for collection and exportation of *A. colemani*. Another parasitoid affecting the RWA in Spain is *Diaeretiella rapae* (McIntosh) (Castañera & Santiago, 1983).

Other beneficial insects are the coccinellids *Scymnus moreletii* Mulsant, which has been observed occasionally searching for prey within rolled-up infested wheat leaves, *Lioadalia flavomaculata* (De Geer), *Exochomus concavus* Fürsch, and *Cheilomenes lunata* (F.). Much more research is necessary to determine the roles natural and imported predators play in the regulation of RWA numbers; ways of enhancing predation of this insect could then be proposed (Aalbersberg et al., 1984).

13-1.1.1.2.2 *Cultural Control of the Russian Wheat Aphid*

Volunteer wheat plants and *Agrotriticum* (*Agropyron* × *Triticum*) serve in South Africa as important alternate hosts to ensure enough aphids to survive summer and fall for infestation of cereal fields in the following season. Cultural control measures such as the elimination of volunteer cereals should be considered. In South Africa, late-planted winter wheat reportedly escapes large infestations (Walters et al., 1984).

13-1.1.1.2.3 *Chemical Control of the Russian Wheat Aphid*

Systemic insecticides are recommended for control of the RWA. As this insect lives inside the leaf sheaths and is protected by the curled leaves, contact insecticides are not effective. Mixing contact and systemic insecticides has reportedly resulted in effective control (Botha, 1984; Valiulis, 1986).

The colonization of the flag leaf by the RWA can be inhibited and significant yield losses prevented when applying chemical control to field plants having the first node visible. An infestation of 5.5% of plants at Feekes growth stage 6.0 (Large, 1954) for a yield expectation of 2.5 t ha⁻¹ justified economically a single insecticide spray in South Africa (Du Toit & Walters, 1984). Du Toit (1986) calculated an economic threshold of 4 to 7% infested plants at growth stage 31 of the Zadoks scale (first node visible; Tott-

man et al., 1979), and economic injury levels (EILs) of 14% infested plants at growth stage 59 (plants with the heads completely visible).

13-1.1.1.2.4 Plant Resistance to the Russian Wheat Aphid

Soon after the detection of the RWA in Texas, plant resistance studies were started in the USA (Webster & Burton, 1987; Webster et al., 1987, 1989a, b). Screening for resistance to the RWA in artificial environments has been difficult because visible damage symptoms can occur independently, and the sequence of damage events is further confounded by apparent environmental interactions. Consequently, traditional screening techniques, that are based on monogenic damage scenarios, have failed to give consistent results. Therefore, studies focusing on the basic nature of RWA damage have been conducted to provide a better understanding of the plant response to facilitate the development of a more precise damage evaluation system (J.D. Burd, R.L. Burton, and J.A. Webster. 1989. Plant damage caused by Russian wheat aphid feeding. *In* Third Russian Wheat Aphid Conf., Albuquerque, NM. 25-27 Oct.). Plant damage rating schemes have been widely used to evaluate host plant resistance. Rating scales typically range from 1 (no damage) to 9 (dead plant), with intermediate ratings corresponding to incremental levels of visible symptoms.

Burd et al. (1989) used plant lines previously tested as resistant or susceptible to compare rating system results with specific plant growth characteristics. Entries evaluated included oat (resistant), triticale (resistant and susceptible), and wheat (resistant and susceptible). In addition to the visible damage rating, plant stunting and leaf rolling ratings were made. Plant components quantitatively measured were tiller and leaf development, total leaf area, and total leaf length. Results of the leaf rolling and 1 to 9 damage ratings were consistent with those obtained from the initial screening tests in greenhouse flats. However, plant ratings for stunting indicated that both oat and resistant wheat entries suffered significant reductions in shoot development. Analysis of plant growth components revealed substantial differences between infested and control plants for all entries except the resistant triticale. Clearly, traditional damage rating schemes were adequate for identifying susceptible entries but performed poorly in measuring intermediate damage. Of the three rating systems used, plant stunting best predicted the quantitative damage responses.

Populations of the RWA can be reared on synthetic diets for as many as six generations (Klingauf & de Coll, 1982). Such diets might be useful in future plant resistance studies.

It is interesting that the RWA in Mediterranean countries, such as Spain, is seldom a serious pest of small grains (Castañera & Gutiérrez, 1982). Some workers suspect that the serious infestations in the USA may be due to the development of an aggressive RWA biotype. Genetic variability, as Bush et al. (1989) observed, may certainly promote the development of insect biotypes, as it has occurred for other aphids, like the greenbug and corn leaf aphid.

Host suitability and harboring of RWA by grain cereals and grasses were evaluated by Kindler and Springer (1989). They found jointed goatgrass [*Triticum cylindricum* (Host) Ces.] to be the most suitable plant host for the RWA. Among cereals, barley and wheat were the most suitable plant hosts, and then oat and rye.

13-1.1.2 Cereal Aphid Feeding Behavior and Biology

Aphids have piercing and sucking mouthparts with four stylets that are housed in a modified lower lip or labium. The inner pair of stylets are held together by matching grooves and ridges. It encloses two canals, one for ingestion of plant sap and one for saliva secreted as the aphid probes the plant. Aphid feeding involves a sequence of actions. These actions include: (i) orientation to the host plant, (ii) examination and probing of the host plant, (iii) location of a food source within the host plant, (iv) ingestion of plant sap, and (v) reactions to and cleaning of plant sap (Pollard, 1973). Initial brief sampling probes by aphids are between epidermal cells or just into them, but most food uptake is from the phloem. Unlike leafhoppers (Homoptera: Cicadellidae) and other more robust plant-sucking insects that penetrate through cells, aphids require several minutes and sometimes hours to penetrate between plant cells to reach the phloem. Stylet penetration of plant tissues is by alternating protraction of mandibular and maxillary stylets, assisted by salivary secretions that flow from the stylet tips via the salivary canal. Salivary secretions coagulate within the plant's tissues to form a protective sheath around the stylets. The saliva is a watery fluid, and a more viscous material that forms the stylet sheath, composed mainly of protein, about 100 g kg^{-1} phospholipids and possibly some conjugated carbohydrate (Miles, 1972, 1987; Klingauf, 1987).

In addition to the general adverse effects due to withdrawal of plant sap by aphids, there may also be "toxic" effects associated with their feeding. The best known example of this type of damage is that caused by the salivary secretions of the greenbug. Greenbug stylets enter the plant tissues intercellularly and occasionally through the stomatal apparatus, with phloem usually the ultimate feeding site. Feeding results in chlorotic (yellow or reddish brownish) lesions on the plants and eventually death of susceptible plants. Chatters and Schlehner (1951) found that greenbug damage varies from lysis of cells in barley, to cell-wall modification in oat, and to a combination of the two in wheat.

Four types of injury caused by greenbugs have been described (Painter et al., 1954): (i) killing of plants in spots by greenbugs that overwinter in the field, (ii) widespread injury of plants in early spring by greenbugs that migrate from the south, (iii) yield reduction by stunting heads when greenbugs feed from the upper leaf sheath or boot, and (iv) thinning of plants and preventing tillering by late-fall feeding. First indications of the presence of greenbugs in fields are dead areas surrounded by yellowed, dying plants infested with the aphids. Plants beyond the yellowed areas may appear

healthy, but are only less heavily infested. If conditions are favorable for reproduction, entire fields may be destroyed.

Greenbugs reproduce continuously throughout the year in warmer climates except at high altitudes. At favorable temperatures, the aphids begin to reproduce when they are 6- to 16-d old. Each female gives birth to 50 to 60 young (nymphs) and there may be 20 or more generations annually. In the southern USA, during wet, cool summers, greenbugs continue to reproduce on volunteer cereals and wild grasses, moving to fall-seeded cereals soon after the plants appear aboveground. Michels (1986) has compiled an updated list of graminaceous host plants of the greenbug.

The greenbug continues to feed during much of the winter and reproduces at temperatures as low as 4°C. Little dispersal from the initial point of infestation occurs when the temperature is below 10°C. The most critical period in the life history of the greenbug is during the summer months (Daniels, 1960). Greenbugs reproduce most rapidly at 18°C. Temperatures as high as 42°C kill some of the aphids. Cool, wet summer months and warm, dry winter weather are therefore most favorable for the aphid's reproduction. A mild winter with above-normal temperatures and below-normal rainfall is favorable for reproduction, and under such conditions the greenbugs become so numerous that they kill the plants and move out in all directions to infest new hosts. Large numbers of winged aphids are produced, which fly to uninfested fields, especially in spring-sown small grains. Flights from these infested fields are usually in a northerly direction, and areas several hundred miles north of the heavily infested area may be affected (Daniels, 1977a, b).

The feeding habits on oat plants and the biology of the English grain aphid (*S. avenae*) are similar to those of the greenbug. This aphid may be associated with the greenbug in grain fields; however, when the oat panicles begin to form, many of the English grain aphids will feed on the developing kernels and cause the grain to shrivel. This type of feeding usually does not occur with the other aphid species.

The English grain aphid overwinters much the same as the greenbug. In the southern states of the USA, it reproduces parthenogenetically on small grains or grasses throughout the winter. In the northern states, sexual forms are produced and they overwinter as eggs on grass plants. In northern areas, viviparous forms of the bird cherry-oat aphid migrate to bird cherry trees (*Prunus* spp.) in the fall and give birth to wingless oviparous females. These lay overwintering eggs in the crevices of the bark or beyond the bud scales of younger twigs. In the early spring, the eggs hatch into viviparous females and as many as four generations may be produced on the bird cherries before winged forms occur. The latter fly to grain fields and grasses and reproduce during the remaining spring and summer.

The greenbug has reacted to the selection pressures caused by the use of resistant cultivars and insecticides by producing biotypes. Prior to 1968, six greenbug biotypes, designated as A, B, C, D, E, and F, had been identified, all differing in their damage to cereals (Wood, 1961, 1971; Harvey & Hackerott, 1969a, b; Wood et al., 1969; Teetes et al., 1975; Puterka et al.,

1982; Araya et al., 1989); Biotype D is closely related to biotype C, but it has as much as a 30-fold resistance to organophosphorous insecticides over biotype C (Peters et al., 1975; Teetes et al., 1975; Chang et al., 1980). In 1988, Puterka et al. (1988) reported the development of biotypes G and H.

13-1.1.3 Oat Aphid Control

Because of their rapid rate of reproduction, the adverse effects associated with their feeding, and their transmission of plant viruses, aphids can cause significant economic loss in small grains if their numbers are not kept under economic injury levels by unfavorable weather conditions and natural enemies. The development of cereal cultivars with resistance to the greenbug has been a significant step in the management of this important pest. Common oat (*A. sativa* and *A. byzantina*) until recently has been the only important cereal without greenbug resistance). Gardenhire (1964) crossed a greenbug-tolerant Russian oat line with two susceptible cultivars and described the inheritance of resistance to biotype A greenbugs as being conditioned by a single gene pair. Further, he studied the inheritance of greenbug resistance in barley (Gardenhire, 1965). The USDA oat world collection was screened by Daniels (1978), who identified two germplasm lines with resistance to biotype C. Resistance in various oat lines to biotype B and C greenbugs, two biotypes prevalent in the Great Plains of the USA, was also studied by Wilson et al. (1978). Chedester et al. (1978) and Chedester and Michels (1982) evaluated greenbug resistance in oat, and Boozaya-Angoon et al. (1981) investigated the inheritance of resistance in oat to two biotypes of the greenbug. The evaluation of resistance in research directed toward the nature of resistance and the development of cereal varieties resistant to the greenbug require careful experimental design. In this regard, Inayatullah et al. (1986) described suitable experimental designs and optimum sample sizes for greenbug antibiosis tests in environmental chambers.

A BYDV-resistant germplasm in cereals and related grasses represents an important germplasm resource for developing cereal varieties with resistance or tolerance to BYDV (Burnett et al., 1984; Gellner & Sechler, 1986). The development of cultivars with resistance or tolerance to BYDV represents the best approach to reducing losses due to this virus. An example of this is the identification of resistance to the PAV isolate of BYDV in barley controlled by one incompletely dominant gene. This gene has subsequently been moved into cultivars of barley. The inheritance of tolerance to BYDV in oat has been reviewed by McKenzie et al. (1986).

The most important natural enemies of the greenbug are lady beetles, especially *Hippodamia convergens* (Guerin-Meneville) and the hymenopterous parasitoid *Lysiphlebus testaceipes* (Cress.) (Hunter & Glen, 1909). Both adults and larvae of lady beetles will devour large numbers of aphids, but often do not occur in sufficient numbers until after damage to crops has been done. The *Lysiphlebus* parasitoid lays its eggs in the body of aphids such as the greenbug. The larvae of the parasitoid feed on the tissues of the host. Adult parasitoids emerge through holes cut in the host's cuticle. While this

parasitoid may be the most important natural enemy of the greenbug, it is not active at temperatures below 18 °C. Thus, cool spring weather is unfavorable to the reproduction of the parasitoid, but will allow the greenbug to reproduce in great numbers resulting in the destruction of large areas of grain fields. This parasitoid is also effective against the English grain and the bird cherry-oat aphids.

The deliberate use of predators and parasites as biological agents for control of the greenbug (Fenton & Dahms, 1951b) and for limiting the spread of a plant virus (Roitberg & Myers, 1978) has been unsuccessful. Under favorable weather conditions, parasites and predators are usually present in sufficient numbers to have a maximum effect on greenbug populations. If weather conditions are unfavorable, predators and parasites do not feed and reproduce effectively and the introduction of more does not increase their effect on greenbug populations. Insecticides can be used to control outbreaks of all cereal aphids when natural controls are inadequate; however, control of BYDV transmission by these aphids through the use of insecticides is unreliable.

13-1.1.4 Transmission of Barley Yellow Dwarf Virus by Aphids

Barley yellow dwarf virus is a group of luteoviruses (yellowing viruses) affecting grasses and causing yellow-dwarf disease in cereals throughout the world (Rochow & Duffus, 1981). Barley, oat, and wheat are particularly affected by BYDV. As with other luteoviruses, BYDV can only be transmitted via various species of aphids. The BYDV is circulative within the aphid vector, and is phloem restricted in the plant. The economic impact of BYDV ranges from severe yellow-dwarf diseases limiting small grains growing in some areas to chronic yield losses of 5 to 10% (Duffus, 1977). Data on BYDV infection often are difficult to obtain since infected plants do not necessarily show symptoms (Clement et al., 1986); thus, most estimates are probably too low.

Five isolates of BYDV have been described (Rochow, 1969) and are identified by using the aphid(s) that transmit them. Two of the most important aphid vectors of BYDV are the bird cherry-oat aphid and the English grain aphid. The bird cherry-oat aphid transmits the *Rhopalosiphum padi* type virus (RPV) and *padi* and *avenae* type virus (PAV) isolates, while the English grain aphid transmits the *Macrosiphum avenae* type virus (MAV) and PAV isolates. Since BYDV is phloem restricted in the host plant and inoculation of plants usually requires that aphids probe for 10 min or more, it has been proposed that an aphid must penetrate phloem tissue to inoculate a plant. Research with electronic monitoring of aphid probing/ingestion behavior has provided evidence that penetration of phloem sieve elements is required for BYDV transmission (Scheller & Shukle, 1986).

13-1.2 Leafhoppers (Homoptera: Cicadellidae)

Leafhoppers are not normally considered of major importance in small grains, but Osborn (1912, 1932), Oman (1949), and Gibson (1915) believed

that they sometimes cause appreciable grain and forage losses. They also transmit blue dwarf virus disease of oat.

Many species of leafhoppers can cause damage to oat crops. Several of them are attracted to oat fields in the late fall or early spring, when small grains are the principal green plants. Some species stay only a short time, but others are able to breed and reproduce on these crops. Many leafhoppers can be found in oat throughout the winter in the southern part of the winter oat area of the USA.

Adult leafhoppers measure from 1.3 to 6.4 mm and rarely 12.7-mm long. They are winged, but usually use their legs to move from plant to plant. Occasionally some species make large dispersal flights. The nymphs resemble the adults except that they are smaller and do not have wings.

One of the most important species damaging oat is the yellow-headed leafhopper [*Carneocephala flaviceps* (Riley)] (Osborn, 1932). This species is easily recognized by its bright yellow or orange head with two light spots on the vertex, and light green forewings; the underside of the abdomen is pale yellow and the borders of the abdomen are slightly reddish. The legs are pale yellow. This species is strongly attracted to light. It is extremely abundant in the southern part of the USA.

The tenderfoot leafhopper [*Draeculacephala mollipes* (Say)], which also infests oat, is about 7.9-mm long and slender. It has a yellowish brown, sharply pointed head and narrow, light-green wings. The pronotum has a yellow frontal margin. Hibernation occurs in all stages, but primarily in the egg stage. This species migrates at night during the summer and is also attracted to lights.

Deltocephalus inimicus (Say) is a widespread and injurious leafhopper, occurring throughout most of the central and northern USA and into Canada. The adults are 6.4-mm long, gray with dark brown or blackish markings, and pairs of black spots on the vertex, pronotum, and scutellum.

The black-faced leafhopper [*Thamnotettix nigrifrons* (Forbes)] often infests oat and is found throughout the northern and eastern USA as far south as Georgia and southwest to New Mexico. The adult has a rather short vertex and a distinct row of black spots next to the border of the upper part of the head bending down toward the eyes in front. The face is marked with numerous black bars. In the south, this leafhopper remains active until late November or early December.

The irrorate leafhopper [*Phlepsius irroratus* (Say)] occurs from the extreme north to the Gulf of Mexico and westward to the Rocky Mountains. It is nearly 12.7-mm long, and dark brown with numerous minute irrorations on the wings and head.

13-1.2.1 Leafhopper Feeding Habits and Biology

Some leafhopper species hibernate as adults, others as partly grown nymphs, and many of the grass-infesting species hibernate in the egg stage. The females lay their eggs in the margin of leaves or in a slit in the epidermis of stem or leaf. Hatching, except for hibernating eggs, takes place in a few days. Depending on the species, the nymphs pass through four or five molts

before they become adults. There are commonly two generations annually, but some species have only one while others have at least three.

Both nymphs and adults suck the sap of the plant causing the plant cells to wilt or shrivel, sometimes leaf curling, and often surface discoloration. Oat damage is most commonly noticed by blotches on the leaves or stems, often reddish in color.

13-1.2.2 Control of Leafhoppers

Osborn (1932) suggested that regular mowing of grass and weeds adjacent to small-grain fields should reduce the leafhopper damage. Chemical control of leafhoppers in oat is not usually economical except under heavy infestations.

13-1.3 The Common Chinch Bug (Hemiptera: Lygaeidae)

The common chinch bug is potentially one of the most destructive insects infesting cereals in the USA. The insect is native to North America and occurs from Central America northward to southern Canada. It was a key pest of cereal crops in the eastern part of the USA until about 1950 when damage became rare. The pest has again become a problem in eastern Texas, Oklahoma, and Kansas, on corn (*Zea mays* L.), wheat, oat, barley, and sorghum (Wilde & Morgan, 1978).

Adults are about 4-mm long, black with white wings having a triangular black area near the outer edge. Eggs are oval, about 1-mm long and cream color when first laid, but become reddish before hatching. Nymphs are reddish at first and become grayish black as they develop.

13-1.3.1 Biology of the Chinch Bug

Chinch bugs overwinter as adults in various types of cover. Clumps of grass are common sites of hibernation; however, in the southern portion of their range, many overwinter beneath the leaf sheaths of dead corn and sorghum plants. In the spring, adults emerge from hibernation and fly to fields of small grains or early corn. Females lay eggs at the base of the plants or behind the leaf sheath. Hatching of the eggs occurs in a few days.

Adults and nymphs feed on sap from host plants and cause severe injury when present in large numbers. Oat plants develop a characteristic reddish color when heavily infested. Similar symptoms occur in sorghum and have been proposed to be due to plugging of vascular tissue in the host plant or injection of a toxin (Painter, 1928). The first generation of the insect feeds on oat or other small grains until the grain ripens and then they migrate to other crops, usually corn or sorghum. Over most of the Midwest, this migration occurs before the first-generation nymphs mature; however, in Oklahoma and Texas the chinch bugs are adults by the time small grain matures and migration is by flight. Succeeding generations develop on corn or sorghum. There are two generations in the north, but usually three in the south-

west. Adults fly to overwintering areas at about the time of the first frost in the fall.

13-1.3.2 Chinch Bug Control

Wet weather is one of the most important factors in controlling chinch bug populations. Heavy, beating rains destroy many of the insects at the time of egg hatch, and wet weather also fosters outbreaks of fungal pathogens. Burning of overwintering cover appears to be a worthwhile practice when the insects are found in bunch grass, but the value of this practice is questionable in other areas. Control of chinch bugs with approved contact insecticides is somewhat difficult and may not be economically feasible. Carbaryl (1-naphthyl methylcarbamate) has been recommended as an insecticide (Kuitert & Nutter, 1952).

13-1.4 Thrips (Thysanoptera)

Many species of thrips feed on oat. The grain thrips [*Limothrips cereali-um* (Haliday)] was recorded in the USA by Hinds (1902) as early as 1898, under the name *L. avenae* Hinds. He also reported *Aeolothrips fasciatus* (L.) on oat, but this species is presumably predaceous. He described the grass thrips *Anaphothrips obscurus* (Mull.) as being 1 to 1.6 mm in length, yellow in color, with dusky or brownish shading in some parts. The eggs are reniform, 0.27- to 0.33-mm long and 0.09- to 0.15-mm wide. The nymphs are fusiform and about 1.2 mm in length when full grown.

Thrips injury to grains in Europe is known as silver-top, badhead, or white-ear. The growing points of infested plants are shriveled, malformed, or blasted, and the white, streaked, or blotched etiolated areas on the leaf blades, contrasting with the normal green tissue. However, Sheals (1950) concluded from his studies in North Wales that these symptoms are not caused by thrips.

In a summary of information on grain- and grass-infesting thrips in the USA, Bailey (1948) emphasized that more attention had been given to thrips in Europe than in the USA, but that thrips would probably become more important with an increase in grassland areas. The grain thrips has damaged oat in California. This species was reported by Zimmerman (1911) as *Thrips cerealium* on oat in Europe.

In Canada, Hewitt (1914) found sterility in oat in Saskatchewan, British Columbia, and Ottawa caused by the grass thrips [*A. obscurus* (Mull.)]. He stated that the injury was confined chiefly to the inflorescence or panicle and had no noticeable effect on the leaves. The sterile spikelets are cream colored, shriveled, thin, and usually confined to the lower part of the inflorescence, but may occasionally be scattered through the inflorescence or occupy a terminal position.

13-1.4.1 Thrips Feeding Habits and Biology

Hewitt (1914) stated that grass thrips hibernate as adults and can withstand temperatures at least as low as -45.6°C . The females become active

in the spring and oviposit over 4 to 6 wk. Each female inserts 50 to 60 eggs just under the plant epidermis. The eggs hatch in 4 to 15 d. The nymphs require 4 to 14 d to become adults, and the entire life cycle is from 12 to 30 d.

Some species of thrips occur on but one species of plant, but many are general feeders. The adults and nymphs of thrips that infest oat feed chiefly within the leaf sheaths. The inflorescence is infested before it leaves the leaf sheath that encloses it. The insects feed upon the developing spikelets and cause complete sterility by sucking the ovaries and feeding on the young anthers. Sometimes two or three nymphs may be found on the base of a single floret.

13-1.4.2 Thrips Control

Some thrips, such as *Prosopothrips cognatus* (Hood), are wingless and therefore can only migrate for short distances. For such species, crop rotation and a clean summer fallow to destroy volunteer weeds and grasses should give satisfactory control (Painter et al., 1954). There is no indication in the literature that insecticides have been tested against thrips infesting oat, but thrips damaging other cereal crops have been satisfactorily controlled with insecticides.

13-1.5 Cereal Leaf Beetle (Coleoptera: Chrysomelidae)

In June of 1962, numerous beetles were collected from a field in Berrien County, southwestern Michigan, and subsequently identified as the cereal leaf beetle (CLB) [*Oulema melanopus* (L.)] (Ruppel, 1972; Haynes & Gage, 1981). This insect may have entered the USA several years earlier, since farmers in the area had been applying insecticides to control an undetermined leaf-feeding pest since 1959 (Castro & Guyer, 1963). Several extensive reference lists or selected bibliographies on the CLB have been published (Venturi, 1942; Anonymous, 1967; Wellso et al., 1970; Battenfield et al., 1982).

13-1.5.1 Cereal Leaf Beetle Feeding Behavior and Biology

Adult CLB can feed on numerous grasses including wild oat (Balachowsky, 1963; Wilson & Shade, 1966), but the larval stage is usually the most destructive. The early instar larvae chew long narrow channels between the leaf veins and do not usually feed through the leaf. Severely damaged leaves are translucent, and heavily infested fields may have the appearance of frost damage. Winter wheat may escape serious injury because of its capacity to grow in the spring by the time the overwintering adult beetles become active (Hatchett et al., 1987). Nevertheless, significant yield losses in winter wheat can occur, with grain losses by adult and larval feeding ranging from 14 to more than 25% (Gallun, 1965; Gallun et al., 1967; Rademacher, 1967; Webster et al., 1972, 1982; McPherson, 1983). Webster et al. (1972) reported losses in grain yield of nine spring wheat cultivars in Michigan ranging from 10 to 55%. Wellso (1976) reported 30% loss in oat straw weight (oat straw may be sometimes more valuable than the grain). Webster et al. (1980) reported

oat grain yield losses averaging 17%. Wilson et al. (1969) reported yield losses of oat ranging from 82 to 147 kg ha⁻¹ in New Carlisle, IN with an infestation level of one larva per stem.

Adults of this univoltine species (with only one generation in the season; Hatchett et al., 1987) are found in grasses and winter wheat, starting about the end of March in southern Michigan, and emerge continuously until mid-May (Ruesink, 1970). The adults are about 6-mm long. The head and wing covers are metallic bluish black, and the legs and prothorax are orange (Hatchett et al., 1987). These adults oviposit on winter wheat, wild grasses, and late spring grain (Haynes & Gage, 1981). The yellow cylindrical eggs are laid singly or in small chains on the upper leaf surfaces (Wellso & Cress, 1972). The larvae are yellowish, but shortly after egg hatch they become covered with a shiny black fecal coating. There are four larval instars (Hatchett et al., 1987). The majority of the larvae enter the soil and pupate by early June (Haynes & Gage, 1981) at a depth of 2 to 5 cm. Each pupa is contained in a cell of soil and a mucous-like substance (Hatchett et al., 1987). Adult populations appear to accumulate in late oat plantings (Casagrande et al., 1977; Gage, 1972). Adult beetles disperse and feed on any available succulent grass crop and corn. They are found in increasing numbers until late October and early November (Haynes & Gage, 1981). Afterwards, adults are found in old hay, in wheat and corn stubble adjacent to wood lots or other topographic features that intercept wind, within hollow weed stems, along fence rows, and under the bark of trees (Castro et al., 1965; Janes, 1967; Yun, 1967; Haynes & Gage, 1981). The cycle is completed when the overwintering adults activate in the spring and return to their plant hosts.

Adult diapause or aestivation are usually more easily recognized in female than in male insects (Beck, 1968), an observation that holds true for the CLB (Wellso, 1972a). Females of this species aestivate from mid-July to mid-November and then remain quiescent until prevailing temperatures permit resumed activity (Hilterhaus, 1965; Wellso, 1972b, 1978). Moreover, the female reproductive system remains undeveloped until spring when the ovarioles begin to develop (Teofilovic, 1969). Hoppingarner et al. (1965), Teofilovic (1969), and Wellso (1972a) have prepared drawings of the reproductive systems of male and female CLB.

In Europe, where CLB is an occasional pest, its distribution extends northward from mid-England to Scandinavia and southward to North Africa. The highest damage by the CLB in Europe occurs in Hungary, Rumania, Yugoslavia, and southern USSR (Commonwealth of Independent States) (Hodson, 1929; Manolache, 1932; Knechtel & Manolache, 1936; Hilterhaus, 1965). The CLB has been a pest of small grains in Europe and Asia for centuries (Ringlund, 1970).

In North America, the initial point of infestation in the southwestern corner of Michigan, rapidly expanded eastward and into southern Canada (Castro et al., 1965; McClanahan et al., 1968) due to adequate environmental conditions, availability of plant hosts, and weather patterns that assisted its dispersion. Movement to the west has been slower. By 1979, the CLB could be found from southern Ontario in Canada, and in the USA, in Tennessee

and North Carolina and from Missouri to the east coast (Baniecki & Weaver, 1972; Haynes & Gage, 1981; Battenfield et al., 1982). By 1982, the CLB had reached Wisconsin (Battenfield et al., 1982), and in 1984, a major infestation was found damaging small grains in Morgan County, Utah (Hatchett et al., 1987).

In the fall of 1962, 20 townships in southwest Michigan and five townships in north Indiana were placed under quarantine. This required all small grain products to be treated prior to moving out of the area. Two years later, the area under quarantine had expanded and required the treatment of 102 000 t of grains and 1.25 million bales of hay. These levels increased to 725 000 t, over 3 million bales of hay, and large amounts of farm machinery, ear corn, sod, and other commodities that had to be treated before being shipped out of the area (Haynes & Gage, 1981). Starting in the spring of 1963, a large-scale eradication attempt using malathion (*O,O*-dimethyl phosphorodithioate of diethyl mercapto succinate) and carbaryl was implemented (Castro & Guyer, 1963). Besides foliar sprays, chemical control of the CLB can be achieved with the use of seed treatments and applications of granular insecticide formulations (Wilson et al., 1964).

13-1.5.2 Cereal Leaf Beetle Rearing

This research has had limited success. The CLB can be reared on artificial media, but with limited survival to the adult stage. Castro (1964) was able to rear limited numbers of beetles in the laboratory but had difficulty in recovering the pupae from the soil. Thus, Connin et al. (1966) sealed the soil of greenhouse flats with plaster of Paris to improve the rearing method. The larvae were forced to pupate in white quartz sand 1 to 2 cm deep poured onto the plaster, from which the pupae were easily recovered.

13-1.5.3 Cereal Leaf Beetle Control

In addition to chemical control, several other potential control strategies against the CLB were studied during the peak period when chemicals were being used for control. These efforts were initiated during the time of peak spray activities for eradication of this pest. Some of them had limited success, as discussed herein.

13-1.5.3.1 Sterile Male Technique. This technique used chemosterilants or radiation. Both methods had problems and did not work well. Certain chemical agents greatly reduced competition (Ezueh, 1966; Ezueh & Hoopingarner, 1967; Hoopingarner et al., 1965), and the radiation levels required for sterilization also produced high mortality (Kymararaj, 1964; Hoopingarner et al., 1965; Brenna, 1967; Myser & Norris, 1967; Carey, 1968; Myser & Carey, 1969).

13-1.5.3.2 Attractants. No such substances have been found. However, a juvenile hormone appears to induce males to mate with treated pre-diapause females (Connin et al., 1967).

13-1.5.3.3 Biological Control. The original idea was to mass rear the parasitoid *Anaphes flavipes* (Foerster) and release it along the perimeters of high density CLB regions, thereby containing the dispersion of this pest, while spraying insecticides over the central population core. Thus, a highly active biological control program was started as part of the eradication program. Since the beetles could not be reared, they had to be mass collected and stored at low temperature (Connin & Jantz, 1969) to provide insects for biological control and other programs.

Survey programs were started in Poland and Yugoslavia in 1963 (Bjegovic, 1967, 1971; Pavlov, 1977). In 1966, a rearing station was established in Niles, MI, to propagate and disseminate parasitoids of the CLB, particularly the egg parasitoid *A. flavipes* (Maltby et al., 1969, 1973; Moorehead & Maltby, 1970). By 1973, four species were reported established: *A. flavipes* (Maltby et al., 1973), the larval parasitoids *Diaparsis carinifer* (Thomson) (Stehr & Haynes, 1972) and *Lemophagus curtus* Townes (Sterh et al., 1974), and the gregarious larval parasitoid *Tetrastichus julis* (Walker) (Stehr, 1970). During 1975, more than 60 000 *Diaparsis* spp. adults from Yugoslavia were released in the USA. According to Montgomery and Dewitt (1975) and Miller (1977), only *D. temporalis* became established. The larval parasitoids established in Michigan were later used for colonization throughout Ontario, Canada (Harcourt et al., 1977; Miczulski & Machowicz-Stefaniak, 1977; Paschke, 1965; Smith et al., 1971).

13-1.5.3.4 Chemical Control. Insecticides, such as malathion, azinphos-methyl (*O,O*-dimethyl-*S*-)]4-oxo-1,2,3-benzotriazin 3(4*H*)-yl)methyl] phosphorodithioate), and endosulfan (6, 7, 8, 9, 10, 10-hexachloro-1,5,5a,6,9,9a-hexahydro-6,9-methano-2,4,3-benzodioxathi epin-3-oxide) are effective against the CLB if applied when eggs are common and small larvae are readily noticeable (Jantz, 1967).

13-1.5.3.5 Host Plant Resistance. The most efficient method of CLB control in oat (McDaniel, 1974) and wheat (Smith & Webster, 1973; Wallace et al., 1974; Guslits, 1976; Webster et al., 1973, 1975, 1982; Roberts et al., 1984) is the use of plant resistance (Vavilov, 1951; Schillinger, 1966, 1969; Webster, 1970; Wellso, 1973, 1979, 1982; Webster & Smith, 1971; Tesic et al., 1975; Smith et al., 1978). Leaf pubescence makes it difficult for CLB to feed and oviposit (Ringlund, 1967; Ringlund & Everson, 1968; Schillinger & Gallun, 1968; Gallun et al., 1973; Leslie, 1974; Tesic et al., 1974; Hoxie et al., 1975; Wellso & Hoxie, 1982). Resistance in barley and oat may eventually be of sufficient quality to reduce or eliminate the need for insecticides in some years (Webster, 1972). Downy was the first commercial soft red winter wheat cultivar with resistance to the CLB due to increased leaf pubescence (Roberts et al., 1976).

Approximately 30 000 wheat, barley, and oat lines were tested in the field in 1963 to 1964 for resistance to larval feeding (Webster, 1972). Development of host plant resistant cultivars on crops other than wheat has been less successful (Hahn, 1967, 1968; Casagrande & Haynes, 1976; Steidl et al., 1979). Wellso (1976) found that CLB adults laid more eggs in the field

on oat than on wheat. A 14-chromosome wheat (*T. persicum fuliginosum* Vavilov) with highly pubescent leaves, has great levels of resistance to *O. melanopus* (Gallun et al., 1966). Smith and Webster (1974) and Steidl et al. (1979) reported antibiosis on *A. sterilis* against larval feeding. McDaniel and Janke (1973) reported prominent leaf-blade pubescence in stable lines derived from *A. sterilis* × *A. byzantina*.

13-1.6 Armyworm (Lepidoptera: Phalaenidae)

The armyworm is one of the most destructive insects infesting oat. This insect is probably a native of North America, but it is also found in South America. It occurs east of the Rocky Mountains in the USA, and in Canada and northern Mexico. The moth is pale brown or brownish gray with a wing spread of 3.8 cm and a prominent white dot near the center of each front wing. Young larvae are pale green and crawl with a looping motion. The full-grown armyworm is a nearly naked, striped caterpillar, about 3.8-cm long. Its color is usually green, and the stripes, one along each side and a broad one down the center of the back, are dark and often nearly black. The stripe along the back usually has a fine, light, broken line running down its center. The color of the body between the dark stripes ranges from greenish to reddish brown. The head is pale greenish brown, finely mottled with darker brown. The armyworm destroys oat in some areas almost every year. Outbreaks are frequently local and sporadic, but occasionally high populations have infested large sections of the eastern USA and Canada (Walkden, 1950). Damage to oat in 1954 was estimated to be over \$5 million (USA); an estimated \$12 million (USA) loss was prevented with insecticides.

13-1.6.1 Armyworm Feeding Habits and Biology

Armyworms pass the winter as partly grown larvae or as pupae. Adults begin to emerge in early spring, and are present in varying numbers until late November. The moths are strong fliers, but are active only at night and are attracted to lights. The females lay their eggs in clusters of 500 or more, principally on the lower leaves of leaf sheaths of rank-growing grasses or small grains. The leaf is generally folded lengthwise, and fastened about the eggs with a sticky secretion. The eggs hatch in 8 to 10 d, and the young larvae feed on vegetation near the ground. At first the larvae are very small and consume little food, and thus may escape notice. As they become larger, they eat more vegetation; and when they have consumed the lower leaves, they feed higher on the plants. Heavy infestations will completely defoliate the oat plants and then sever the lateral panicle branches. The larvae normally remain hidden under clods and leaves during the day, but in heavy infestations they may assume the army habit and migrate and feed during the day when food becomes scarce.

A full-grown caterpillar usually burrows under litter on the ground, under clods, or into the soil to a depth of 5 to 7.5 cm, where it forms a cell in which it changes to a pupa. The moth emerges 2 to 3 wk later and makes

its way to the surface. It takes from 7 to 8 wk for the insect to develop from egg to adult. There are two to three generations each year. The larvae of the first generation do most of their damage to oat in May and June, usually at about the time the oat head is emerging from the boot.

13-1.6.2 Armyworm Control

Several insecticides are effective against armyworms. It is important that control be initiated when the worms are small, so as to avoid serious injury. Small grain fields with growth of vegetation or lodging should be watched, especially during April and May. If young worms are found, an insecticide should be applied immediately.

Since armyworms damage oat in the late boot or headed stage, spraying is done almost exclusively by airplane to avoid damaging the plants with ground spray equipment, using from 14 to 28 L ha⁻¹ of insecticide in concentrated emulsion.

The armyworm is often parasitized. Walkden (1950) recorded three species of Hymenoptera and six species of Diptera in his observations in the Great Plains of the USA. One of the most common and most effective parasites is *Winthemia quadripustulata* (F.), a gray fly that lays its eggs on the skin of the larvae. The maggots that hatch from these eggs bore into the flesh and soon devour the inside of the armyworm. These flies multiply rapidly and often become numerous enough to control the armyworm.

13-1.7 Grasshoppers (Orthoptera: Acrididae)

Many species of grasshoppers infest oat and nearly all other cultivated plants. The migratory grasshopper [*Melanoplus bilituratus* (Sauss.)], is one of the most important species on oat. It is 2.5 to 2.65 cm in length and brownish with an irregular black flecking on the neck or collar. The upper wings are grayish brown, flecked with darker markings. The hind tibiae are reddish yellow to bluish green. As its name indicates, it often migrates in great swarms. It has often invaded the Red River Valley in north-central USA and destroyed oat and other small grains.

The differential grasshopper [*M. differentialis* (Thos.)], and the two-striped grasshopper [*M. bivittatus* (Say)], may damage early fall-sown oat in Texas, Oklahoma, Kansas, Arkansas, and Missouri. The differential grasshopper is about 3.1-cm long. The color ranges from olive brown through orange yellow to bright yellow and, in the northern part of the range, it may be almost black. Ten to 12 black bars on the outside of the hind femora are arranged in the manner of chevrons. It occurs in most of the eastern, mid-western, and great plains states of the USA south of the 47th parallel.

The two-striped grasshopper is about the same size as the differential grasshopper. The color ranges from yellow black to brownish yellow. The chief distinguishing characteristic is the pair of yellowish stripes extending from the eyes across the back and down the wing covers. This species is found throughout the USA and north into the Canadian provinces.

An important species in the USA, especially in the southeast, is the American grasshopper [*Schistocerca americana* (Drury)]. This is one of the largest insect species in the USA. The females are often 6.25 cm from head to tip of wing, with the males smaller than 5 cm. The adults are reddish brown, with numerous brown patches on the front wings, thorax, and abdomen (Connin & Kuitert, 1953).

13-1.7.1 Grasshopper Feeding Habits and Biology

All of these species, except *S. americana*, deposit eggs in the late summer or early fall, and spend the winter in the egg state. The latter overwinters as an adult, laying eggs early in the spring. The eggs are laid in pods, 2.5 to 3.75-cm long, 2.5 to 5.0 cm below the surface of the ground. Each pod contains 15 to 100 eggs, depending upon the species. The different species may choose a special type of soil and vegetation in which to deposit eggs.

Melanoplus bilituratus lays its eggs throughout grain, alfalfa (*Medicago sativa* L.), and other cultivated crops and also in idle land field margins, fence rows, ditchbanks, roadsides, and rangeland. *Melanoplus differentialis* and *M. bivittatus* lay a few eggs within cropped land, but concentrate their eggs among the roots of weeds or grasses along fence rows, roadsides, ditchbanks, and other margins of cropped fields and pastures. *Schistocerca americana* lays its pods in old weedy pastures, stump, and abandoned lands among cropped fields in the southeast in early spring.

In the spring oat area of the midwestern and northern USA, species of grasshoppers infesting oat have but one generation a year. Since the overwintered eggs usually do not hatch until oat has made considerable growth, damage consists of feeding on the foliage and later on the panicle, and clipping the peduncle and making the panicle fall to the ground. In the winter oat area of the south and southeast, some grasshopper species have two or more generations a year, but the summer generation develops during the period when oat is not growing in the field. Major damage is done to oat in the early fall by destroying young plants along the edge of fields bordering fence rows, pastures, or alfalfa fields.

13-1.7.2 Grasshopper Control

In the winter oat area of the USA, border damage to newly seeded oat can often be reduced, if not prevented, by delaying planting until the grasshoppers have deposited their winter eggs and died, usually the latter part of October. In the spring oat area, early seeding is an important means of reducing grasshopper damage. This allows considerable growth before grasshoppers hatch, and large plants are better able to withstand feeding. Grasshoppers prefer succulent vegetation, and oat that is green is more attractive than oat that is nearly mature.

Tillage at the proper time destroys many grasshopper eggs. Grasshopper-infested grain stubble that is to be summer-fallowed should be worked before the eggs hatch. Moldboard plowing in the fall or early spring, 12.5 or more centimeters deep, is the best method of destroying the eggs, but this

is recommended only where soils are heavy and soil blowing is not a problem. Shallow cultivating with one-way disk or duck-foot cultivators is less effective than moldboard plowing, but will destroy many of the eggs. Prior to 1947, the best known method of controlling grasshoppers was with poison-bran bait, but such treatment was only partly effective even under ideal conditions. In the early 1950s, organochlorine insecticides gave good control of grasshoppers (Connin & Kuitert, 1953). Sprays of organophosphate and pyrethroid insecticides are now used for control. The lower dosages are used early in the season on young nymphs in short, dense, lush vegetation and on open stands of taller growth, and the heavier dosages on adults or when vegetation is tall and dense. Spraying newly hatched nymphs while they are still concentrated in their egg beds is most effective.

13-1.8 Frit Flies (Diptera: Chloropidae)

Frit flies are widely distributed, having been reported from Norway, Sweden, Denmark, Finland, USSR (Commonwealth of Independent States), Bulgaria, Austria, Germany, Holland, France, British Isles, USA, and Canada. Several types may comprise the European frit fly [*Oscinella frit* (L.)] (Becker, 1912; Aldrich, 1920). Sabrosky (1939) considered that *O. nitidissima* (Meigen) is a type of *O. frit* but that *O. soro* (Macq.) and *O. carbonaria* (Lw.) are distinct species. He also considered *O. pusilla* (Meigen) and *O. nigra* (Tucker) synonymous with *O. frit*, and *O. variabilis* (Loew.) synonymous with *O. soro*. He found *O. frit* and its variant *nitidissima* especially prevalent in the north and western USA. *Oscinella soro* and *O. carbonaria* predominated in the east, but there was considerable overlapping in the central states. According to Collins (1918), the two species that cause damage in Europe are *O. frit* and *O. pusilla*.

Adult frit flies are 1.1- to 2.0-mm long. The head, thorax, and abdomen are black, although the first segment of the abdomen may have a yellowish tinge. The eggs are white, 0.7-mm long and 0.18 mm in greatest diameter, approximately straight on one side and curved on the other with fine ridges running lengthwise. Young larvae are 1.06-mm long and 0.14 mm in diameter. They are whitish, semitransparent, and pointed in front. Full-grown larvae are 3-mm long, 0.4 mm in greatest diameter, and yellow in color. The larvae have two mouth hooks.

In Europe, frit flies often cause serious loss in oat. According to Collins (1918), in some years the loss in oat in England was estimated at 30 to 40% and the annual loss averaged 287 kg ha⁻¹, or 18% of the crop. Frit flies prefer oat but also infest rye, barley, wheat, corn, and various grasses. In England, they are found chiefly in spring oat, but have been recorded on winter oat. Aldrich (1920) found that frit flies did not normally feed on oat in the USA but preferred wheat, and concluded that the American species might be physiologically different from the European species.

According to Simmons (1953), frit flies are not serious pests in Canada because: (i) the spring permits a rapid growth of plants, which enables them to recover from damage by these flies; (ii) there is no grain-infesting genera-

tion as in Europe; and (iii) several beneficials parasitize the flies. Roebuck (1920) described a condition of oat caused by frit flies that he called *blindness*, in which some of the spikelets are sterile. Blind spikelets are white or pale green and the floral parts are reduced or absent. He stated that there were three broods of the fly on the oat crop, and that blindness was caused by larvae of the second brood feeding on the developing panicles. Sheals (1950) concluded that in North Wales frit fly larvae and thrips on developing panicles were of little importance in causing blindness, which appeared to be due to adverse physiological conditions probably operative during early growth.

13-1.8.1 Frit Fly Feeding Habits and Biology

The eggs are laid in the fall and spring on the leaves of the young plant hosts, usually on the underside or the stem close to the ground. Eggs may be laid on the sheaths or panicles when the plants are larger. One female may lay from 20 to 70 eggs. The eggs hatch in 3 to 7 d.

Adult males probably live not more than 24 h. The average life of females is 2 to 4 wk, but they may live 12 to 16 wk. Adults have a short, hopping flight. They may emerge in immense numbers from grain at threshing time or from oat grain in storage a few days after threshing.

The young larvae of the fall or spring brood make their way into the stem and eat the tender central leaves or shoots, ultimately killing the shoots. They mine the leaves before working their way into the stem. The larvae migrate from one shoot to another. Normally there is only one larva per shoot, but there may be as many as 10. The larvae of the summer brood live in the top of the stem, feeding on the hidden panicles. This brood may feed from 2 to 5 wk depending on temperature. The larvae of the fall brood hibernate, and then pupate in the spring.

The spring and fall larvae leave the center of the stems and pupate under the sheath of the outer leaves and between the first node and 3.6 cm above. The summer larvae pupate among the leaves surrounding the hidden panicle, in the grain itself, or between the grain and husks. The pupal stage lasts from 8 to 14 d. According to Collins (1918), in England there are three generations but in continental Europe there may be as many as four or five generations, depending on the weather.

13-1.8.2 Frit Fly Control

Collins (1918) suggested several cultural practices to reduce frit fly damage in England. Late-sown spring oat were injured most severely. Oat sown on 29 March were almost completely immune from attack, while those sown on 29 April were 70% destroyed. He suggested that oat be sown as early as possible, but not so early as to be injured by frost, and that they be fertilized (topdressed) with sodium nitrate or ammonium sulfate as soon as the plants emerge to induce rapid early growth. He also suggested that oat not be sown near fields that were damaged in previous years.

Data presented by several investigators indicate that certain oat cultivars are resistant to damage by frit flies. Collins (1918) found that oat plants that tillered freely were better able to stand up against damage than those that did not. Roebuck (1920) found a wide difference in the amount of blindness caused by frit flies in West Midlands (British Isles), ranging from 74% in the 'Potato' cultivar to <25% in the White Tartarian, Supreme, and Blainslee. Cunliffe (1936) first suggested that the difference might be due to deposition of silica, which increased the difficulty of larval travel. Later Cunliffe and Hodges (1946) showed that resistance was not correlated with either carbohydrate or silica content. They concluded that resistance was indirect and due to some form of plant attractiveness that determined the extent of oviposition. They showed that oviposition on susceptible cultivars, such as Victory and Star, was three times as great as on resistant cultivars, such as Summer and Spet, and that selections from crosses between susceptible and resistant cultivars were intermediate in resistance, received a proportionate number of eggs, and transmitted the resistance. Summer was the most resistant of 22 named cultivars and Richland, Iowa 411, and Eagle were moderately resistant. In the same study, late nitrogenous dressings had no effect on grain infestation or sterility. Five applications of DDT (dichloro diphenyl trichloroethane) afforded substantial but not complete protection.

Breeding for resistance is an important means of reducing damage in Sweden (Akerman, 1951). The most resistant cultivars of Swedish origin are 'Great Mogul II' (Stormogul II), 'Engelbrekt II', and the white oat derived from the resistant German cv. Van Lochows Gelbhafer.

13-1.9 Winter Grain Mite (Acarina)

The winter grain mite [*Penthaleus major* (Duges)] is the most important mite damaging oat, but the brown wheat mite [*Petrobia latens* (Mull.)] and the date mite [*Oligonychus pratensis* (Banks)] occasionally cause some damage.

The adult of the winter grain mite is dark brown to black and approximately 1-mm long. The anal aperture is on the dorsum about one-third the distance from the apex of the abdomen, and it is usually surrounded by a reddish orange spot. The mouth parts and legs are reddish orange. The eggs are kidney shaped and about 0.25-mm long and 0.14 mm in diameter. They are reddish orange when first laid, but later become straw-colored. The larva and nymph are similar to the adult except in size. The larva has only six legs, but the nymph and adult have eight.

Although it was first recorded in the USA by Banks (1902), the winter mite was not reported as an economic pest until 1911 when it was found to be damaging small grains in Arizona. It has also been reported from California by Essig (1939) and Campbell (1941) and from South Africa and Australia by Wormersley (1933), mostly on pea (*Pisum sativum* L.), clover (*Trifolium* spp.), and grass. Chada (1956) gave an account of the different stages, biology, distribution, damage, and control in Texas; most of the information on this pest is taken from his paper. It is destructive to oat in Texas,

Oklahoma, Kansas, and Missouri, but its major damage appears to be in the winter oat area of Oklahoma and Texas.

13-1.9.1 Winter Grain Mite Feeding Habits and Biology

As the common name implies, this mite is active during the winter months. There are two generations in Texas (Chada, 1956). The aestivated eggs hatch in October and November, and the larvae and nymphs feed on the leaf sheaths, leaves, or tender shoots near the ground. The later stages of the nymphs may feed higher on the plants. All stages avoid the bright light and heat of the sun, and do most of their feeding at night. During the day they can be found on moist ground under foliage or, if the soil is dry and there is little foliage cover, they may dig or go into cracks in the soil.

The female mite deposits eggs on the leaves or stem or on the soil near the base of the plant. Optimum oviposition temperatures are between 9.5 and 15.6°C. Mite activity drops rapidly when daily temperatures in the spring exceed 23.9°C and the eggs do not hatch until there is adequate moisture in the fall. Spread from field to field appears to be mainly by the transportation of aestivating eggs on debris and soil when farm implements are moved or straw is carried from infested fields in feeding operations.

13-1.9.2 Winter Grain Mite Control

Cropping practices have a marked effect upon the occurrence and damage caused by the winter grain mite. Rotations to avoid continuous cultivation of small grains in the same field greatly reduces infestation. In Texas, damage usually was extensive when small grains were grown continuously in the same field for three or more years, and infestation was light or spotted in the second year of small grain. The mites were either absent or scarce in fields where the previous crop was not a small grain (Chada, 1956). The winter grain mite is especially susceptible to P insecticides.

13-2 CUTWORMS

13-2.1 Cutworm (Lepidoptera: Phalaenidae)

Several species of cutworm may injure oat, but only a few are very destructive. Among the most injurious on oat in the USA, according to Walkden (1950), are the army cutworm [*Chorizagrotis auxiliaris* (Grote)] and the variegated cutworm [*Peridroma margaritosa* (Haw.)]. The red-backed cutworm [*Euxoa ochrogaster* (Guenée)], the pale western cutworm (*Agrotis orthogonia* Morr.), the glassy cutworm [*Crymodes devastator* (Brace)], and the yellow-headed cutworm [*Apamea amputatrix* (Fitch)], have at times caused serious damage to oat, especially in Canada (Gibson, 1915).

Cutworms are the larvae of noctuid moths, or millers. The moths are dull gray, brown, or tan with a wing spread of 3.6 to 4.3 cm. The front wings often have white or silvery-white marks on the upper surface. The full-grown

larvae are 3.6- to 4.9-cm long. They are sluggish and curl up when disturbed. Their color and markings vary with the species.

The army cutworm varies in color from pale greenish gray to brown, with two brownish stripes on each side of the body and two chocolate-colored stripes on the back, separated by a narrow gray line. This species is most injurious in the western portions of the winter oat area of the USA, but occasionally occurs in outbreak numbers in the northern USA and Canada.

The variegated cutworm, as the name indicates, varies in color ranging from pale gray to almost a dull brown; some specimens have a greenish tinge. The body is mottled and streaked with dark brown or none at all and has a conspicuous yellowish band along the side. It is cosmopolitan in distribution.

The red-backed cutworm is red along the back, with a pale stripe in the middle and a dark stripe on each side. It is the most destructive species in Canada, occurring in every province.

The glassy cutworm is dirty white with a greenish tinge but has no stripes on the body, in contrast to many other species. It is found in the Central Great Plains of the USA, but usually has not been of economic importance. In Canada, however, it is found from Nova Scotia to British Columbia and has caused serious damage to oat crops.

The yellow-headed cutworm is similar to the glassy cutworm in appearance except that it has a yellow head. This species is also found in the Great Plains of the USA, and is of major importance as a pest of oat in Canada, especially in Ontario.

The pale western cutworm is whitish or grayish with no body markings. It occurs west of the principal oat-growing region in the USA, but has caused serious damage to oat fields in Alberta and Saskatchewan in Canada.

13-2.1.1 Cutworm Feeding Habits and Biology

Cutworm damaging oat may be divided into three groups based on its feeding habits (Walkden, 1950): subterranean cutworm, surface feeder, and climber. The army cutworm and the red-backed cutworm are surface feeders, the variegated cutworm is a climber, and the pale western cutworm is subterranean. The subterranean species usually cut the plants off so low that none recover. The species that climb feed on the oat leaves and panicles.

In the winter oat area of the USA, surface feeding injury may have about the same effect on the plants as close grazing by livestock, and if damage occurs in early spring, the plants may recover without serious injury. If the fields have been grazed and there is little vegetation for the cutworm to feed on, however, they may eat the stems below the crown and kill the plants. In spring oat, many infested plants are killed and others that are injured cannot fully recover. Most of the cutworms overwinter as larvae. However, the pale western and the red-backed cutworm overwinter as eggs, and the variegated cutworm does not overwinter north of Kansas. The larvae are injurious in early spring, and some species, such as the army cutworm, when abundant, migrate in large bands devouring all vegetation as they go.

The larvae of most species feed only at night or on cloudy days and are most active during warm nights; however, the variegated cutworm often feeds in the daytime. The larvae become full grown in late spring or early summer, change in the soil to brown pupae, and later emerge as adults. The pale western cutworm, however, aestivates as a larva 7.4- to 12.3-cm deep in the soil from early May to August, and the adult emerges in September. The adults of most species fly at dusk or in the night and congregate around lights on warm nights. They shun light during the day, hiding under boards or clods and under dense clumps of grass. Most of the species injurious to oat have but one generation a year, but the variegated cutworm has from two to four generations. Some species, notably the army and pale western cutworm, lay eggs directly on or in bare soil; others lay their eggs on the stems of grasses and weeds or behind the leaf sheath of such plants. Each female moth lays from 200 to 500 eggs, either in masses or singly. The egg stage lasts from a few days to 2 to 3 wk, except in species that overwinter as eggs.

13-2.1.2 Cutworm Control

Cutworms that lay eggs during late summer on weeds and grasses can sometimes be controlled by clean culture during the egg-laying period. Such measures are not effective against species that lay their eggs on bare ground. Walkden (1950) found that damage from the pale western cutworm in the Great Plains of the USA could be minimized by the use of summer fallow. Crusted soil is unattractive to egg-laying females of this species.

Various insecticides have been effective against cutworms that feed at the surface or above the soil. Lower dosages are used for young larvae when the weather is warm enough for considerable activity, and higher dosages for large larvae or when low temperatures limit their activity. For best results, the larvae should be controlled while in the first or second instars, before they have caused serious damage. Most subterranean feeders cannot be controlled by surface applications of insecticides.

13-3 SOIL INSECTS

Soil insects live in the soil, and the larvae feed on roots or underground portions of the stems of oat. Because they are hidden, many of the injurious forms may escape attention.

13-3.1 Wireworm (Coleoptera: Elateridae)

Wireworm occurs throughout the world, but abound in the temperate and subtropical zones. The true wireworm is the larvae of a brownish to black, slender, active beetle with a body tapering toward each end. The adult has a loose, flexible connection between the prothorax and middle part of the thorax. This loose joint contains a structure that enables the beetle to make a clicking sound and to jump or throw itself some distance when disturbed.

or placed on its back; because of this it is known as a click beetle. The larva is slender, shiny, rather sluggish, buff to reddish brown, heavily sclerotized, and about 1.2- to 6.1-cm long. A distinct head is clear, and there are three pairs of short, stumpy legs. The wireworm usually does more damage to corn, wheat, and potato (*Solanum tuberosum* L.), but they may on occasion seriously injure oat sown in infested soil. Some species may cause much more injury per wireworm than others. Hawkins (1936) stated that a large wireworm population is generally associated with severe injury, and that about 105 wireworms m^{-2} or 1 049 750 ha^{-1} , can destroy an oat crop.

Wireworm injury to grain is often inconspicuous because of the large number of plants, and yet the loss may be considerable (Thomas, 1940). Although a little thinning of small grains may be overcome by additional tillering, the blank spaces left by the worm may be occupied by weeds. Wireworm injury appears as irregular spots in the field. Injury to young plants delays maturity, but later damage stimulates a heavy production of late tillers that do not head or are still green at harvest time.

13-3.1.1 Wireworm Feeding Habits and Biology

Adult beetles in general are not injurious to plants. They are active at night, feeding on honeydew and pollen and occasionally rasping the stems and leaves of grasses and sucking the juices. The females lay eggs slightly below the soil surface, usually around the roots of grasses. The adults live 44 to 52 wk. The larval stage lasts from 44 wk for the sand wireworm (*Horistonotus uhlerii* Horn.) and up to 9 yr for the prairie grain wireworm (*Ludious aeripennis tinctus* Lec.) [now *Ctenicera aeripennis destructor* (Brown)]. Bryson (1934) found that wireworms of the genus *Melanotus*, a pest of oat in Kansas, required 8 yr or more to mature if food was limited or unfavorable, but the usual time was 3 yr or less when favorable organic matter was available. The major damage was done by second- and third-year larvae. Wireworms prefer the inner, more succulent portions of plants and seeds and will bore through the outer layers to get to them. Such feeding, if it takes place before or as the seed germinates, may prevent the seedling from emerging or may kill it soon thereafter. The larvae bore into the stems of oat, causing the plants to be yellow, weak, and stunted, but usually do not kill them. The larvae move up and down in the soil along with moisture and temperature variations. Tenhet and Howe (1939) found that sand wireworms move rapidly through the soil, chiefly in a vertical direction. Bryson (1934) found that *Melanotus* larvae remain near the surface throughout the winter, seldom going deeper than 14.7 cm. They move downward from late June to mid-July, either to escape high temperature or pupate. The larvae return toward the surface in mid-September but descend below the 14.7-cm plow line in late autumn. In early spring they return to near the surface and feed on seeds and roots of grass and cultivated plants. During late summer or fall, when full-grown, they change to soft, naked pupae in cells in the ground. The adults emerge a few days later but usually remain in the soil until the following spring.

13-3.1.2 Wireworm Control

Fenton and Whitehead (1944) found that wireworm damage was less when there was sufficient moisture and satisfactory temperature to ensure immediate germination and rapid growth of oat seedlings. The value of early planting may be affected by soil temperature, moisture, wireworm species, or other factors (Thomas, 1940). Oat sown too early or in wet, cold soil, germinate slowly, and this seems to favor wireworms that come up near the surface and damage the weakened plants. Masaitis (1927) favored late seeding in Siberia, since he found that only 15% of the late-sown oat were destroyed, as compared with 45% in early sowings. In Canada, oat should be seeded early; late-seeded oat may be damaged severely by wireworms, particularly in a hot, dry spring (King & Arnason, 1931).

It is advisable to seed infested fields rather thickly to provide an overabundance of wireworm food so that more plants can survive and reach maturity. Good viable seed capable of quick germination should be used. Masaitis (1927) stated that the same percentages of plants were destroyed in seeding of 56, 90, and 123 kg ha⁻¹. Lane (1931), King and Arnason (1931), and King et al. (1933) also recommended that extra seed should be sown on land infested with wireworms. Strickland (1933), King and Arnason (1931), and King et al. (1933) recommended seeding grain not more than 3.7- to 4.9-cm deep with the seed in contact with moist, mellow soil. They advised using a press drill or a drill with a press attachment.

Cultivation for the control of wireworms frequently has been advised. Cultivation may be effective, particularly if it is timed to destroy the wireworms in their soil cells or to turn them up to the surface where they will be exposed to the sun and to their natural enemies. However, older larvae usually move downward when turned up by the plow. Plowing or cultivation does not destroy wireworm pupae that are below plow depth. Clean fallowing may be effective against newly hatched larvae, but not against older larvae. Many half-grown *Limonius* spp. larvae have remained alive and apparently healthy in loam soil containing no plant roots for as long as 8 mo. Munro and Riddle (1930) found that summer fallowing only intensified wireworm injury the next year. Strickland (1933) found that summer fallow did not prevent the production of viable eggs of the prairie grain wireworm but that newly hatched larvae must have roots or other food within a few weeks after hatching. Mature larvae lived as long as 2 yr without food except for the organic matter in the soil. Clean fallowing by shallow tillage from mid-June to the end of July will kill many of the young larvae. This practice, continued for two or three consecutive years, will reduce heavy infestations.

Crop rotation is one of the oldest and most frequently recommended methods for wireworm control. Oat should not follow sod since most wireworms lay their eggs in grass fields and the larvae thrive best in grass. Most species of wireworms remain in the larval stage for several years; therefore it is necessary to grow resistant or immune crops on infested land for several years to reduce infestation levels. Recommended wireworm-resistant crops include buckwheat (*Fagopyrum esculentum* Moench), flax (*Linum usitatissimum*)

simum L.), millet [*Setaria italica* (L.) Beauv.], and woad (*Genista tinctoria* L., a dyestuff plant in Europe), and legumes such as clover, sweetclover (*Melilotus* spp.), alfalfa, soybean [*Glycine max* (L.) Merr], bean (*Phaseolus* spp.), and pea.

Chemical sprays are usually not practical, and soil fumigants are too expensive for use against wireworm in oat. Insecticides applied to the soil, however, often give satisfactory control of wireworm for at least 3 yr. Several investigators, including Fox and Neary (1953) and Arnason et al. (1949), have recommended seed treatments.

13-3.2 False Wireworm (Coleoptera: Tenebrionidae)

Adults of false wireworms are dull-black to reddish brown robust beetles. They range from 0.92 to 2.76 cm in length and from 0.61 to 1.53 cm in width. The elytra (wing covers) are fused together making it impossible for them to fly, so they only disperse by walking. The elytra of several species are indented by longitudinal grooves, but are smooth on others. The prothorax is smooth and constricted near the base of the elytra. When the beetles are disturbed, they place their heads on the ground and elevate the hind part of their bodies as though standing on their heads.

The larvae closely resemble true wireworms, but have longer legs and antennae. They are slender, yellowish brown, brownish, or nearly black hard-shelled worms up to 3.19-cm long, with three pairs of thoracic legs.

At least 11 species are injurious to small grains (Painter et al., 1954; Wakeland, 1926). *Eleodes hispilabris* Say is the most abundant and damaging species in Idaho. Three species common in Kansas are *Eleodes opaca* (Say), *E. tricolorata* (Say), and *E. suturalis* (Say).

Adults feed on organic matter such as small grain seed and chaff left in the field and on grass and weed seeds. Species that are injurious to oat and other small grains occur in the USA from the Mississippi River to the Pacific Coast north into Canada and south into Mexico. They are generally considered pests of wheat, but may cause serious damage to oat, barley, sorghum, and corn. They are chiefly pests on dryland farms. Injury varies greatly between seasons, and it is very difficult to anticipate infestations.

13-3.2.1 False Wireworm Feeding Habits and Biology

According to Wakeland (1926), false wireworm larvae can cause injury to the kernel, the sprout, and the stem. The false wireworm does major damage to the seed and germinating seed, whereas the true wireworm feeds more on roots. In the winter oat area of the USA, the greatest injury occurs during dry falls. Oat may be sown in soil too dry for the seeds to germinate, and the larvae follow the drill rows eating the germ of many seeds before rainfall starts germination. One larva can destroy a large number of kernels. Damage also is caused by larvae feeding on the tender sprout just as it is pushing out of the seed. Even after the seedling is established, the larva may cut the stem off below the surface of the soil immediately above the node where the permanent roots form.

In Idaho, adults of *Eleodes hispilabris* (Say) emerge in July and August and are active until they hibernate in October (Wakeland, 1926). They live from 240 to 480 d, averaging about 300 d. Eggs are laid in dry soil close to the moisture line over a rather long period in the spring and summer. The eggs are white, oblong, and coated with a viscous substance that causes dirt particles to adhere to them and makes them difficult to observe in the soil. The eggs hatch in about 15 d. The larvae live from 302 to 644 d, with an average of 369 d, and pass through 11 instars. Those surviving for more than a year often remain inactive for several weeks, during which time they consume little or no food. The pupal period lasts approximately 33 d. The average complete life cycle of each generation is approximately 2 yr, but may vary from 1½ to 3½ yr. Thus, there are two and sometimes three generations in the soil at one time.

In Kansas, Painter et al. (1954) reported that egg laying begins in July and the eggs hatch in 10 to 14 d. The larvae feed on fall-sown grain sprouts until the soil becomes cold in November, and then they burrow below the frost line and remain inactive until spring. When the soil temperature rises, the larvae return to the surface and resume feeding, but they cause little damage in the spring. They transform to pupae in May or early June and adults emerge in June and July. Thus the life cycle in Kansas is only 1 yr.

13-3.2.2 False Wireworm Control

Since the larvae are especially injurious to seed before it germinates, oat should be sown in a well-prepared seedbed only when there is enough moisture to stimulate growth. Clean summer fallow reduces the amount of injury, but cannot be relied upon to control all species satisfactorily.

Rotation with crops unfavorable to the larvae has been the most universally recommended control measure. The adults cannot fly to other fields. The rotation usually recommended in the winter oat area (Fenton & Whitehead, 1944) is oat, 2 yr; sorghum, 1 yr; and summer fallow, 1 yr. Legumes may be substituted for the sorghum or summer fallow in areas where they are adapted. Treating the soil as recommended for wireworms is also effective against false wireworms.

Seed treatment is often more effective against false wireworm than against true wireworm. The insecticides may be used alone or in combination with fungicides recommended to control seed-borne diseases of oat. Overdoses of seed treatment may be injurious.

13-3.3 White Grub (Coleoptera: Scarabeidae)

White grubs, a large group of beetle larvae that live in the soil, are found throughout the world and feed on nearly all cultivated crops. They represent a large group of beetle larvae that live in the soil. More than 100 species have been described in the USA and Canada. White grubs are among the most destructive soil insects. Injury to oat first appears as areas of dead or dying plants scattered throughout the field (Hayes, 1925).

Luginbill and Painter (1953) published an extensive taxonomic key and maps of the distribution of scarabeid beetles in North America. Adult May beetles are grayish or blackish when grown and are commonly known as May or June beetles. Most species vary from 1.84 to 2.45 cm in length. The body is elongated oval. The upper surface is usually smooth and polished, but may be sparsely covered with fine hairs. In some species the elytra are fused together so that the beetles are unable to fly. The tip of the abdomen usually extends slightly beyond the elytra. The front legs are adapted for digging in the soil. The antennae are lamellate and cannot be seen from above unless they are extended.

The larvae of all species are white to bluish in color, with brown heads, strong chewing mouth parts, and six short legs. Dark body contents are visible through the semitransparent skin of the last abdominal segment. The body is soft and wrinkled and is curved so as to bring the head and tip of the abdomen close together. The small brownish spiracles are discernible on each side of the body.

13-3.3.1 White Grub Feeding Habits and Biology

The larvae feed on roots and when abundant they may kill the plant. The grubs often move directly down a drill row and one grub may kill several plants in a short time. In mild winters, the grubs continue to feed, but in cold weather they go deep in the soil and remain there until spring. Well-established oat plants usually are not killed by spring feeding, but the grubs may prune the roots so that the plants are stunted and may fail to head. In the spring oat areas, plants may be killed soon after they emerge in the spring.

13-3.3.2 White Grub Control

Damage can be reduced by rotating resistant crops such as the deep-rooted legumes, alfalfa, sweetclover, or red clover, with the susceptible crops, corn, small grains, and grasses. In Oklahoma, Fenton and Whitehead (1944) suggested a corn or sorghum, oat, and wheat rotation for the control of the wheat white grub [*Phyllophaga lanceolata* (Say)]. They found that cotton (*Gossypium barbadense* L.) and soybean were injured severely by the adults and should not be included in the rotation. If oat seeded in the fall or early spring are so heavily damaged by this grub that they are unlikely to produce a profitable crop, they can be plowed up and the land planted to corn or sorghum without risk of economic loss. However, this method might not retard other species of white grubs. Painter et al. (1954) recommended clean culture, including destruction of weeds in and along field borders, to remove plants on which the adults feed. They also suggested that small grain should not be sown too early in the fall, as such a practice exposes young seedlings to the feeding of grubs longer before cold weather forces them to hibernate.

Several insecticides control white grub larvae when applied to the soil. Chemical control has proved effective (Painter et al., 1954).

13-4 NEMATODES

13-4.1 Nematodes Affecting Oat

There are thousands of species of nematodes or roundworms (nema-thread; oides-resembling). These worms can be found in soil, fresh and saline water, plants, animals, and man. Most plant-parasitic nematodes are small (0.2-mm long) and are frequently found in the soil in very large populations. Several hundred species are parasites of plants. These can differ considerably from each other in morphology, ecology, biology, and behavior. Their taxonomic classification has generally been based on morphological characters; however, the current taxonomic grouping of nematodes is not satisfactory and does not reflect their phylogenetic development. Plant-parasitic nematodes have been grouped based on the plant parts they parasitize (e.g., root, stem, leaf, and seed nematodes). Further division of these groups is based on various biological, ecological, or morphological characters.

Cereals are the oldest domestic crops, and in most of the world they are the principal crops in terms of acreage and importance to man. Various nematodes are parasites of cereals and can significantly reduce yield. Nematode species that are of importance as pests to oat are: (i) the cereal cyst nematode, (ii) the cereal root-knot nematode, and (iii) the stem nematode.

13-4.1.1 Cereal Cyst Nematode

The cereal cyst nematode (*Heterodera avenae* Wollenweber) has been reported from most European countries, Australia, Canada, Israel, Morocco, South Africa, Japan, and India. The pest was recently reported in the USA in Michigan, Oregon, and Idaho (J.M. Ferris, 1989, personal communication). Light soil types are generally favorable to this nematode; however, it will generally cause economic damage irrespective of soil type with continued cereal cropping. Distribution of damage within a field is frequently uneven and the extent of patchiness depends on the rate of multiplication of the nematode in the field and initial infestation level.

The host range of the cereal cyst nematode is restricted to graminaceous plants. Sexual dimorphism occurs with the males remaining filiform while the females become oval-shaped and are found inside or attached to the roots of the host plant. In the white cyst stage, the body of the female is about 1-mm wide and visible on the surface of infested roots. Feeding females form enlarged "giant cells" that restrict transport of water and nutrients through the xylem and phloem in the roots. The formation of such enlarged cells near the feeding site is characteristic of cyst-forming nematodes and is essential for the development of the female nematodes. When the female dies, the body wall hardens to a resistant brown cyst that contains and protects the eggs. Emergence of larvae from the cysts shows a seasonal rhythm irrespective of the crop infested and normally occurs between mid-March and July. Fall-sown crops are infested by second-stage larvae that continue their development the next spring.

Although all cereals are hosts for the cereal cyst nematode, differences in susceptibility between cereals occur, with oat and barley the most susceptible, while wheat and rye are less-efficient host plants (Hesling, 1959; Ban & Dubd, 1986). Infestation by the cereal cyst nematode results in a stunted, knotted root system. Aerial parts of infested plants show reduced growth and yellowed leaves. Panicle development of infested oat plants is delayed or is absent in severe infestation.

Weather conditions can significantly modify damage by the cereal cyst nematode. Moist, cool weather at the time of larval emergence is favorable to the nematode, and if such a favorable period is followed by a drought during the growing season of the crop, severe damage to an oat field may result.

13-4.1.2 Stem Nematode

The stem nematode, *Ditylenchus dipsaci* (Kuhn) Filipjev, is widespread throughout western and central Europe, North and South America, Australia, and North and South Africa. Plants are more readily attacked in clayish sand and light loam soils, where water conditions are more favorable for nematode activity. The nematode invades the foliage and the base of the stem of cereals, causing a breakdown of the middle lamellae between cells by secreting a pectinase. Nematodes inhabit the resulting intercellular spaces and move through the tissue feeding on adjacent cells. Reproduction continues inside the plant host almost year round, but is minimal at low temperatures. When an infested plant dies, the infesting nematodes return to the soil and infest neighboring plants. The nematodes are highly mobile in moist, sandy soil and can spread rapidly from one plant to another.

Various morphologically indistinguishable biological races (strains) of the nematode differing in host range have been described (Robertson, 1955). The rye strain of the nematode infests oat, corn, and several other plants. The oat strain infests oat, onion (*Allium cepa* L.), pea, bean, and potato; however, infestation of rye is uncommon.

Infestation by the stem nematode results in local cell hypertrophy and hyperplasia, basal swellings, crinkling of leaves, and dwarfing of plants. Plant internodes are shortened and multi-tillering occurs. Heavily infested plants usually do not survive through the seedling stage, causing bare patches to appear in the field. More lightly infested plants fail to produce panicles and the crop assumes a thin appearance. Root development is also reduced, causing lodging by wind and rain.

The extent of damage done by stem nematode infestation depends in large part on a variety of factors such as host plant susceptibility, level of infestation, soil type, and moisture content. Greater nematode populations persist in heavy soils than in light soils, due in part to the higher moisture content of heavy soils. Cereals are infected by the nematode in the surface layer of the soil. Optimum soil moisture in this layer is favorable for nematode activity and increases the chance of a heavy infestation. Nematode activity is greatly decreased in well-drained fields.

13-4.1.3 Cereal Root-knot Nematode

The cereal root-knot nematode (*Meloidogyne naasi* Franklin) has been reported on oat from Europe, Iran, and the USA (Watson & Lownsbery, 1970). In Europe, oat is a poor host for the nematode compared with barley, wheat, and rye; however, in the USA oat is readily infested. Young larvae invade the roots of the host plant and form small galls. Females become spherical in shape, and females with eggs in an egg-sac occur 8 to 10 wk after infestation within the gall tissue. Hatching of eggs has been reported to be stimulated by exposure to low temperatures followed by warm temperatures (Watson & Lownsbery, 1970). As with the cereal cyst nematode, moist and cool weather at the time of hatch favors dispersal of larvae of the nematode. The symptoms of cereal root-knot nematode infestation resemble those caused by the cereal cyst nematode. Patches of yellowed, poorly growing plants develop within the field and later in the season production of panicles in infested oat is delayed or absent.

13-4.2 Control of Nematode in Oat

Of the control measures commonly used for nematodes, rotation with a nonhost crop is the most recommended (Brown, 1986). Unlike many other cyst-forming nematodes, cereal cyst nematode populations are reduced 45 to 65% by rotation with nonhost crops or by leaving fields fallow (Hesling, 1958; Kort, 1959, 1972).

The occurrence of different strains of the stem nematode with different host ranges makes it difficult to select nonhost crops for rotation. The risk of heavy crop loss, however, can be minimized by not following any crop that was damaged by this nematode with oat, rye, or corn. Effective non-host cereal crops for both the rye and oat strains of the stem nematodes are barley and wheat.

13-5 PRECAUTIONS FOR THE USE OF TOXIC CHEMICALS

The insecticides mentioned in this chapter are poisons. Store them where children and animals cannot reach them. Follow the directions and heed all precautions on the container label and avoid unnecessary exposure while mixing or applying them. Parathion (*O,O*-diethyl *O*-4-nitrophenyl phosphorothioate), TEPP (tetraethyl pyrophosphate), and endrin (1,2,3,4,10,10-hexachloro-1,4,4a,5,6,7,8,8a-octahydro-6,7-epoxy-1,4:5,8-dimethanonaphthalene) are especially dangerous and should be used only by trained operators who will assume full responsibility for their safe use and comply with all precautions prescribed by the manufacturer. In the USA, insecticide-treated oat grain must lack chemical residues or any residues present must be within tolerances established by the Food and Drug Administration.

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