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Issues

Prevalence of Sporadic Insect Pests of Seedling Corn and Factors Affecting Risk of Infestation

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Abstract

A preventative insecticide treatment is a tactic compatible with an integrated pest management (IPM) strategy for a particular pest only when a rescue treatment is not a realistic option, and if there is a reasonable expectation of economic damage by that pest. Most corn, *Zea mays* L., planted in the United States is protected from several sporadic early-season insect pests by neonicotinoid seed treatments, usually without the knowledge of the threat posed in a given field. We undertook an extensive literature review of these sporadic pests to clarify the prevalence of economic infestations in different regions of the United States, and the agronomic, biotic, and abiotic factors that affect the likelihood of attack. The summaries of the prevalence and risk factors presented here should help farmers and consultants better assess the value of preventative protection of seedling corn under local conditions, and provide others with a better understanding of the complexities farmers face in assessing risks posed by potential pests. The profiles suggest that, in general, pressure from most sporadic pests on seedling corn is rare or local, seldom high enough to decrease yield. However, this is not true in all regions for all sporadic pests. An important issue exposed by the profiles is that the value of preventative insecticide protection of seedling corn depends on understanding the likely combined pressure from multiple species. While such risk may often still be negligible, there is a great need for robust methodology to assess the risk posed by multiple pests. This represents a significant challenge for future research.

Key words: Seedling corn pests, sporadic pests, secondary pests, risk factors, pest prevalence

During the last half of the 20th century, two major pests of field corn dominated insect management concerns in most of the corn-growing regions of the United States: lepidopteran corn borers, mainly the European corn borer, *Ostrinia nubilalis* (Hübner), and the rootworm complex, *Diabrotica* spp., mainly the western corn rootworm, *Diabrotica virgifera virgifera* LeConte. Corn rootworms in particular can be devastating and are commonly present at economic levels in continuous (i.e., non-rotated) cornfields except in the far western states. Crop rotation is generally a very effective way of protecting corn from rootworms but is not always a possible or economically desirable option for a variety of reasons (Gray et al. 2009, Sappington 2014). Because rootworm larvae inhabit the soil, it is especially difficult to monitor populations, making economic thresholds and rescue treatments impractical (Chandler et al. 2008). Instead, thresholds of adults were developed to guide decisions about soil insecticide application the following year (Pruess et al. 1974, Foster et al. 1982, Steffey et al. 1982, Stamm et al. 1985). Foster et al. (1986) found that the use of a static economic threshold in this scheme was not always reliable, and they concluded that a preventative soil insecticide in continuous corn was the optimal strategy, something most farmers were doing anyway (Turpin 1977).

Transgenic corn expressing a gene derived from *Bacillus thuringiensis* (Bt) that protects it from western corn rootworm was commercially introduced in 2003, and was adopted quickly by farmers. It provided a number of significant benefits to farmers, including much better control of rootworm larvae than the level of control provided by soil insecticides and simplification of the production system (Rice 2004). However, the discontinuance of routine soil insecticide application for rootworms in continuous corn raised the possibility of injury from other sporadic early-season soil pests, such as wireworms and white grubs, that may have been controlled collaterally, and for which rescue treatments are not effective (Steffey and Gray 2000, 2009; Rice 2004). This possibility was addressed by applying neonicotinoids to seed, most of which already routinely received fungicide treatments as well, to provide systemic protection of the young plant (Steffey and Gray 2009, Tiwari and Youngman 2011, Munkvold et al. 2014). Virtually all Bt corn seed sold in the United States is now treated with neonicotinoid insecticide, and has been for well over a decade (Mullin et al. 2005, Magalhaes et al. 2007, Douglas and Tooker 2015).

Although preventative control of early-season soil-dwelling pests of corn has been widely practiced in continuous corn since the 1960s, in the last 12 yr it has been practiced mostly through the combination of rootworm Bt corn and insecticide seed treatment rather than the application of a broad-spectrum soil insecticide. The realized economic value of a preventative measure taken to protect a crop from a certain pest depends on the realized pest pressure (i.e., level of exposure to damage by the pest) in-season. In the case of continuous corn, preventative control of corn rootworms with Bt corn may be the optimal strategy for a farmer (Crowder et al. 2006), as was an at-planting soil insecticide in earlier years (Foster et al. 1986). In contrast, soil insecticide treatments were not historically routine for corn in rotation with soybean, *Glycine max* L., except in limited regions where rotation-resistant rootworms became a problem beginning in the 1980s (Krysan et al. 1986, Gray et al. 2009). Historically, early-season above-ground pests of corn were sometimes controlled collaterally with foliar sprays for first-generation European corn borer, but treatment for the latter was not routine, and certainly not preventative. Thus, preventative control of early-season soil-dwelling pests in corn planted after soybean, and of above-ground pests of seedling corn, has become a new paradigm for managing insects otherwise difficult to monitor and predict.

One question that confronts us now is what level of economic risk does a corn grower incur from sporadic seedling pests in the absence of preventative control measures (Douglas and Tooker 2015)? This is a critical question for corn growers who would likely forego or reduce the frequency of using an at-planting soil insecticide or insecticidal seed treatment if the level of risk on their farms was deemed acceptable. As a first approach for corn, we have reviewed the literature and created risk profiles for the sporadic seedling corn pests listed on the labels of seed-treatment products containing clothianidin, imidacloprid, or thiamethoxam. Our overall goal in this review is to qualitatively assess the likely frequency of economic problems caused by these insects in seedling corn, based in part on the pressure they exerted before the era of widespread use of neonicotinoid seed treatments. For each pest, we highlight: 1) the nature and severity of damage it can cause to the seed or seedling; 2) aspects of the ecology, biology, behavior, life cycle, and life-history traits that influence colonization of the crop and that characterize the dynamics of an early-season infestation; 3) frequency and severity of early-season economic infestations to be expected across a region in the absence of control measures; 4) local and regional factors (agronomic, biotic, abiotic) that increase or decrease risk of infestation; and 5) general management options and strategies available to farmers.

Sporadic Pest Risk Profiles

In each of the following profiles, publications that provide useful summary information on the insect's biology, ecology, pest status, management options, and other general information are listed at the beginning without comment. Any of these or other publications that cite unique observations, interpretations, or insights, or that support statements with original data, are cited in the text in the normal way. This method of presentation has been adopted to improve the flow of the narrative without neglecting the important contributions of many authors.

Billbugs

The following references provide useful summary information on the insect's biology, ecology, pest status, management options, and other general information discussed in this profile: Satterthwait (1931), Musick (1985), Dicke and Guthrie (1988), Rice (1997), O'Day et al. (1998), Van Duyn and Wright (1999), Steffey and Gray (2000), Kluchinski (2003),Van Duyn et al. (2005), Anonymous (2009a), Catchot (2016), and Flanders (2016).

Billbugs comprise a group of widely distributed weevil species in the genus *Sphenophorus* (Coleoptera: Curculionidae). The two most important pest species in corn are the southern corn billbug, *Sphenophorus callosus* (Olivier) (Fig. 1), principally in the south, and the maize billbug, *Sphenophorus maidis* Chittenden, which predominates in the Corn Belt. Each species completes one generation per year, overwintering as adults in soil or plant debris. Adults seldom fly, preferring to walk, limiting most dispersal to about 400 m (1,312 ft) or less from the overwintering site. Furthermore, they have a limited host range; corn and yellow nutsedge, *Cyperus esculentus* L., are the most favorable for adult feeding and larval development (Wright et al. 1982). Both adults and larvae can damage seedling corn. The adult feeds by puncturing the stalk near its base to feed on the plant tissue inside the pith or meristem regions (All et al. 1984). Females oviposit in feeding holes in the plant, after which the larvae tunnel in the stalk at or below the soil surface; or they oviposit in the soil, after which the larvae feed on or in the roots. Plants can outgrow light to moderate feeding that injures only leaf tissue. However, injury to the growing point of plants up to the six-leaf stage may result in excessive tillering, stunting, or death (All et al. 1984). A large billbug population can cause serious damage through stand reduction. In experiments in which corn 5–81 cm (2–32 in) in height was manually infested with treatments of 5–320 adult southern corn billbugs per 100 plants, yield was significantly reduced in every treatment tested, even though plant population was not significantly reduced (DuRant 1982).

Billbugs are important pests in the Atlantic Coastal Plain region, especially in the Carolinas and Georgia (DuRant 1982, Van Duyn and Wright 1999). The four most important corn insects comprising the soil pest complex in Georgia—billbugs; lesser cornstalk borer, *Elasmopalpus lignosellus* (Zeller); wireworms (Elateridae); southern corn rootworm, *Diabrotica undecimpunctata howardi* Barber—accounted for most of the control costs and most of the yield loss on untreated hectares (acres) from the 1980s through at least the early 1990s (e.g., Isenhour et al. 1988a, All and Hudson 1993). Outside of this region, billbugs have been considered sporadic, minor, and

Fig. 1. Southern corn billbug. Photo: Marlin E. Rice.

local pests (NAS 1975, Van Duyn and Wright 1999). In a 1972–1974 survey of 234 Indiana cornfields not treated with a soil insecticide, billbugs were present in three fields (1.3%) and did not cause yield loss (Turpin and Thieme 1978). Typical maize billbug pressure in the Corn Belt was ranked by a National Academy of Sciences panel in the mid-1970s as 'Very Low' (0–1% losses) in general and 'Moderate' (11–35% losses) in local areas (NAS 1975). Billbugs were estimated to infest <1% of cornfields in New Jersey (Kluchinski 2003) and Illinois (Pike et al. 2000), with 0% average crop losses in Illinois. Nevertheless, an increase in billbug problems was noted in Illinois in 1998 and 1999, for reasons that were unclear (Steffey and Gray 2000). Similarly, billbugs are of little concern in Iowa in most years, but at least two infestations in that state in May 1997 were alarming enough to warrant an alert to farmers (Rice 1997).

An insecticide applied as a rescue treatment is possible for control of adult billbugs if early scouting indicates extensive feeding and possible stand loss (Steffey and Gray 2000, Michel 2013). There is no rescue option for controlling larvae inside the stalk, which can reduce yield up to 50% (Van Duyn and Wright 1999). A preventative application of a soil insecticide for billbug control is of uncertain benefit and usually not recommended, although it may be justified in fields where billbugs are a chronic problem.

Cultural management options such as crop rotation, good weed control (especially of nutsedges, *Cyperus* spp.), and early planting are usually sufficient to avoid billbug problems. Limited dispersal and limited host range together make crop rotation an effective tool for avoiding billbug problems, and conversely place non-rotated corn at more risk because populations can build up over years (Gardner and All 1985). However, rotations out of grass sod; rye, *Secale cereale* L.; wheat, *Triticum aestivum* L.; or clover, *Trifolium* spp. increase risk of billbugs in the following corn crop (Gardner and All 1985, Kuhlman and Steffey 1987, House and Alzugaray 1989, Steffey and Gray 1989). Corn is most at risk around field edges that receive overwintering adults immigrating from adjacent weeds or fields planted with corn the previous year. Likewise, corn within a field surrounding patches of yellow nutsedge is prone to billbug problems. In both situations, spot treatment of adults in problem areas may be justified (Van Duyn and Wright 1999). Nutsedge is often associated with low-lying areas and poorly drained soil or soil with high organic matter content (Hoffman 2004), making such areas at highest risk of billbug problems. In Kansas, the maize billbug is considered a minor pest in overflow land where sedges are present (Higgins 1994). In the Atlantic Coastal Plain region, fields are most at risk from southern corn billbug in tidewater areas and cleared lowlands (Van Duyn et al. 2005). Better drainage and weed control probably are the main reasons that billbugs are not as threatening in most regions of North America as they were during the first half of the last century (Dicke and Guthrie 1988). No-till cornfields are at significantly greater risk of billbug problems than conventionally tilled fields, presumably because of increased survival of overwintering adults in plant debris (All et al. 1984, Musick 1985, House and Alzugaray 1989).

Black Cutworm

The following references provide useful summary information on the insect's biology, ecology, pest status, management options, and other general information discussed in this profile: Sherrod et al. (1979), Dicke and Guthrie (1988), Showers (1997), O'Day et al. (1998), Fournier et al. (1999), Showers and Keaster (1999), Kluchinski et al. (2003), McLeod and Studebaker (2003), Van Duyn et al. (2005), Krupke and Obermeyer (2011a), Catchot (2016), Flanders (2016).

Cutworms are a complex of several species of moth (Lepidoptera) larvae in the family Noctuidae, but the species that is most frequently a problem in corn is the black cutworm, *Agrotis ipsilon* (Hufnagel) (Story et al. 1984) (Fig. 2). The black cutworm is polyphagous and the larvae prefer weeds to corn for feeding, attacking corn seedlings only when deprived of weeds by tillage or herbicide application (Busching and Turpin 1976, Mulder and Showers 1983, Showers et al. 1985, Engelken et al. 1990). The larval stage consists of six to seven instars. Fourth instars and older can kill corn seedlings up to the fourth- or fifth-leaf stage by severing the stalk at or below the soil surface, but plants cut above the growing point usually recover (Archer and Musick 1977; Showers et al. 1979, 1983; Levine et al. 1983; Whitford et al. 1989; Santos and Shields 1998). This species does not overwinter north of about 38° N latitude, and infestations during the spring in most of North America are the result of moths that have migrated from overwintering areas along the Gulf Coast or Mexico (Showers et al. 1989a, b; Hendrix and Showers 1992). Migratory flight is substantially aided by winds associated with weather systems (Domino et al. 1983, Smelser et al. 1991), affecting both the timing and location of arrival by immigrant cohorts, generating considerable year-to-year variability in local black cutworm populations. Thus, management relies mostly on scouting of seedling corn and application of foliar-applied insecticides as rescue treatments as needed.

Black cutworm was formerly a more frequent cause of economic loss in corn than it is now, with outbreaks common in the Corn Belt in the early 1980s and earlier (Showers et al. 1983, Foster and Tollefson 1986). But black cutworm infestations have always been sporadic in most areas. Of 234 cornfields in seven counties in Indiana sampled during 1972–1974, cutworms were present in two fields (0.8%) and caused no yield loss (Turpin and Thieme 1978). In a survey of 127 cornfields in Missouri, Illinois, and Iowa from 1979 through1981, black cutworm larvae were present in 78 fields (61%) (Story et al. 1984). Thirteen of the 29 (45%) fields scouted in six counties in Missouri in 1979 required rescue treatment for

Fig. 2. Black cutworm, late instar cutting plant. Photo: Marlin E. Rice.

black cutworm infestations (Story et al. 1983). In a 1992 survey, the mean ranking of severity of cutworm infestations by 1,598 farmers from 12 Midwestern states was 0.73 on a scale of 0–3, where 0 = pest not present, and 1 = pest occurs occasionally and may not warrant control measures (Aref and Pike 1998). Of the 501 farmers surveyed from 12 states and who grew a minimum of 48.6 ha (120 acres) (mean 528 ha [1,304 acres]) of corn in 2013, 5.6% indicated they actively managed cutworms and 1.4% indicated black cutworm was the most important insect pest to manage (Hurley and Mitchell 2014). In Illinois, about 25% of fields were estimated to be infested annually, but with only 0.1% crop loss resulting (Pike et al. 2000). Only a small percentage of fields in North Carolina were treated for black cutworm (Van Duyn et al. 2005). Less than 10% of fields in New Jersey (Kluchinski 2003) and 5–15% of sweet corn fields in New York (Stivers 1999) were infested annually. One percent of corn in Texas suffered economic damage from cutworms annually (Anonymous 2003).

The trend for planting corn earlier in the year is partly responsible for the relative decline in importance of black cutworm in recent decades, because offspring of moths that arrive later in the spring do not have time to develop to cutting size before the plants outgrow the risk (Krupke and Obermeyer 2011b). Another factor that has lessened the impact of black cutworms has been the wide adoption of transgenic herbicide-tolerant crops (Dill et al. 2008) and the routinely excellent control of weeds they have made possible over the last two decades. Weed-free fields with or without corn seedlings are not attractive to female black cutworms, and evidence strongly suggests that the larvae starve in fields cleared of weeds more than 8–14 d before planting (Showers et al. 1985). It is possible that use of Cry1F-expressing Bt corn hybrids and neonicotinoid seed treatments have lessened cutworm problems (Kullik et al. 2011), but observations (Krupke and Obermeyer 2011a, c) suggest that these products do not always adequately protect corn when infestations are severe.

Despite its decreased frequency of impact in recent decades, the black cutworm is still quite capable of inflicting sporadic economic losses and cannot be ignored (e.g., Krupke et al. 2011c). Its annual recolonization of most states via wind-aided spring migration makes it impossible to predict whether an individual field will be infested. However, there are factors that make certain fields or parts of fields more attractive to ovipositing females, and thus more at risk of damage. The most important is the presence of winter annual and perennial weeds (Sherrod et al. 1979, Showers et al. 1985). Corn in flood plains and low-lying areas of a field is at greater risk. Cloddy fields, often caused when farmers work the soil when it is too wet, may harbor higher cutworm populations (McLeod and Studebaker 2003). Reduced-tillage fields, especially with soybean stubble, are more at risk of black cutworm infestation. The underlying reasons for why low-lying, cloddy, and reduced tillage fields are a problem are unknown, but may be related to complications with weed control or possibly better microhabitat for larval survival. Certain fields or areas of fields may have a history of cutworm problems for reasons known or unknown, thus serving as a risk factor by itself. In Illinois, the estimated probability of economic infestations of cutworms in corn was 1% when corn was planted after corn, 2% when corn was planted after small grains, and 4% when corn was planted after soybean, legumes, or grass sod (Kuhlman and Steffey 1987).

Chinch Bug

The following references provide useful summary information on the insect's biology, ecology, pest status, management options, and other general information discussed in this profile: Dicke and Guthrie (1988), Higgins (1994), Spike et al. (1994), O'Day et al. (1998), Byrd et al. (1999), Riley and Wilde (1999), McLeod and Studebaker (2003), Anonymous (2009a), Catchot (2016), and Flanders (2016).

The chinch bug, *Blissus leucopterus leucopterus* (Say) (Hemiptera: Blissidae) (Fig. 3), is a native of North America east of the Rocky Mountains, and a sporadic pest of corn. Adults overwinter in bunchgrasses and in plant debris, especially in fence rows, and fly to host plants in the spring to oviposit. Chinch bugs prefer sorghum and barley over corn and wheat (Smith et al. 1981), but the plants must be at an appropriate developmental stage to be attractive. In more northern parts of the chinch bug's range, this means that small-grain crops are usually infested first by the overwintering adults and their offspring. When the crop senesces, nymphs crawl across the ground up to 400 m (1,312 ft) to alternative hosts, often seedling corn or sorghum (Negron and Riley 1985, 1991). There are two generations of chinch bugs per year in the north and three or more generations per year in the south. Both adults and nymphs feed on plant fluids by piercing the stalk near the base with their mouthparts. Seedling corn up to 46 cm (18 in) is at most risk of economic damage (Stewart et al. 1982, Negron and Riley 1985). Feeding on young plants can cause wilting or death, but older plants can tolerate all but severe infestations (Negron and Riley 1985). Young plants that survive injury may nevertheless be stunted and suffer a yield loss (Negron and Riley 1990).

Chinch bugs are commonly managed by early planting, a preventative planting-time application of a soil insecticide, or a rescue treatment with a foliar-applied spray. A spectrum of susceptibility to chinch bugs has been observed among corn hybrids (Dicke and Guthrie 1988, Davis et al. 1996, Wilde et al. 2004), but research to develop host plant resistance has been limited.

Although the chinch bug has been only an occasional minor pest of corn in recent decades, historically it was responsible for widespread economic losses (Smith 1934, Shelford and Flint 1943, Spike et al. 1994). Its decline in importance on corn is due in part to earlier planting dates, which presents overwintered adults with older, less-susceptible corn plants for colonization (Negron and Riley 1990, Davis et al. 1996). In addition, preferred overwintering habitat is less abundant now that native grasslands have largely disappeared from major corn-growing regions (Spike et al. 1994). In a 1992 survey, the mean ranking of severity of chinch bug infestations in corn by 1,598 farmers from 12 Midwestern states was 0.30 on a scale of 0–3, where 0 = pest not present, and 1 = pest occurs occasionally and may not warrant control measures (Aref and Pike 1998). Chinch bugs have been considered very minor pests in North Carolina (Van Duyn et al. 2005), and only 3 of 501 corn growers surveyed across 12 states indicated they actively manage them (Hurley and Mitchell

Fig. 3. Chinch bugs. Photo: Marlin E. Rice.

2014). Spot treatment for localized chinch bug populations in Indiana has rarely been needed (Anonymous 2009a).

While economic impact by chinch bugs on corn in northern states is negligible, it is more important in southern states. Yield increases of 1.68 mt/ha (25 bu/ac) were reported in Arkansas where chinch bugs were controlled, but populations were highly variable across time and space (McLeod and Studebaker 2003). They cautioned that application of a soil insecticide or insecticidal seed treatment is not always justified. In the 1990s, 25% of Mississippi corn area was treated with a soil insecticide, and chinch bug was usually the most important target pest (Byrd et al. 1999). In Texas, chinch bugs infest about 5% of corn area, but pressure depends on the region of the state, with the greatest (20%) occurring in the South-Central and Upper Coast regions; when chinch bugs are present and left untreated, an 8% yield loss is possible (Anonymous 2003).

Certain factors can increase risk of a chinch bug problem in a given cornfield. The 30–40 border rows of a cornfield are at increased risk of infestation by nymphs leaving an adjacent small-grain crop as it matures or is harvested. Planting date relative to emergence of overwintered adults is an important factor, with early-planted corn being at least risk (Negron and Riley 1985, 1990; Davis et al. 1996; McLeod and Studebaker 2003). Because older plants are better able to tolerate chinch bug attack, anything that slows growth of the seedlings increases the window of susceptibility to damage. This may include cool spring temperatures, excess water, and herbicide injury (Flanders 2016), but drought stress is the most likely factor to exacerbate susceptibility of the plants (Peters 1983). Cornfields with reduced tillage and grassy weeds may be at increased risk of chinch bug infestations (Flanders 2016).

Corn Flea Beetle

The following references provide useful summary information on the insect's biology, ecology, pest status, management options, and other general information discussed in this profile: Poos (1955), Stewart et al. (1982), Dicke and Guthrie (1988), Higgins (1994), O'Day et al. (1998), Pike (1998), Byrd et al. (1999), Fournier et al. (1999), Gray (1999), Munkvold (1999, 2001a), Stivers (1999), Esker and Nutter (2000), Rice (2000, 2001a), Sandell et al. (2002), Johnson (2002), Kluchinski (2003), McLeod and Studebaker (2003), Hensley et al. (2005), Rice et al. (2005), Van Duyn et al. (2005), Brown-Rytlewski and Kirk (2006), Rice and Pope (2006), Jia et al. (2007), Westgate and Hazzard (2007), Nutter et al. (2008, 2009, 2011), Foster and Obermeyer (2010), Hodgson (2011), Jackson and Wright (2012), Anonymous (2016), Flanders (2016).

Several species of flea beetle feed on corn, but the corn flea beetle, *Chaetocnema pulicaria* Melsheimer (Coleoptera: Chrysomelidae) (Fig. 4), is by far the most common and economically important (Poos 1955, Adams and Los 1986). The corn flea beetle occurs throughout most of the eastern United States and into the Great Plains. Its range in New England has been expanding northward with warmer winters (Westgate and Hazzard 2007). It overwinters as an adult at or just under the soil surface in grassy areas near cornfields. Several grass species can serve as hosts for corn flea beetles, but adults move to corn after the plants emerge to feed on leaves and oviposit on the soil surface. Larvae feed on plant roots but are not a significant source of damage. In Iowa, a 2- to 3-wk 'beetle-free' period occurs in June between the death of the overwintered adults and the emergence of the next generation of adults (Esker and Nutter 2003). Subsequent generations overlap, usually totaling two or three generations per summer.

Large populations of corn flea beetles can cause economic damage to seedling corn by skeletonizing the leaves, resulting in stunting and yield loss, or even death. Nevertheless, most plants recover fully from all but severe damage, which is rare.

Fig. 4. Corn flea beetle. Photo: Marlin E. Rice.

The main economic importance of the corn flea beetle, however, arises from its role as the overwintering host and primary vector of the bacterial pathogen *Pantoea* (formerly *Erwinia*) *stewartii* (Smith) Dye, which causes Stewart's disease in corn (Elliott and Poos 1934, Adams and Los 1986, Esker and Nutter 2003), also commonly called Stewart's wilt or bacterial leaf blight. Although other beetle species can vector the bacterium, their importance is negligible. Stewart's disease occurs in two phases, seedling wilt and leaf blight in older plants (Munkvold 2001a). The bacterium is efficiently acquired and transmitted during leaf feeding by adult corn flea beetles (Menelas et al. 2006). Plants infected as seedlings often die, and stunted survivors suffer yield loss or produce no ears at all. Stewart's disease is endemic to North America and is common in the eastern United States and southern Corn Belt, with more sporadic epidemics to the north and south (Pataky et al. 2000b).

The disease cannot be controlled directly with pesticides, and the best management tool is host plant resistance (Pataky et al. 2000b). Most field corn hybrids are sufficiently tolerant of Stewart's disease that infection does not cause economic loss, although some hybrids can be impacted (Pataky et al. 2000b, Yang 2000, Van Duyn et al. 2005, Anonymous 2016), especially when corn flea beetle populations are large (Munkvold 2001a). However, many inbred lines in seed production fields and many sweet corn hybrids are susceptible to *P. stewartii* and are at higher risk of economic damage than commercial grain-corn hybrids (Munkvold 2001a). Young plants up to five-leaf stage are most at risk from the beetle and the disease. For susceptible lines or hybrids, management of Stewart's disease depends on management of corn flea beetle populations.

A well-timed treatment with a foliar-applied insecticide can be effective in reducing a corn flea beetle population and thus Stewart's disease transmission to plants. However, an unresolved management issue is that flea beetle population thresholds for rescue treatments were developed to protect the plants from beetles feeding on leaves, not for prevention of Stewart's disease. Yet rescue treatments tend to be applied in the context of protecting the crop from Stewart's disease where lower adult densities can result in economic losses (Munkvold 2001a). Neonicotinoid seed treatments are effective against the corn flea beetle and can reduce the impact of Stewart's disease (Pataky et al. 2000a). Transmission of the pathogen during feeding is relatively fast (~7 h) (Menelas et al. 2006), but not instantaneous, implying that the neonicotinoid insecticide stops adult feeding before transmission is accomplished in most cases (Pataky et al. 2000a).

Large populations of the corn flea beetle are not always associated with a severe outbreak of Stewart's disease (Poos 1955), but there is nevertheless a reasonably strong association between numbers of flea beetles and risk of the disease (Pike 1998, Esker et al. 2006). Models that predict prevalence and severity of Stewart's disease are based on winter temperatures, because cold temperatures increase mortality of overwintering adults harboring the bacterium, although insulating snow cover can improve survival at lower temperatures. Predictions of moderate-to-high severity of the disease are used to alert farmers to scout for flea beetle populations early in the season. However, such predictions are necessarily coarse-grained, because disease pressure in spring depends not only on the rate of survival of overwintering corn flea beetle adults, but also on the absolute abundance and proportion of adults infected, both of which vary spatially and temporally (Esker and Nutter 2003, Nutter et al. 2009, Jackson and Wright 2012). Sweep samples from several locations in Iowa indicated 10–11% of corn flea beetles were infected by *P. stewartii* in spring of 1999, contrasted with 8–30% in spring of 2000 (Esker and Nutter 2003). Infection rates of overwintered adults in New England can range from 20 to 40% (Westgate and Hazzard 2007).

Although widespread throughout the Corn Belt and Mid-Atlantic states, economic outbreaks of Stewart's disease (mainly in sweet corn) are sporadic in time and space (Fournier et al. 1999; Pataky 2000a, 2000b; Munkvold 2001a; Anonymous 2016). Losses from the corn flea beetle and the disease are rare in southern states (Byrd et al. 1999, McLeod and Studebaker 2003, Flanders 2016). The estimated threat of losses caused by corn flea beetle in the Corn Belt in the mid-1970s was 'Low' (2–10%) in the absence of any control measures, and 'Moderate' (11–35%) in 'special local areas' (NAS 1975). Of 234 cornfields in seven counties in Indiana sampled from 1972 through 1974, flea beetles were present in two fields (0.9%; one each in 1972 and 1973), and did not cause yield loss in any (Turpin and Thieme 1978). In the 1990s and early 2000s, Stewart's disease increased in importance in Iowa as several warm winters improved overwintering survival of corn flea beetles (Pike 1998, Munkvold 2001b, Esker et al. 2006). Outbreaks diminished again in the mid-2000s, possibly as a result of cold winters and widespread adoption of neonicotinoid seed treatments (Nutter et al. 2008, 2009, 2011). In Indiana and Nebraska, the corn flea beetle and Stewart's disease are more common in southern than in northern areas (Foster and Obermeyer 2010, Jackson and Wright 2012), presumably because of differences in winter temperatures.

In addition to mild winters and susceptibility of the corn line or hybrid to Stewart's disease, other factors can affect the level of risk posed by corn flea beetle. Early planting or cool spring temperatures that slow seedling growth can increase exposure of young plants (before the five-leaf stage) to corn flea beetles. Weedy fields or proximity of fields to grassy weeds or wheat may increase risk to seedling corn. Dry conditions may exacerbate stress on infected plants, and fields with reduced tillage may be at greater risk of a flea beetle infestation.

Corn Leaf Aphid

The following references provide useful summary information on the insect's biology, ecology, pest status, management options, and other general information discussed in this profile: McColloch (1921), Stewart et al. (1982), Gesell and Calvin (1983), Dicke and Guthrie (1988), Steffey and Gray (1989), Higgins (1994), Bing (1999), Byrd et al. (1999), Delahaut and Thiede (1999), Sandell et al. (2002), Bessin (2003a), Kluchinski (2003), Baniecki and Dabaan (2004), Hoffman (2004), Hensley et al. (2005), Godfrey et al. (2006), Hodgson (2009), Boucher (2012), Catchot (2016).

A number of aphid species can be found in corn, but the corn leaf aphid, *Rhopalosiphum maidis* (Fitch) (Hemiptera: Aphididae) (Fig. 5), is the most common and most likely to cause economic damage. In North America, adults overwinter in southern states and migrate in the spring to colonize hosts in northern latitudes (Kieckhefer et al. 1974, Foott 1977, Irwin and Thresh 1988). The corn leaf aphid prefers sorghum, but has many host plants, including wild grasses (Bing et al. 1991, Carena and Glogoza 2004).

Economic damage is usually associated with heavy infestations of corn leaf aphid in the late-whorl stage and during pollination when aphids tend to feed on the tassel and upper leaves of the plant (McColloch 1921, Foott and Timmins 1973). Yield loss also can be substantial if seedlings are infested (Bing et al. 1991), but frequency of seedling attack in the field is unclear. Foott (1977) cited numerous studies that indicated corn cannot be colonized until plants are about 30 d old, but Dicke and Sehgal (1990) reported that corn leaf aphid alates are highly attracted to seedlings, and seedlings of inbred lines were successfully colonized in the greenhouse (Bing et al. 1991). In Texas and Mississippi, farmers are advised that seedlings might be attacked (Stewart et al. 1982, Byrd et al. 1999). In northern regions where the corn leaf aphid cannot overwinter, colonization by immigrants does not begin until late spring or early summer, around mid-to-late-whorl stage (Foott 1977). Although populations on seedling corn are usually too small to warrant treatment, early infestations may still be important because there is more time for the population to build on plants to cause injury later in the season (Foott 1977). Damage is caused mainly through removal of plant nutrients that would otherwise go to reproduction (Foott and Timmons 1973), and possibly physiological damage caused by aphid saliva (Carena and Glogoza 2004), leading to stunting, delayed development, and yield loss (Everly 1960, Bing et al. 1991). Economic damage to sweet corn is mainly cosmetic (Stivers 1999, Hensley et al. 2005).

In addition to causing direct feeding injury, the corn leaf aphid is a vector of *Maize dwarf mosaic virus (MDMV)*, transmitting it to corn from wild grasses, especially johnsongrass, *Sorghum halepense* (L.) Persson (Dicke and Guthrie 1988, Carena and Glogoza 2004). *MDMV* can cause economic loss, but its importance varies widely in space and time (Godfrey et al. 2006). The significance of its transmission by corn leaf aphid is not always clear (Blair 1970, Shaunak and Pitre 1971, Stivers 1999, Westgate and Hazzard 2007).

Despite the ubiquity of corn leaf aphid in cornfields throughout North America, it is considered only a minor pest (Everly 1960; Bing et al. 1990a, 1992) of little economic importance in field corn. An outbreak in 1980 in Illinois resulted in 162,000 ha (400,140 ac)

Fig. 5. Corn leaf aphids (majority, no red on abdomen), with a few bird cherry-oat aphids, *Rhopalosiphum padi* (L.). Photo: Marlin E. Rice.

treated, but many fewer hectares (acres) were treated the 2 yr before and after (Irwin and Thresh 1988). In a typical year in Illinois, corn leaf aphid is estimated to infest <1% of cornfields with 0% average crop losses (Pike et al. 2000). Corn leaf aphid injured 5–10% of corn plants in northern Indiana in 1959 (Everly 1960). Carena and Glogoza (2004) listed 12 other outbreaks of corn leaf aphid in the Corn Belt, all before 1970, and all but one limited to a particular state. Typical corn leaf aphid pressure in the Corn Belt was ranked by a National Academy of Sciences panel in the mid-1970s as 'Low' (2–10% losses) in general and 'Moderate' (11–35% losses) in local areas (NAS 1975). It causes problems in New Jersey field corn only once every 15 yr (Kluchinski 2003), and infestations in Pennsylvania in a typical year were estimated as 0–3% of plants (Gesell and Calvin 1983). In a 1992 survey, the mean ranking of severity of aphid infestations in corn by 1,598 farmers from 12 Midwestern states was 0.56 on a scale of 0–3, where 0 = pest not present, and 1 = pest occurs occasionally and may not warrant control measures (Aref and Pike 1998). Six of 501 corn growers surveyed across 12 states in 2013 indicated they actively managed any of four species of aphid, including corn leaf aphid, and none listed aphids as the most important corn pest for management (Hurley and Mitchell 2014).

In the Corn Belt, infestations of corn leaf aphid are difficult to predict because colonization is dependent on immigrants from southern latitudes carried north on winds (Irwin and Thresh 1988). Most colonization in this broad region occurs well after seedling stage (discussed earlier), and severe infestations at the time of tasseling are controlled with a foliar insecticide treatment (Bing et al. 1992, 1999; Carena and Glogoza 2004; Hodgson 2009; Flanders 2016). Colonization is effected by only one or a few alates on a given plant, and attrition is high through the late-whorl stage of corn growth (Foott 1977) when the plants are at most risk of injury. Aphid populations are usually suppressed by natural enemies, and heavy rains can destroy aphid populations in the whorl (Foott and Timmons 1973, Dicke and Guthrie 1988). Risk factors include drought stress, which exacerbates injury by aphids (Foott and Timmons 1973, Bing et al. 1991), and a late planting date, because aphid populations have more time to grow before the plants produce tassels (McColloch 1921, Everly 1960, NAS 1975). For the same reason, seed corn fields are often more at risk than field corn, because of the need to delay planting for some genotypes (Gesell and Calvin 1983, Bing et al. 1991). Infestations of johnsongrass near cornfields may increase the risk of inoculation of *MDMV*, especially in late-planted corn (Sandell et al. 2002). Some corn lines are more tolerant of corn leaf aphid feeding than others (Bing and Guthrie 1991; Bing et al. 1991, 1992), but breeding for resistance has been hindered in part by unreliable field populations of the aphid (Carena and Glogoza 2004). Some cultivars carry resistance to *MDMV* (Anzola et al. 1982, Jones et al. 2007).

Grape Colaspis

The following references provide useful summary information on the insect's biology, ecology, pest status, management options, and other general information discussed in this profile: Bigger (1928), Lindsay (1943), Dicke and Guthrie (1988), O'Day et al. (1998), Steffey (1999a), Rice (2003a), Estes et al. (2006), Kaeb and Tollefson (2006), Steffey and Gray (2009).

The grape colaspis, *Colaspis brunnea* (Fabricius) (Coleoptera: Chrysomelidae), is found east of the Rocky Mountains but is a sporadic pest of corn mainly in the North-Central states. Half-grown larvae overwinter in the soil and feed on the roots of corn seedlings in the spring (Bigger 1928). Adults oviposit in large clusters (Lindsay 1943), so even though the larvae are small, several attacking simultaneously can stunt or even kill a corn seedling (Kaeb 2006). Infestations within a field are aggregated, and areas of stand loss are usually patchy. There are no effective rescue treatments, making replanting after significant stand loss the only recourse after injury is detected. The grape colaspis is considered an infrequent pest of corn that seldom causes economic damage, especially since the 1950s and early 1960s when modern crop rotation sequences and continuous corn became more predominant. In a 10-yr survey of soil pests in 452 cornfields in Illinois from 1954 through 1963, grape colaspis was detected on 4% of plants and in 10% of fields (Bigger and Petty 1965). In a similar study in neighboring Indiana, grape colaspis was detected in only one of 234 (0.4%) cornfields sampled over a 3-yr period (1972–1974) and did not cause yield loss in that field (Turpin and Thieme 1978). Losses from this insect in the Corn Belt in the mid-1970s were ranked by a National Academy of Sciences panel as 'Very Low' (0–1%), both in general and in localized areas (NAS 1975). In seed treatment efficacy trials in western Illinois, grape colaspis was present in all plots, but not in numbers large enough to cause significant yield loss (Estes et al. 2006). Likewise, populations of grape colaspis at several experiment sites in Illinois in 2009–2011 were extremely low, and Estes et al. (2016) concluded that preventative use of soil insecticides for their control (and control of other secondary underground pests of corn) is unnecessary in the 'vast majority' of production cornfields in that region. Despite being uncommon, grape colaspis occasionally causes problems in a few fields clustered in local regions (e.g., Steffey and Gray 2000, Rice 2003a).

Because of grape colaspis oviposition preferences, corn planted after a legume, especially red clover, *Trifolium pratense* L., may be at increased risk of injury at localized spots within a field. To a lesser extent, corn planted after sweetclover, *Melilotus* spp., alfalfa, *Medicago sativa* L.; and lespedeza, *Lespedeza cuneata* (Dumont) G.Don may be at risk, especially if the legumes were grown for 2 yr (Stone and Smith 1951, Dicke and Guthrie 1988, Steffey and Gray 2000). Until relatively recently, corn planted after soybean was considered to be at minimal risk. For example, Kuhlman and Steffey (1987) estimated the probability of economic damage in corn planted after legumes such as clover and alfalfa as 1:4, but only 1:1,000 in corn planted after soybean. However, reports of grape colaspis injury in corn planted after soybean increased in the late 1990s in the Midwest (Kaeb 2006), and Steffey and Gray (2000) speculated that the insect may have adapted to this modern rotation scheme.

Injury caused by grape colaspis is more likely when seedling growth is slowed, such as during cool weather, making early planting a risk factor (Lindsay 1943, NAS 1975, Steffey and Gray 2000). Dry conditions can increase the occurrence of symptoms resulting from feeding, including stand loss, because of the plant's compromised ability to compensate for damage (Kaeb and Tollefson 2006). Conversely, grape colaspis is unlikely to be a problem when growing conditions are good (Steffey and Gray 1989). The lower vigor of inbred seed corn lines places them at more risk than commercial hybrids (Kaeb 2006). Lindsay (1943) found an association of grape colaspis damage with silt loam and loess soils, including spotty damage within fields that tended to be on higher ground with poor soil. It is difficult to anticipate the presence of grape colaspis in any particular field, and a history of infestation may be the best predictor of fields at risk of future injury (Kaeb 2006).

Imported Fire Ant

The following references provide useful summary information on the insect's biology, ecology, pest status, management options, and other general information discussed in this profile: Lofgren et al.

(1975), Drees et al. (1991, 2013), Drees (1999a), Anonymous (2003), Studebaker et al. (2013), Catchot (2016), Collins and Scheffrahn (2016), Flanders (2017).

There are two species of imported fire ant in North America, the red imported fire ant, *Solenopsis invicta* Buren (Hymenoptera: Formicidae), and the black imported fire ant, *Solenopsis richteri* Forel. The black imported fire ant is found in a relatively small region of northern Mississippi and northern Alabama. The red imported fire ant was introduced from Brazil to Alabama or Florida in the 1930s or 1940s and is now established in at least 13 states across the southern United States from California to North Carolina. The red imported fire ant is economically the far more important of the two species, and we focus on it in this profile.

The red imported fire ant is a species adapted to colonize disturbed habitats (Tschinkel and King 2013), so it is not surprising that agricultural fields are often infested. It is considered a pest of corn because it injures newly planted or germinated seed by feeding on the embryo (Drees et al. 1991, Ready and Vinson 1995, Morrison et al. 1997). Stand reduction can occasionally be severe, and the ants' large mounds can cause problems during harvest (Lyle and Fortune 1948, Eden and Arant 1949, Polk 1999).

In the initial decades after its introduction to North America, red imported fire ant was monogyne, having a single queen per mound, but in the 1970s it began shifting to a predominantly polygyne form, that is, with multiple queens per mound (Macom and Porter 1996), and both forms are often sympatric in the landscape. The multi-queen form spreads mainly through ground migration of colonies, whereas the single-queen form founds new colonies after mating flights (Drees et al. 2013).

Management is primarily accomplished with insecticidal baits, seed treatments, or soil insecticides applied at planting (Drees et al. 1992, 2013; Williams et al. 2001; Calixto et al. 2007), although biological control may be making modest headway as a management tactic (Oi et al. 2008). Before neonicotinoid seed treatments became nearly ubiquitous in corn, some growers simply accepted yield losses rather than incur the expense of treatment (Lard et al. 2002).

The red imported fire ant is very common throughout the landscape, including agricultural cropland (Summerlin et al. 1976, Summerlin and Green 1977, Adams 1986, Morrison et al. 1997, Knutson and Campos 2008), putting many fields in the South above a treatment threshold of about 50 mounds/ha (124 mounds/ac) (Oi et al. 1994, 2008; Drees et al. 2013). A 1989 survey of 52 roadside sites along two transects from northern Florida through Louisiana revealed red imported fire ant present at all except two sites (which were occupied by *S. invicta* x *S. richteri* hybrids) at an average density of 170 mounds/ha (420 mounds/ac) for the single-queen form (83% of sites) (Porter et al. 1992). Densities of the multi-queen form are about twofold greater than those of the single-queen form (Macom and Porter 1996). Reports of economic damage in agricultural fields were rare from the 1950s through 1960s, but began increasing during the 1970s, perhaps due to discontinued heavy use of organochlorine insecticides (Smittle et al. 1983, Adams 1986). Alternatively, increasing numbers of reports of crop damage into the 1990s (Ready and Vinson 1995) may be related to the corresponding shift to the multi-queen form. Red imported fire ant is omnivorous, and seeds tend to be only a minor part of its diet (Green 1952, Hays and Hays 1959, Lofgren et al. 1975, Wilson 1978, Tennant and Porter 1991). However, seeds may represent an important nutritional resource, especially since the transition to widespread multi-queen colonies and the extra food needed to sustain their larger densities (Ready and Vinson 1995, Macom and Porter 1996). Some areas in Texas have mound densities >1,900/ha (4,693/ac), and a 9% yield loss is estimated if the ants are not controlled in an infested field (Anonymous 2003). Polk (1999) estimated that red imported fire ant caused at least $4.67 million in annual losses to corn production in Texas.

Some cornfields are more at risk than others of economic seed damage by red imported fire ant. Different regions of Texas support different population densities of fire ants in agricultural fields (Lard et al. 2002, Anonymous 2003), probably related directly or indirectly to moisture and temperature. The heaviest losses in Texas occur in a north-south belt from Fannin and Grayson counties along the Red River to Cameron and Hildalgo counties in the Lower Rio Grande Valley (Polk 1999). Because seed is normally a minor part of the ants' diet, the degree to which seed is attacked in a given field depends in part on abundance of other food sources. Corn planted in previously uncultivated land or in fields with reduced tillage is at higher risk of fire ant damage. Dry seed is less often attacked, and less susceptible to damage, than wet or germinating seed (Drees et al. 1991, Ready and Vinson 1995, Morrison et al. 1999). On the other hand, dry soil conditions increase exposure to ant predation by delaying germination and cracking open the planting furrow to allow ants easy access (Drees et al. 1991). Morrison et al. (1997) concluded from laboratory experiments that 15–95% fire ant damage to corn seed could be expected under conditions of slow emergence. Although wet corn seed is more readily attacked and injured by red imported fire ant, optimal germination conditions that minimize exposure time to ant predation, including moist soil, are preferred (Drees et al. 1991; Morrison et al. 1997, 1999). A history of seedling injury by red imported fire ant may be considered a risk factor by itself (Drees 1999a).

Seedcorn Beetles

The following references provide useful summary information on the insect's biology, ecology, pest status, management options, and other general information discussed in this profile: NAS (1975), Pausch (1979), Stewart et al. (1982), Dicke and Guthrie (1988), Higgins (1994), O'Day et al. (1998), Pike (1998), Pope (1998), Witkowski and Ayyappath (1999), Edwards et al. (2000), Van Duyn et al. (2005), Anonymous (2009b), Nuessly et al. (2010).

The slender seedcorn beetle, *Clivina impressifrons* LeConte, and the seedcorn beetle, *Stenolophus lecontei* (Chaudoir) (Fig. 6), are widely distributed species of ground beetles (Coleoptera: Carabidae) that occasionally attack seed corn; a similar third species, *Stenolophus comma* (Fabricius), occurs in northern states (Kirk 1975, Pausch 1979, Carmona and Landis 1999, O'Rourke et al. 2008). All three species will be generically referred to here as seedcorn beetles unless otherwise specified.

Fig. 6. Seedcorn beetle. Photo: Marlin E. Rice.

Only adults cause injury by feeding on the endosperm of the seed before germination or on the mesocotyl after germination but before emergence, resulting in stand loss. Seedcorn beetles overwinter as adults and complete two generations per year. Like many other carabids, both adults and larvae are predacious and are considered beneficial insects in other crops, such as crucifers, where they are important predators of cabbage maggots, *Delia radicum* (L.) (Wyman et al. 1976), and are perhaps beneficial even in corn after seedlings have emerged (Pausch 1979). In essence, seedcorn beetles are opportunistic omnivores, feeding mainly on both live and dead arthropods, but also on vegetation such as grass, and on seeds of many plant species, including weeds (Bryson and Dillon 1941, Johnson and Cameron 1969, Pausch 1979, Hagley et al. 1982, Lundgren et al. 2006). Thus, whether seedcorn beetles are considered pests or beneficial insects depends on the agronomic context.

Although seedcorn beetles can cause economic damage, either throughout a field or in patches within a field, they are considered only an infrequent pest of corn. From 1967 through 1973 in South Dakota, Kirk (1975) found that seedcorn beetle (primarily *S. comma*) population numbers varied greatly from year to year, but that even in years and fields of highest abundance (110 adults/m^2), no injury to corn seed was observed. Either these seemingly large populations were not large enough to cause damage, or environmental conditions favored feeding on other items (Kirk 1975). Losses from seedcorn beetles in the Corn Belt in the mid-1970s were ranked by a National Academy of Sciences panel as 'Very Low' (0–1%) in general and 'Moderate' (11–35%) in localized areas (NAS 1975). In a survey of 234 cornfields in Indiana from 1972 through 1974, seedcorn beetles were detected in two fields (0.9%), but did not cause yield loss in either (Turpin and Thieme 1978).

As with many soil-dwelling insects, there are no effective rescue treatments for seedcorn beetles. When stand loss warrants replanting, seed treated with insecticide or application of a soil insecticide in-furrow is usually recommended. Insecticidal seed treatments have been recommended for more than a century when a problem with seedcorn beetles has been anticipated (Swenk 1909, NAS 1975, Stewart et al. 1982, Steffey and Gray 1989, Anonymous 2009b). Unfortunately, there is no effective sampling methodology to determine when treatment is justified. Although presence of large numbers of beetles when a farmer works the soil in early spring may alert that farmer to a possible problem, most treatments are made preventatively without foreknowledge of need.

Given their polyphagous nature, seedcorn beetles are found in many habitats. In agricultural settings, populations seem to be larger in moist, heavy soils with high organic matter content (Kirk 1975, Nuessly et al. 2010). Risk of damage is greater in such soils when germination is delayed by cool, wet weather, which exposes the seed to adult feeding over a longer period of time. Early or deep planting increases risk for the same reason. Risk is greater in corn planted after pasture or previously fallowed land than in other crop rotation schemes, and there may be a slightly increased risk in corn planted after wheat (Steffey and Gray 1989). Pope (1998) suggested that seedcorn beetles should not be a problem in no-till fields or in other fields with crop residue on the surface at planting time.

Seedcorn Maggot

The following references provide useful summary information on the insect's biology, ecology, pest status, management options, and other general information discussed in this profile: Reid (1940), Floyd and Smith (1949), Miller and McClanahan (1960), Rice et al. (1990), O'Day et al. (1998), Delahaut and Thiede (1999), Gesell and Calvin (2000), Sandell et al. (2002), Boyd and Bailey (2002), Johnson (2002), Bessin (2003b), McLeod and Studebaker (2003), Hensley et al. (2005), Van Wychen Bennett et al. (2011), Holm and Cullen (2012), Gill et al. (2013).

The seedcorn maggot, *Delia platura* Meigen (Diptera: Anthomyiidae) (Fig. 7), is a polyphagous fly found throughout North America. It attacks a number of crops, including corn, legumes, and vegetables (Barlow 1965, Hough-Goldstein and Hess 1984), and tends to be more of a threat to soybean than corn. The larvae feed on the endosperm of seeds and all parts of the underground seedling, preventing or reducing germination and resulting in stand loss. Plants that do emerge from injured seed are weakened and either do not survive or suffer reduction in yield potential.

Seedcorn maggot completes several generations per year. In northern states, it overwinters as a pupa and emerges as an adult in the early spring. In states from North Carolina, Tennessee, Arkansas, and southward, adults and other stages are present year-round. Usually only the offspring of the overwintered adults, or adults present during planting, are of concern, because the plants rapidly outgrow the threat of serious injury (Eckenrode and Chapman 1971, Funderburk et al. 1984, Hammond and Cooper 1993).

Despite the seedcorn maggot's ubiquitous presence throughout arable regions, economic infestations are sporadic and uncommon (Eckenrode et al. 1973, Funderburk et al. 1984, Hough-Goldstein and Hess 1984). Damage can be locally severe with stand losses up to 30–60% (Gesell and Calvin 2000, Kluchinski 2003), forcing the farmer to replant. Seedcorn maggot pressure in the Corn Belt in the mid-1970s was ranked by a National Academy of Sciences panel as 'Very Low' (0–1% losses) in general and 'Moderate' (11–35% losses) in local areas (NAS 1975). Of 501 corn farmers surveyed from 12 states, 3.2% indicated they actively managed seedcorn maggots and 0.4% indicated seedcorn maggot was the most important insect pest to manage (Hurley and Mitchell 2014). Kuhlman and Steffey (1987) estimated that the probability of a cornfield in Illinois being economically damaged from seedcorn maggot to be about 0.7% in corn planted after soybean, 2% in corn planted after corn or a small grain, 4% in corn planted after grass sod, and 10% in corn planted after legumes (clover, alfalfa). In New Jersey, 1% of fields are infested each year, with ≤2% of the plants infested in those fields (Kluchinski 2003). There are indications that seedcorn maggot may be more of a problem in some parts of the South, but information is sparse. Only about 2% of cornfields in Kentucky are infested annually, resulting in yield losses of <1% (Sandell et al. 2002), but 33% of farmers surveyed from the Coastal Plains region of Virginia indicated that

Fig. 7. Seedcorn maggot adult. Photo: Marlin E. Rice.

seedcorn maggot was a major pest of corn on their farms (Malone et al. 2004). A 1994 survey of Mississippi farmers ranked seedcorn maggot as an important pest on 26% of corn area (Byrd et al. 1999).

Whether a field is attacked by seedcorn maggot depends almost entirely on whether it is attractive to ovipositing females during or just before seed germination. Adults are attracted to fields where manure or green plants, such as weeds or cover crops, are incorporated into the soil through spring tillage (House and Alzugaray 1989, Hammond 1990), and Hammond and Cooper (1993) indicated that this is the only situation in which economic infestations of seedcorn maggots will occur. Females are attracted to volatiles of decaying matter and are especially attracted to moist, freshly tilled soil (Barlow 1965, Hough-Goldstein 1987). The type of vegetation incorporated into the soil affects risk of seedcorn maggot infestation; legumes are more attractive than grasses (Van Wychen Bennett et al. 2011). Because the agronomic factors that attract ovipositing females are characteristic of an entire field, infestations are usually field-wide, rather than patchy (Hodgson 2016). Reciprocally, no-till fields and fields where cover crops are terminated by a herbicide are at little or no risk of damaging populations (Hammond 1997, Cullen and Holm 2013). Early planting tends to the increase risk of damage because cool, wet conditions that delay seedling emergence expose the young plants to seedcorn maggot feeding over a longer period (Bessin 2003b, Cox et al. 2007). Economic damage by seedcorn maggot can be avoided if a farmer uses degree-day accumulation to estimate when it is safe to plant after incorporation of cover crops or other organic matter, or simply by delaying planting for 2–3 wk after tillage (Floyd and Smith 1949, Hammond and Cooper 1993, Cullen and Holm 2013).

Southern Corn Leaf Beetle

The following references provide useful summary information on the insect's biology, ecology, pest status, management options, and other general information discussed in this profile: Kelly (1915), O'Day et al. (1998), Steffey (1999b, 2002), Rice (2001b), Bessin (2004), Jia et al. (2007).

Very little has been published on the biology and ecology of the southern corn leaf beetle, *Myochorus denticollis* Say (Coleoptera: Chrysomelidae) (Fig. 8), since a USDA Bulletin published more than 100 yr ago by Kelly (1915). Adults overwinter in the soil or under plant debris and feed on weeds in the early spring until corn emerges. Southern corn leaf beetles are strong fliers, and they move into seedling corn when it becomes available, usually from the first half of May through mid-June. Adults feed on the leaves and into the stalks, which can kill the plant when beetles are present in large numbers, sometimes leading to stand loss that requires replanting (Kelly 1915; Smith and Dean 1950; Jia et al. 2007). Larvae feed on corn roots, but the amount of injury caused by such feeding is unknown.

When Kelly (1915) conducted his study in the early 20th century, the southern corn leaf beetle had been causing sporadic economic damage mainly in Ohio, Kansas, Arkansas, and Missouri, although it had been recorded from numerous states south of 41° N latitude and from the central Great Plains eastward (Webster 1901, Kelly 1915). Smith and Dean (1950) reported severe damage in a small area of northeastern Kansas in 1948, but otherwise the southern corn leaf beetle became a historical footnote until the late 1990s and early 2000s when localized economic outbreaks were reported in corn from northeastern and north-central Kansas, southeastern Nebraska, Missouri, Iowa, Illinois, and Tennessee (Roozeboom and Jardine 1999, Gray and Steffey 2001, Wright and Jarvi 2005, Michaud 2013). The surprising reappearance of this pest motivated tests of neonicotinoid efficacy against it (Wilde et al. 2004) and its inclusion on seed treatment labels containing clothianidin and imidacloprid.

Risk factors for southern corn leaf beetle infestations include fields grown in land that was previously in pasture or that was uncultivated, and possibly no-till fields. Bottomland soils have been associated with infestations, whereas sandy and light soils have not (Kelly 1915). Early-planted fields may be at greater risk of infestation (Kelly 1915, Gray and Steffey 2001). The reason for its late 20th century revival as a sporadic pest is not known. Regardless, both in the early and late 20th century, the presence of southern corn leaf beetle in economic numbers was rare and localized. It has returned to relative obscurity since the early 2000s, and it remains 'one of those odd insects' (Rice 2001b) that we know little about.

Southern Corn Rootworm

The following references provide useful summary information on the insect's biology, ecology, pest status, management options, and other general information discussed in this profile: Turner (1911), Luginbill (1918), Sweetman (1926), Arant (1929, 1934), Eden and Arant (1953), Stewart et al. (1982), Townsend and Bessin (1984), Brust and House (1990a), Wedberg (1996), Drees (1999b), Johnson (2002), Anonymous (2003), Hensley et al. (2005), Van Duyn et al. (2005), Akin et al. (2012), Buntin and All (2013), Varenhorst et al. (2015), Catchot (2016), Flanders (2016), Porter et al. (2016).

The southern corn rootworm, *Diabrotica undecimpunctata howardi* Barber (Coleoptera: Chrysomelidae) (Fig. 9), is present in most corn-growing areas east of the Rocky Mountains. The western corn

Fig. 8. Southern corn leaf beetle. Photo: Marlin E. Rice.

Fig. 9. Southern corn rootworm. Photo: Marlin E. Rice.

rootworm, *D. virgifera virgifera*, and the northern corn rootworm, *Diabrotica barberi* Smith & Lawrence—both major oligophagous pests of corn—are univoltine. Although the southern corn rootworm is in the same genus, it is multivoltine and polyphagous.

Southern corn rootworm adults overwinter only in the southern states and become active in the early spring, ovipositing at the base of seedling host plants, including corn seedlings. Larvae also may move to corn when weed or cover crop hosts are killed. Only these first-generation larvae (i.e., the offspring of overwintered adults) are of concern in corn. The larvae may hollow out the germinating seed or drill into the below-ground stem just below the soil surface, killing smaller seedlings outright and resulting in stand loss, or causing dead-heart symptoms—wilting and death of the central leaves in the whorl after damage to the growing point—and stunting in larger seedlings (V6–V9) (Buntin et al. 1994). Because it overwinters as an adult, the southern corn rootworm cannot be controlled by crop rotation to a non-host, unlike western and northern corn rootworms which overwinter as eggs (Gray et al. 2009). Furthermore, current rootworm Bt corn varieties are not effective against the southern corn rootworm. Active management is preventative, via insecticidal seed treatment or soil insecticides applied at planting (Eden and Arant 1953, Buntin et al. 1994, Buntin and All 2013).

Adults migrate long distances into the Great Plains and northern states each summer, but they are not considered serious pests of corn in those states because they typically arrive too late for their offspring to attack seedlings. Although southern corn rootworm was historically a major pest of corn in the Gulf Coast states where it overwinters, modern agronomic practices of conventional tillage, weed control, and discontinued use of cover crops had 'virtually eliminated' it as a significant corn pest for many years (Buntin et al. 1994). It is now considered an infrequent and minor pest that causes variable damage from year to year in much of the South, although it is a frequent and widespread pest in coastal Texas and Louisiana (Drees 1999b). Within Texas, its pest status varies with region: it is of little or no significance in the High Plains and Winter Garden regions, a moderate problem in the Blacklands and South Texas regions, and a major problem in the Upper Coast and South-Central regions of the state (Anonymous 2003, Porter et al. 2016). If not controlled, southern corn rootworms cause an estimated 0.5% yield loss in Texas (Anonymous 2003).

Southern corn rootworm can be a serious problem in cornfields where a legume winter cover crop is used (Arant 1929, 1934; House and Alzugaray 1989), especially hairy vetch, *Vicia villosa* Roth (Buntin et al. 1994). The cover crop should be killed 4 wk before planting to ensure enough time for rootworm larvae to complete development or starve (Arant 1929); cover crop destruction 2 wk before planting was not early enough to avoid severe injury in no-till plots in Georgia (Buntin et al. 2013). Females lay more eggs in no-till fields than in conventionally tilled fields (Brust and House 1990a, b), and no-till fields in combination with a legume cover crop or weeds are particularly at risk (House and Alzugaray 1989, Buntin et al. 1994, Buntin and All 2013). Planting in a weedy field increases risk (Brust and House 1990a). High levels of soil moisture and heavy soils, especially in poorly drained bottom lands, are associated with increased risk of southern corn rootworm injury, whereas light, well-drained soils are at less risk (Chalfant and Mitchell 1967, Brust and House 1990a). Southern corn rootworm is unlikely to be a problem during springs when soil conditions are very dry or saturated (Drees et al. 1999b).

Stink Bugs

The following references provide useful summary information on the insect's biology, ecology, pest status, management options, and other general information discussed in this profile: Clower (1958), Townsend and Sedlacek (1986), Bergman (1999), Byrd et al. (1999), Steffey and Gray (2000), Van Duyn et al. (2005), Anonymous (2009a), Tillman (2010), Michel et al. (2013), Catchot (2016), Flanders (2016).

Several geographically widespread species of stink bug (Hemiptera: Pentatomidae) can injure seedling corn, but the dominant species differ depending on region. The primary species of concern in the Corn Belt are the brown stink bug, *Euschistus servus* (Say) (Fig. 10), and the onespotted stink bug, *Euschistus variolarius* (Palisot de Beauvois). In the South, the southern green stink bug, *Nezara viridula* (L.), is often predominant, although the brown stink bug can also be important. Though a widespread pest of other crops and capable of injuring corn, the green stink bug, *Chinavia hilaris* (Say) (formerly *Acrosternum hilare*), is seldom found in corn and is not a significant pest of this crop (Herbert and Toews 2012, Cottrell and Tillman 2015).

Adults overwinter in grassy field borders, plant litter, cover crops, and other protected places. Stink bug pests are polyphagous, moving from host to host through a season, preferring fruiting crops when available; corn seedlings are vulnerable when fruiting crops are not present in the landscape (Herbert and Toews 2011, Tillman 2011, Pilkay et al. 2015). Adults and nymphs pierce plant tissue and inject a digestive enzyme before sucking the liquified tissue. In addition to causing localized injury to the plants, the injected compounds can induce tillering, stunting, or death of seedling plants up to the 6-leaf stage (Fig. 11) (Sedlacek and Townsend 1988, Apriyanto et al. 1989a, Pilkay et al. 2015). Adults often feed on the stalk at the soil line; they can injure the growing point if it is close enough to the soil line or if cracks in the soil permit feeding below the soil line. The insect makes multiple punctures per day (Apriyanto et al. 1989b), and 1 d of feeding can be enough to reduce yield by 50%, especially on younger plants (Annan and Bergman 1988).

Fig. 10. Brown stink bug. Photo: Marlin E. Rice.

Fig. 11. Normal corn plant (left) and stunted plants (four on right) after stink bug feeding during seedling stage. Photo: Marlin E. Rice.

Stink bugs are difficult to manage on seedling corn, in part because irreversible damage can occur very soon after seedling emergence, leaving little time for scouting. Nevertheless, scouting and rescue treatment with an insecticide is a frequently recommended option. Preventative soil insecticide treatments are ineffective and not recommended, but clothianidin seed treatments at high dose may provide some protection (Van Duyn et al. 2005).

Stink bugs are considered only sporadic, minor pests of seedling corn in the Corn Belt (Annan and Bergman 1988, Koch and Pahs 2015), although they have been increasing in incidence over the last 15 yr (Hunt et al. 2014). In contrast, they are frequent, serious pests in the Southeast, especially in the Carolinas, Georgia, and southern Alabama (Van Duyn et al. 2005, Flanders 2016), and occasionally in southern Mississippi (Byrd et al. 1999, Catchot 2016). This is a relatively recent development. Stink bugs did not begin to cause consistent, significant damage in corn in Georgia until about 1987, and by 1989 they had become the most important pest of corn (Isenhour et al. 1988b, 1989; All and Hudson 1992, 1993). Incidence of stink bug problems in Kentucky and southern Indiana began to increase at about the same time (Townsend and Sedlacek 1986, Sedlacek and Townsend 1988). The cause for this sudden upsurge in importance as a pest is unknown, but may be related to the increase in no-till practices (Van Duyn et al. 2005). In Texas, stink bugs are only occasional pests, affecting 1% of corn area, with the highest incidence of problems (10% of corn area) in the Upper Coast region about every 2 yr (Anonymous 2003).

One of the most important factors that increases risk of damage by stink bugs to seedling corn is no or minimum tillage, especially if the field is weedy. Plant debris in a no-till field may be attractive to overwintering adults. Furthermore, the propensity of stink bugs to kill plants is greater where good closure of the seed slot is not effected, as is common when planting in no-till fields, or in soil that is too wet (Annan and Bergman 1988), allowing for direct damage to the growing point below the soil line. Because stink bugs migrate from host to host depending on crop development stages, immigrant insects may concentrate around the edges of a field. For seedling corn, this is most likely in fields that border wheat, an early-season host (Reisig 2011, Reisig et al. 2013, Pilkay et al. 2015). Other higher-risk factors include a mild winter, delayed planting, using wheat or rye as a winter cover crop, double-cropping, or stink bug-infested weeds in the field before planting.

Sugarcane Beetle

The following references provide useful summary information on the insect's biology, ecology, pest status, management options, and other general information discussed in this profile: Phillips and Fox (1924), Ingram and Bynum (1932), Eden (1954), Henderson et al. (1958), Riley (1986), All (1999), Byrd et al. (1999), Hammond (2002), McLeod and Studebaker (2003), Patrick and Thompson (2004), Akin et al. (2012), Gyawaly et al. (2012), Brown (2013), Catchot (2013), Studebaker et al. (2013), Smith et al. (2015), Buntin and All (2017), Reisig (2017).

The sugarcane beetle, *Euetheola humilis* (Burmeister) (Coleoptera: Scarabaeidae) (Fig. 12), attacks a number of crops, including corn seedlings, in the southeastern United States (Smith et al. 2015). Unlike other scarab beetles comprising the pest complex called white grubs, most of the life cycle of the sugarcane beetle is spent in the adult stage, and the adults, rather than the larvae, cause economic damage to corn (Billeisen and Brandenburg 2014).

Adults overwinter in soil in grassy areas or pasture, and they may move into nearby fields of corn to feed on plants from newly emerged seedlings through whorl-stage corn, but most typically the V2–V5 stages. The overwintered adults feed just below the soil surface, gouging a ragged wound that may extend halfway or more through the main stem. Such feeding may cause stunting or dead heart in larger plants and can kill small seedlings outright, resulting in stand losses that are sometimes severe. A single beetle can kill several plants (Patrick and Thompson 2004, Smith et al. 2006). Rescue treatments with insecticides are generally ineffective, but preventive treatment with a soil insecticide applied at planting or planting seed treated with insecticide are options for suppressing potential damage by this insect.

Damage is often local and isolated, and sugarcane beetle is considered a serious, but sporadic or occasional, pest of corn in the southeastern United States (Ingram and Bynum 1932, Hammond 2002, Stewart and McClure 2016). Economic infestations of sugarcane beetle seem to be less common in states along the northern edge of its distribution, such as Arkansas (Baerg and Palm 1932,

Fig. 12. Sugarcane beetle. Photo: Marlin E. Rice.

McLeod and Studebaker 2003), Tennessee (Patrick and Thompson 2004), and North Carolina (Van Duyn et al. 2005). In Mississippi, the beetle is present throughout the state but causes more problems in the Hill region than in the Delta region (Catchot 2013). Likewise, although present throughout Arkansas, Baerg and Palm (1932) judged from reports that sugarcane beetle damage occurred mainly in the southern half of the state and along its eastern border.

Determining which fields the sugarcane beetle might attack is notoriously unpredictable (Phillips and Fox 1924, Patrick and Thompson 2004, Catchot 2013, Billeisen and Brandenburg 2014), but some fields seem more at risk than others (Akin et al. 2012). The main risk factor is related to the species' preferred habitat of grassy fields. Corn planted after sod or pasture is at greater than normal risk, and proximity of corn to sod or grassy areas increases risk. Buntin and All (2017) observed sugarcane beetle associated with bahiagrass, *Paspalum notatum* Fluegg. No-till corn may be at increased risk, although conventionally tilled fields are not exempt from infestation. Early planting can help avoid peak activity of sugarcane beetle but also risks increased exposure to attack if seedling growth is delayed by cool weather.

Thrips

The following references provide useful summary information on the insect's biology, ecology, pest status, management options, and other general information discussed in this profile: Dicke and Guthrie (1988), O'Day et al. (1998), Hudson (1999), McLeod and Studebaker (2003), Godfrey et al. (2006), Anonymous (2009a), Flanders (2016).

Thrips species (Thysanoptera: Thripidae) that can cause problems in corn include corn thrips, *Frankliniella williamsi* Hood, especially in the southern United States; western flower thrips, *Frankliniella occidentalis* (Pergande); and grass thrips, *Anaphothrips obscurus* (Müller), in the northern states. Several other species in these genera can injure corn, as well. Thrips cause injury by rasping the plant epidermis and sucking fluid from the wound (Farrar and Davis 1991, Hudson 1999). Overwintered adults feed on weeds, alfalfa, wheat, or other hosts, and they or their offspring may colonize seedling corn when those hosts senesce or are cut in the spring (Parsons and Munkvold 2010). Thrips' generation time is rapid and continuous throughout the growing season.

Thrips are common wherever corn is grown in North America. 'Outbreak' years have occurred in the past, for example, in central Iowa in 1988 (Bing et al. 1990b), but thrips are considered minor, sporadic pests of corn that seldom justify control measures. Thrips in corn was classified by a National Academy of Sciences panel in the mid-1970s as a 'secondary pest,' meaning less destructive than primary pests when present. Severe infestations of seedling corn can wilt or stunt the plant, although young corn plants usually outgrow the injury (Godfrey et al. 2006, Anonymous 2009a). The economic impact of this insect is poorly documented, and the benefit of insecticide treatment is assumed to be minimal or lacking except under rare circumstances. Interestingly, thrips are effective egg predators of early-season spider mites (Godfrey et al. 2006), making the normal, small populations beneficial to the crop where spider mites are a threat. Host plant resistance may be an option for thrips management (Dicke and Guthrie 1988, Bing et al. 1990b), but efforts in that direction have been minimal.

Certain conditions increase the risk of a rare thrips problem in corn. Because early-season thrips populations may build up on weeds, cultivation can increase the risk to nearby seedling corn when the thrips move out of the destroyed weed hosts. Similarly, seedling corn adjacent to thrips-infested wheat may be at increased risk as the wheat matures (McLeod and Studebaker 2003). Late planting or planting corn after alfalfa may increase risk (NAS 1975). Extended periods of hot and dry conditions exacerbate the effects of thrips injury on young corn that is already drought stressed (Anonymous 2009a). Large thrips populations are often associated with very dry weather, but the greatest damage in such cases is in irrigated fields (Hudson 1999). The underlying reason for this counterintuitive observation is unclear. Conversely, thrips populations can be reduced by heavy rains (Bing et al. 1990b).

White Grubs

The following references provide useful summary information on the insect's biology, ecology, pest status, management options, and other general information discussed in this profile: Stewart et al. (1982), Kuhlman and Steffey (1987), Steffey and Gray (1989, 2000, 2009), Rice et al. (1990), Higgins (1994), Wright (1995), Rice (1996), Pike (1998), McLeod et al. (1999), Edwards et al. (2000), Pike et al. (2000), Johnson (2002), Anonymous (2003), Catchot (2016).

White grubs constitute a complex of many species in the beetle (Coleoptera) family Scarabaeidae and are categorized as either annual or 'true' white grubs. Annual species have one generation per year, whereas true white grubs, *Phyllophaga* spp., require 2–4 yr to complete a generation depending on species and region of the country, with 3 yr being the most common. The distinction between these two types of grubs is important. Although large populations of annual white grubs, including the Japanese beetle, *Popillia japonica* Newman, and the southern masked chafer, *Cyclocephala lurida* Bland, can cause sporadic economic damage in some regions such as the mid-Atlantic states (Youngman et al. 1993, Jordan et al. 2012), they are considered to be of little or no economic importance in the Corn Belt (Rice 1994, Estes et al. 2016). In contrast, true white grubs, most commonly *Phyllophaga implicita* (Horn), can cause

Fig. 13. White grub larva. Photo: Marlin E. Rice.

serious economic damage and are the main grubs of concern to corn growers.

True white grub larvae (Fig. 13) injure the plant by stripping off root hairs. The main threat is to seedling corn plants, which can wilt and die before growing to 15 cm (6 in) tall, resulting in stand loss and the need to replant, which might include application of a soil insecticide. Plants that are not killed may be stunted. Second-year larvae of true white grubs tend to cause the most damage, because they feed on the roots throughout the year. Damage by first- and third-year larvae is not as severe, because they feed during only part of the season, although third-year larvae can still cause stand loss (Hammond 1948, Glogoza et al. 1998). One reason annual white grubs tend not to cause economic damage is that they begin feeding early in the spring, and often start to pupate by the time corn is planted (Rice 1994).

A National Academy of Sciences panel in the mid-1970s estimated the threat of economic losses caused by white grubs in the Corn Belt in the absence of any control measures as 'Low' (2–10% losses) in general and 'Moderate' (11–35%) in 'special local areas' (NAS 1975). Of the 501 corn farmers surveyed from 12 states in 2013, 2.4% indicated they actively manage grubs, and 0.2% indicated white grubs were the most important insect pests to manage (Hurley and Mitchell 2014). In Illinois, before the use of neonicotinoid seed treatments, <1% of corn area was treated for white grubs annually, 2% of fields were infested, and the average crop loss statewide was 0.1% (Pike et al. 2000). Kluchinsky (2003) estimated 1% of corn area in New Jersey was infested with white grubs annually, but indicated reports had increased in the southern part of the state. In Iowa, white grubs were reported to be a more common problem in the northwestern part of the state (Pike 1998). In Texas, white grubs are present annually in the South-Central region; are sporadically or seldom encountered in the Upper Coast, Winter Garden, and Coastal Bend regions; and are sporadically or seldom encountered in the Blacklands and South Texas regions (Anonymous 2003). Statewide, about 4% of corn area was estimated to have economic infestations annually, and if not controlled could cause an estimated yield loss of 3% (Anonymous 2003).

Infestations of true white grubs can be severe, but they are sporadic in time, patchy in space, and difficult to predict. Risk of an infestation in corn is high when corn is planted after sod or pasture, and a preventative planting-time application of a soil insecticide is routinely recommended in such cases. There is some indication that risk is increased in corn planted after soybean (NAS 1975, Kuhlman and Steffey 1987, Steffey and Gray 2000), but even so, Rice (1996) did not recommend insecticide treatment unless true white grubs (not annual) were found before planting or if stand loss occurred in the same field the previous year. Risk of annual white grub infestations in Virginia increases in corn planted after soybean (Jordan et al. 2012). Infestations of true white grubs in continuous corn are uncommon (NAS 1975), but infestations that do occur are typically confined to areas of the field bordered by trees. Adults of true white grubs feed on the leaves of trees, especially cottonwood, *Populus deltoides* Marshall; poplars, *Populus* spp.; ashes, *Fraxinus* spp.; and willows, *Salix* spp.; so areas within about 100 m (328 ft) of shelterbelt tree-lines are at most risk of infestation (Forbes 1916, Sweetman 1927, Rice 1996, Glogoza et al. 1998). Years when large populations of true white grub adults occur tend to be followed 2 yr later by increased risk of damage from second-year larvae (Glogoza et al. 1998).

Wireworms

The following references provide useful summary information on the insect's biology, ecology, pest status, management options, and other general information discussed in this profile: Kulash and Monroe (1955), Foster and Tollefson (1986), Rice et al. (1990), Wright (1995), O'Day et al. (1998), Simmons et al. (1998), Byrd et al. (1999), Fournier et al. (1999), Gotlieb et al. (1999), Keaster and Riley (1999), Pope et al. (1999), Pike et al. (2000), Sandell et al. (2002), Steffey and Gray (2000), Johnson (2002), Petroff (2002), Kluchinski (2003), Rice (2003b), Hoffman (2004), Hensley et al. (2005), Van Duyn et al. (2005), Westgate and Hazzard (2007), Willis et al. (2010), Traugott et al. (2015).

Wireworms are the soil-inhabiting larvae of click beetles (Coleoptera: Elateridae) (Fig. 14) and constitute a complex of many generalist species in several genera that are pests of a variety of crops. Wireworms have multi-year life cycles, with the larval stage typically living for 2–6 yr depending on species, weather conditions, and food availability. This is a particularly difficult group of pests to characterize because the community and predominant species threatening a given crop vary depending on region, cropping system, and soil type (Willis et al. 2010, Etzler et al. 2014, Traugott et al. 2015). For example, species in the genus *Melanotus* are the primary wireworm pests in the north-central United States, *Conoderus* spp. are more prevalent in the Southeast, and *Limonius* spp. are pests in the north-central and western states (Riley et al. 1974, Riley and Keaster 1979, Lindroth and Clark 2009, Willis et al. 2010). Also,

Fig. 14. Wireworm larvae. Photo: Marlin E. Rice.

not all wireworm species are pests; non-pest species can be present alongside one or more pest species in the same field, but the larvae of all are very difficult to distinguish morphologically. This is a serious problem that inhibits development of the most effective IPM strategies, because the ecology, biology, and response to management tactics can differ markedly among the different species. Molecular methods of species identification are a promising new approach in this regard (Lindroth and Clark 2009, Benefer et al. 2013, Etzler et al. 2014), but much baseline ecological research remains to be conducted on many species, a task that is not simple given wireworms' long life cycles and underground habitat.

The most serious damage caused by wireworms is stand reduction as a result of larvae destroying the seed before or during germination, or death of young plants caused by larvae burrowing into the underground portion of the stem. Plants that are not killed outright may be stunted. Damage in a field tends to be confined to relatively small (one-half or a few hectares [one or a few acres]), patchy areas. There is no effective rescue treatment if an infestation is discovered after planting, so the only option if stand reduction is severe is to replant with application of a soil insecticide. Although farmers are encouraged to use bait traps to determine the need for insecticide treatments at planting (e.g., Rice 2003b), this is a labor-intensive task, and many farmers prefer a preventative treatment with a soil- or seed-applied insecticide.

Wireworm damage can be severe, but is sporadic, localized, and usually not a widespread concern. Wireworms were a more widespread problem in the mid-20th century and earlier, but they have become much less of a concern with modern crop rotations (Turpin and Thieme 1978, Foster and Tollefson 1986). Of the 501 farmers surveyed from 12 states in 2013, 5.2% indicated they actively managed wireworms and 1.2% indicated wireworms were the most important insect pest to manage (Hurley and Mitchell 2014). Wireworm pressure in the Corn Belt was ranked by a National Academy of Sciences panel in the mid-1970s (NAS 1975) as 'Low' (2–10% losses) in general and 'Moderate' (11–35% losses) in local areas. In a 1992 survey, the mean ranking of severity of wireworm infestations by 1,598 farmers from 12 Midwestern states was 0.58 on a scale of 0–3, where 0 = pest not present, and 1 = pest occurs occasionally and may not warrant control measures (Aref and Pike 1998). Among estimates of typical pest infestations from 13 Corn Belt states, only representatives from Kansas, Michigan, Missouri, and Wisconsin reported economic infestations of wireworms; of these, 1% of fields were treated annually and 3% were infested but not treated (Pike 1998). Turpin and Thieme (1978) reported that from 234 cornfields in seven counties in Indiana sampled over 3 yr (1972–1974), wireworms were present in nine fields (3.8%), and caused yield loss in only one field (0.4%). Of the 151 fields scouted in southwestern, central, and northeastern Iowa from 1978 through 1982, none had an economic infestation of wireworms (Foster and Tollefson 1986). Of the 44 fields sampled with bait traps across the northern half of Missouri in 1987 and 1988, wireworms were detected in 11 fields (25%), and potentially economic infestations were found in four fields (9%) (Belcher 1989). In Illinois, before the use of neonicotinoid seed treatments, 2–3% of corn was treated for wireworms annually, although only 1% of fields were infested, and the average crop loss statewide was only 0.1% (Pike et al. 2000).

Outside of the Corn Belt, wireworm pressure in corn likewise is low. In 45 fields surveyed in Virginia over 2 yr (1990 and 1991), none suffered economic stand loss from wireworms, white grubs, and seedcorn maggots combined (Youngman et al. 1993). Less than 1% of cornfields in Kentucky had wireworms, and none suffered yield loss (Sandell et al. 2002). Hensley et al. (2005) estimated 0.1% yield loss caused by wireworms in Tennessee in 2004. In Texas, wireworms are present annually in parts of the Blacklands; are sporadically or seldom encountered in the Upper Coast, Winter Garden, South, South-Central, and Coastal Bend regions; and are not a problem in the High Plains. They are estimated to cause about 1% yield loss in fields where they are present but not controlled (Anonymous 2003). In New Jersey, 5% of fields are infested annually (Kluchinski 2003).

Although it is clear that the risk of an economic infestation of wireworms in any given cornfield is low, risk of a severe local infestation increases under certain predictable circumstances, usually related to particular crop rotations (Evans 1944, Kulash and Monroe 1955, Turpin and Thieme 1978, Willis et al. 2010). Furthermore, because wireworms have multi-year life cycles, economic infestations can persist for 2–4 yr, making previous infestation a risk factor by itself (Belcher 1989). Extended risk can remain even when a crop is protected with neonicotinoid seed treatments, because these insecticides may render wireworm larvae temporarily moribund, but do not necessarily kill them (Vernon et al. 2009, 2013).

The greatest risk from wireworms is to corn planted after sod, pasture, Conservation Reserve Program land, and small grains (Felt 1917, Riley and Keaster 1984, Belcher 1989, Kluchinski 2003, Rice 2003b, Hensley et al. 2005, Lindroth and Clark 2009). Although Belcher (1989) did not find a relation between tillage and wireworm infestations, reduced-tillage fields may be at increased risk, especially if they are weedy (Pike 1998, Van Duyn et al. 2005). In North Carolina, corn planted after soybean, regardless of tillage, is at increased risk (Kulash and Monroe 1955, Van Duyn et al. 2005, Willis et al. 2010). In Illinois, the probability of an economic infestation of wireworms was estimated as 1% in corn planted after soybean, and 0.5% in corn planted after corn (Kuhlman and Steffey 1987). Others have suggested that corn-soybean rotations decrease risk in the Midwest (NAS 1975, Belcher 1989) unless wheat is part of a three-crop rotation (Pike et al. 2000, Steffey and Gray 2000). Early-planted fields are at greater risk of damage if wireworms are present because plants are vulnerable over more days during slow growth in cool soils, compared with faster-growing plants in warm, later-planted fields (Rice 2003b). Damage is worse during cool, wet springs for the same reason. Within fields, areas of grassy weed problems are at increased risk. Soil type and texture can be an important variable, too; well-drained soils are at greater risk of infestation in most regions than poorly drained soils (Keaster and Fairchild 1960; Lefko et al. 1998a, b), and possibly peat-muck soils in eastern North Carolina are at increased risk (Kulash and Monroe 1955).

Discussion

A preventative insecticide treatment can be compatible with IPM if it meets two conditions (Douglas and Tooker 2015, Catchot 2016). The first condition is that rescue treatments are not an option, which Douglas and Tooker (2015) point out seldom applies to foliar-feeding insects. Our summaries reveal that realistic rescue tactics are not available for seven of the 16 pests reviewed (Table 1), and all but one of these are soil-dwelling insects. The exception is sugarcane beetle, which is visible above ground but difficult to control with a foliar insecticide application because the beetle attacks the plant at or just below the soil line. Stink bugs also tend to feed on corn seedlings at the soil line, or below if cracks in the soil allow; they can be controlled with a rescue treatment, but the window of opportunity for an effective rescue treatment is narrow. Our review highlights what is sometimes lost in discussions of whether preventative seed

Table 1. Summary of prevalence, economic importance, risk factors, and management options for sporadic pests of seedling corn that are listed on labels of neonicotinoid seed treatments

Pest	Region of concern	Presence in seedling corn	Importance in seedling corn	Risk factors	Management options[a]			Comments
					Rescue treatment?	Cultural	Other	
Billbugs	Corn Belt, South, Southwest	Sporadic, local	Minor, patchy Usually 0%; locally >10%	Continuous corn Yellow nutsedge Low-lying areas Poor drainage	Yes (adults) Spot treatment	Crop rotation Weed control Early plant	Preventive SI (unclear value)	Damage often patchy, especially around field edges, or associated with patches of yellow nutsedge.
	Carolinas and Georgia Coastal Plain	Common	Moderate	No-till Crop rotation from sod, wheat, rye, clover				
Black cutworm	North America	Sporadic, occasional	Usually 0–1%; locally severe	Winter annual and perennial weeds Flood plains Low-lying areas Soybean stubble Late planting History of cutworm problems	Yes Spot treatment	Weed control Early plant Wait 8–14 d to plant after clearing weeds	Cry1F: some control at low pressure	Adults migratory from Gulf Coast and Mexico, so variability in pressure in more northern states from year to year.
Chinch bug	North	Sporadic	Negligible	Border rows as small grain crop matures	Yes	Early plant	Preventive SI	Host plant resistance possible but limited research.
	Mid-South	Variable, 0–20%	0–8%	Late planting Slow growth (e.g., via cool temperatures, excess water, herbicide damage) Drought stress				
Corn flea beetle	Corn Belt and Mid-Atlantic	Widespread	Direct damage by beetle: rare Stewart's disease: rare in field corn; sporadic in inbred lines, sweet corn	Mild winter Susceptible lines (mainly inbreds and sweet corn) Early planting Cool spring Weedy field Nearby grass or wheat	Yes	Host plant resistance to Stewart's disease	Models to predict overwinter survival as surrogate for Stewart's disease risk	Most field corn hybrids are tolerant of Stewart's disease; seed production and sweet corn fields are at most risk.
	South	Sporadic	Rare	Reduced tillage				
Corn leaf aphid	North America	Widespread	Minor, of little importance Occasional local outbreaks	Early arrival of migrants in northern states Late planting Drought stress Nearby johnsongrass (source of *MDMV* inoculant)	Yes (rarely needed for young corn, but an option before tasseling if population numbers build up early)	Avoid late planting		Overwinters in South, migrates north on winds, where timing of infestation is variable. Early infestation not usually important itself, but can lead to damaging population at tasseling.

Table 1. *Continued*

Pest	Region of concern	Presence in seedling corn	Importance in seedling corn	Risk factors	Management options[a]			Comments
					Rescue treatment?	Cultural	Other	
Grape colaspis	North-Central states	Sporadic, infrequent	Patchy, aggregated infestations Occasional problem in local cluster of fields	Corn planted after legume, especially red clover Recently, corn planted after soybean Slow growth after early planting Inbred seed corn History of infestations	No	Do not plant after red clover Conditions for fast seedling growth		Unlikely to be a problem under good growing conditions.
Imported fire ant	Southern states, from California to North Carolina	Widespread, common	Abundant in disturbed habitat, such as agricultural fields	Reduced tillage Planting into uncultivated land Slow emergence conditions, e.g., cool or dry weather History of seedling loss	Yes, (but baits act slowly)		Insecticidal baits kill whole colony, but slow acting At-planting SI, fast acting but short-term control	Seeds are minor part of diet, so level of attack depends on abundance of more preferred food.
Seedcorn beetles	North America	Sporadic	Infrequent Usually 0%; locally >10%	Moist, heavy soils of high organic matter content Early planting Delayed emergence Corn planted after pasture or fallow	No	No-till Surface residue	Preventive SI	Omnivorous, so high populations do not necessarily translate to economic damage. Can be beneficial by consuming weed seeds, other insects.
Seedcorn maggot	North America Virginia Coastal Plains Mississippi	Widespread	Sporadic, uncommon; Locally severe Major pest on 33% of farms Important on 26% corn area	Corn planted after alfalfa, clover, sod Manure or green plants (especially legumes) incorporated during spring tillage Moist freshly tilled soil Early planting	No	No-till Terminate weeds with herbicide Delay planting 2–3 wk after tillage		Infestations usually across entire field, not patchy.
Southern corn leaf beetle	Great Plains eastward, south of ~41° N Latitude	Sporadic, uncommon	Sporadic, rare, local	Corn planted after pasture or uncultivated land Cocklebur present Early planting Low-lying areas No-till	Yes	Late planting		Absent for decades. Sporadic damage in late 1990s and early 2000s in local areas of Kansas, Nebraska, Iowa, Illinois, and Missouri.

Table 1. *Continued*

Pest	Region of concern	Presence in seedling corn	Importance in seedling corn	Risk factors	Management options[a]			Comments
					Rescue treatment?	Cultural	Other	
Southern corn rootworm[b]	Louisiana and Texas Gulf Coast Other southern states Northern states and west of central Texas	Common	Frequent, widespread Minor, infrequent Arrives too late to damage seedling corn	Legume cover crop, especially hairy vetch No-till Weedy field Poorly drained soil	No	Good weed control	Preventive SI	Bt corn ineffective. Crop rotation ineffective. Migrates into most corn-growing regions north and west of southern overwintering region, but arrives too late to damage seedling corn.
Stink bugs	Corn Belt Southeast	Sporadic Frequent	Minor but increasing Serious	Reduced tillage Field edge bordering wheat Mild winter Late planting Infested weeds before planting Planting in wet soil	Yes (but narrow window of application)	Good closure of seed slot Avoid late planting		Increased importance since 1980s probably due to increased minimum tillage practices.
Sugarcane beetle	Southeast	Sporadic, occasional	Local, isolated, but serious	Corn planted after sod or pasture, or proximity to sod or pasture No-till Slow growth caused by cool weather	No	Early planting (unless cool weather ensues)	Preventive SI (fair control, can help suppress)	Larva is annual white grub, but only adult causes injury.
Thrips	North America	Sporadic, minor	Rare	Proximity to infested weeds, wheat, or alfalfa Late planting Corn planted after alfalfa Hot and dry conditions	Yes (but economic benefits unclear)			Beneficial in low numbers to keep spider mites in check.
White grubs (true)	East of Rocky Mountains	Sporadic, patchy	Uncommon; locally severe	Corn planted after sod or pasture Corn planted after soybean and stand loss previous year Within 100 m of tree-line 2 yr after large adult population	No	Continuous corn	Preventive SI	Annual white grubs usually not economic. However, Japanese beetle can cause sporadic losses in Mid-Atlantic states. European chafer can be locally severe in Michigan and Ontario, especially in sandy soils.

Table 1. *Continued*

Pest	Region of concern	Presence in seedling corn	Importance in seedling corn	Risk factors	Management options[a]			Comments
					Rescue treatment?	Cultural	Other	
Wireworms	North America	Sporadic, patchy (one or a few acres)	Uncommon; locally severe	Corn planted after sod, pasture, uncultivated land, and small grains Well-drained soils Peat-muck soils (in North Carolina) Previous infestation Early planting Cool, wet spring Grassy weed patches	No	Avoid wheat in crop rotation sequence	Preventive SI	Many species in this is complex, difficult to distinguish, and each with its own distinctive ecology, biology, and dynamics. Not all wireworms are pests. Generalizations must be taken with caution. Multi-year life cycles, so infestations may persist 2–4 yr.

SI (soil insecticide); *MDMV* (*Maize dwarf mosaic virus*).

[a]Neonicotinoid seed treatments are a current management option in all cases, so this option is not listed in the table.

[b]Western, northern, and Mexican corn rootworms are on some neonicotinoid seed-treatment labels, but are not reviewed because they are major, midseason pests usually controlled by Bt corn.

treatments are compatible with IPM: a seedling crop may be at risk from multiple sporadic pests simultaneously, only some of which can be managed with a rescue treatment. Attractively, from the farmer's point of view, all can be controlled by a single preventative insecticide treatment (Catchot 2013). One of the problems with using the classical economic injury level (EIL) strategy to determine need for treatment is that EILs are not designed to account for simultaneous pressure from multiple pests (Pedigo et al. 1986). This shortcoming can be alleviated to some degree by developing EILs for groups of pest species, or injury guilds, that cause similar kinds of damage and damage responses by the plant (Hutchins et al. 1988). Youngman et al. (1993) suggested grouping white grubs, wireworms, and seedcorn maggots into an injury guild for seedling corn. To our knowledge, little progress has been made in this direction for corn, but the benefits would be great for assessing the need for and value of preventative treatments for control of sporadic seedling pests. The array of pests targeted by neonicotinoid seed treatments do not form an injury guild in the original sense, because of the wide variety of types of damage—from below-ground cutting to above-ground piercing-sucking—and of plant responses—from death of the growing point to stunting caused by toxins in the saliva. But from a management decision standpoint, these pests functionally comprise a guild based on the ability of a single tactic (neonicotinoid seed treatment) to protect the plant against any and all such pests. This is an area for which future research would be of great benefit, although the task will be complex and difficult to accomplish. Simulation modeling could provide insights when applied under scenarios of realistic probability of pressure from multiple sporadic pests under given farm-scale circumstances.

The second condition for a preventative insecticide treatment to be compatible with IPM is that the pest is likely to cause economic damage (Douglas and Tooker 2015, Catchot 2016). Research on many of these sporadic pests under modern production practices is sorely needed (Steffey and Gray 2000), and knowledge is scarce regarding how much economic threat is posed by these pests (Douglas and Tooker 2015). We have tried to address the question of economic risk by reviewing the factors that can place a particular field at increased risk of attack by the insects discussed herein. The question that drives the need for our review—what level of threat to corn production is posed by sporadic pests targeted by routine preventative treatments with insecticides?—is not new. Four decades ago, Turpin and Thieme (1978) wondered whether the benefits of widespread use of soil insecticides applied at planting, which corn farmers in the Midwest assumed to be a necessary input at the time (NAS 1975), outweighed the costs. They approached this question for Indiana corn growers by assessing the level of pressure imposed by an array of stand-reducing pests and the level of yield losses they caused. Their study involved a survey of soil pests over several years from many fields across the state. The methodology is different, but we are addressing essentially the same question for the sporadic corn seedling pests targeted by routine, widespread use of neonicotinoid seed treatments. Given the caveat that western corn rootworm was still in the process of expanding its range into Indiana in the early 1970s (Gray et al. 2009) and its populations were not as high as they would become later, Turpin and Thieme (1978) concluded 'that prophylactic use of soil insecticides on corn is seldom profitable in Indiana.'

From our findings, we cannot draw the same kind of blanket conclusion about the value of preventative insecticidal seed treatments to farmers, and we caution others against doing so, too. We have examined a much wider array of pests than Turpin and Thieme (1978), including both soil-dwelling pests and foliar-feeding insects, which, because they attack seedlings, are vulnerable to control by systemic neonicotinoids for a few weeks after corn germinates. The large geographic scale we examined also increases the number of sporadic pests that must be considered, as well as introduces regional variation in pest pressure and agronomic practices, all of which must be considered when designing or assessing management strategies (Esser et al. 2015). Our survey of the literature suggests that the pressure from many of these sporadic pests on seedling corn is rare or local, and seldom high enough to cause detectable yield losses. But at the scale of a field, which is what a farmer cares about, an attack can be very costly. Seedlings in general are particularly vulnerable to injury (Forbes 1909, Bing et al. 1991, Catchot 2016, Flanders 2016), and many of the pests we have examined can kill seedlings outright, leading to the need for replanting—an expensive outcome. As succinctly stated by Steffey and Gray (2000), managing these pests is difficult because predicting their occurrence is difficult. Although we agree with Douglas and Tooker's (2015) analysis that neonicotinoid seed treatments are applied largely preventatively, and often without knowledge of pest pressure in most fields, this insurance approach (Gray 2011) is understandable given the uncertainties a farmer faces regarding risk posed by sporadic pests to a considerable investment in the crop. We hope that by collecting what is known about the factors that may increase the risk of these pests in a given field (Table 1), as well as the conditions that indicate little or no risk, farmers and consultants can better assess the value of preventative protection of seedling corn under the conditions at hand.

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