Abstract

Eastern grape leafhopper, *Erythroneura comes* (Say), is a key pest of grapes (Vitaëlas: Vitaceae) in the central and northeastern United States and eastern Canada. This native insect uses its piercing-sucking mouthparts to puncture the mesophyll cells of leaves and suck out the contents, thereby reducing the quality and quantity of fruit. Eastern grape leafhopper has been reported as a vineyard pest for nearly 200 yr and is one of several *Erythroneura* spp. that feed on grapes in North America. Overwintered adults become active in early spring and may feed on grasses, weeds, and other plants before feeding on grapevines. Although eastern grape leafhopper has an extensive host range, it is only known to oviposit on wild and cultivated grapes. This multivoltine species can outbreak periodically, which has generated much research into improved monitoring and integrated pest management strategies employed throughout its native range. In this review, we describe the biology, life history, population dynamics, and phenology of eastern grape leafhopper and provide a historical account of monitoring and management strategies for this important vineyard pest.

Key words: IPM-Agricultural, horticultural entomology, monitoring, berry crop insect

Biology, Ecology, and Management of Eastern Grape Leafhopper (*Hemiptera: Cicadellidae*), a Key Pest of Vineyards in North America

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Host Plant Preference

Although eastern grape leafhopper is only known to oviposit on grape (*Vitis* L.), it feeds on the leaves of apple (*Malus pumila* Mill.),...
approximately 0.09 cm² (0.01 in²) of leaf area daily. A severe degree of chlorosis may occur, whereby leaves become dry and nearly devoid of green pigmentation (Fig. 2B), leading to premature leaf drop. Heavy infestations of eastern grape leafhopper may hinder photosynthesis, stuntng affected shoots. If stunting occurs over one or two consecutive seasons, the vine may be stunted for years afterward or even become damaged permanently (Johnson 1914).

Fig. 1. Eastern grape leafhopper, Erythroneura comes: nymphs, (A) early instar and (B) late instar, and (C) adult. All life stages were collected from an experimental vineyard located at the Cimarron Valley Research Station, Perkins, OK. Photograph credit: Kevin Jarrell, Oklahoma State University.

Bees (Fagus grandifolia Ehrh.), blackberry (Rubus X paracaulis L.H. Bailey), dogwood (Cornus L.), goldenrod (Solidago L.), hickory (Celtis L.), hawthorn (Crataegus L.), honeysuckle (Lonicera L.), hornbeam (Carpinus L.), nettle (Urtica L.), raspberry (Rubus idaeus L.), strawberry (Fragaria L.), thimbleberry (Rubus parviflorus Nutt.), wild cherry (Prunus avium L.), wild columbine (Aquilegia canadensis L.), wild plum (Prunus americana L.), Virginia creeper (Parthenocissus quinquefolia (L.), and a great variety of “weeds and grasses” (Johnson 1914). Additional host records include burdock (Arctium minus Bernh.), catnip (Nepeta cataria L.), currant and gooseberry (Ribes L.), and sugar maple (Acer saccharum Marsh.) (Hartzell 1913), as well as alder (Alnus x fallacina Callier), alfalfa (Medicago sativa L.), dewberry (Rubus sp.), dwarf oak (Quercus intricata Trel.), redbud (Cercis canadensis L.), rye (Secale L.), and sugar beet (Beta vulgaris spp. vulgaris L.) (Slingerland 1904).

Several studies have documented variable abundance of Erythroneura spp. across grape species and varieties. Martinson et al. (1994) observed seventh greater abundance of eastern grape leafhopper nymphs on the variety ‘Diamond’ than on the variety ‘Duchess’ and concluded that this difference was due to ‘Duchess’ being less preferred. Williams and Martinson (2000) reported that eastern grape leafhopper more commonly attacks varieties of fox grape, Vitis labruscana L., whereas E. bistrata McAtee and E. vitifex Fitch are most abundant on V. vinifera L. varieties. Erythroneura reflecta McAtee and E. viti (Harris) are reported to prefer riverbank grape, V. riparia Michx. (Dmitriev 2011). Runner and Bliss (1923) reported that E. viti was dominant on V. vulpina L. and varieties having thin leaves. Zimmerman et al. (1996) recorded higher numbers of Erythroneura vulnerata (Fitch) and Virginia creeper leafhopper, Erythroneura ziczac Walsh, nymphs on certain V. vinifera varieties compared with other varieties of the same species.

Feeding Injury and Damage

Eastern grape leafhopper punctures mesophyll cells of the leaf and sucks out the contents, leaving behind light brown or yellowish-white specks known as “stippling” (Fig. 2A). The resulting injury may lead to a reduction in photosynthesis due to the removal of chlorophyll, ultimately reducing the quantity and quality of grapes (Johnson 1914). Elsner (1986) estimated that each nymph can injure approximately 0.09 cm² (0.01 in²) of leaf area daily. A severe degree of Injury to workers at harvest, as adults fly into their eyes, mouths, and noses (Johnson 1914).
Phenology and Population Dynamics

Beginning in the late 1940s, eastern grape leafhopper populations in New York vineyards were kept at low to nondamaging levels by calendar-based chemical applications intended for management of grape berry moth, Paralobesia viteana (Clemens) (Martinson and Dennehy 1995a). However, increased leafhopper injury was noticed in the early 1990s as regular insecticide applications were reduced following development of a risk assessment procedure and pheromone mating disruption techniques for grape berry moth. In response to increased populations of eastern grape leafhopper, more detailed studies were initiated to describe its biology and life history and develop effective sampling methods and appropriate treatment thresholds for this pest (Martinson et al. 1994). Based on a lower developmental threshold of 10°C (50°F; Johnson 1914), eastern grape leafhopper was observed to require 623 growing degree days (GDD) to develop from egg to adult and complete postdiapause development (Martinson and Dennehy 1995a). In New York, eastern grape leafhopper usually undergoes one generation per year, but in warmer years, there can be a partial second generation (Martinson et al. 1994). In Oklahoma, three to four generations per year have been reported (McCraw et al. 2005, Arnold et al. 2008, Jarrell 2019). Martinson et al. (1994) used the single sine wave growing degree-day model (Baskerville and Emin 1969) to determine GDD for life stages of eastern grape leafhopper in New York. Calculation of GDD began on 1 April because this is generally the date at which temperatures in New York reach the lower developmental threshold of eastern grape leafhopper. The first observation of nymphs during the grape-growing season occurred on June 14 ± 4 d at 390 ± 71 GDD. The peak population of nymphs of the first generation occurred on July 6 ± 8 d at 648 ± 86 GDD, whereas the second-generation peak occurred on August 26 ± 14 d at 1,190 ± 154 GDD. In a 3-yr study in an Oklahoma vineyard, Jarrell (2019) used similar GDD calculation methods, but initiated degree-day accumulation on 1 January to account for warmer spring temperatures in Oklahoma versus New York. The author observed three peaks of eastern grape leafhopper nymphs: first generation occurred on May 22 ± 11 d at 604 ± 132 GDD; second generation occurred on July 20 ± 7 d at 1,595 ± 145 GDD; and third generation occurred on August 3 ± 10 d at 2,348 ± 111 GDD. Leafhopper development may be hastened in years when early-season temperatures are generally warmer (Martinson et al. 1997).

In the early part of the twentieth century, outbreaks of eastern grape leafhopper were reported at a regional level in the northeastern United States for a period of two or three seasons, after which they decreased and were below damaging levels for several years until the next cycle of outbreaks (Johnson 1914). In the outbreak year of 1922, Van Dine (1923) reported an average of about 64 nymphs per leaf in a heavily infested vineyard in Pennsylvania. Martinson and Dennehy (1995a) explained that year-to-year variability in eastern grape leafhopper population density is determined by differences in temperature and photoperiod. Photoperiod, which is consistent from year to year, determines the timing of reproductive diapause, which is around late July to early August in New York. Temperature, in contrast, is variable across years, resulting in variable rates of population development. From these variables, the proportion of the population entering reproductive diapause, and consequently the number of individuals in the next generation, may be estimated (disregarding other factors known to influence rate of development, such as host plant quality). In years with cooler temperatures, leafhoppers develop more slowly and mature to adulthood later. In such years, the proportion of the population entering reproductive diapause will be larger and fewer eggs will be laid throughout the season. Conversely, warmer years will result in a smaller proportion entering reproductive diapause, producing a larger overall population because of an increased proportion of the population laying eggs. Through its effect on population size, temperature influences the potential for both early-season and late-season leafhopper injury to grapevines. Using a probability model, Martinson and Dennehy (1995a) determined that if fewer than 760 GDD accumulated by the time of reproductive diapause on 1 August, the ratio of second-generation to first-generation leafhoppers could be as low as 5 to 1, whereas if over 890 GDD accumulated by that date, the ratio could be as large as 35 to 1. Slingerland (1904) suggested that weather conditions during the 6 mo of overwintering by eastern grape leafhopper may also be important in determining interannual variability in infestation levels.

In addition to temperature and photoperiod, rainfall also plays an important role in predicting population density of eastern grape
leafhopper. Eyer (1931) investigated the effects of precipitation and temperature on eastern grape leafhopper populations across 5 yr in multiple Pennsylvania vineyards. The author concluded that above-average rainfall in combination with below-average temperatures from May through July resulted in a reduction in eastern grape leafhopper populations. Conversely, below-average rainfall was thought to favor the development of large populations (Eyer 1931).

Monitoring and Treatment Thresholds

Monitoring for eastern grape leafhopper is possible for any of its life stages. Monitoring for eggs is not a common practice due to the difficulty of seeing them; they are smaller than a millimeter and hidden under the leaf epidermis. In addition, because leafhopper species cannot be distinguished by their eggs, monitoring for eggs only has utility when the dominant leafhopper species is known. Nevertheless, there are three methods that may be used for monitoring eggs. The simplest method is to inspect the surface of a backlit leaf under high magnification, recognizing the eggs as raised, bean-shaped areas on the leaf surface. This method is probably the most prone to human error as the raised areas are easy to miss. The second method is to stain the eggs with McBride’s stain (containing fuchsin dye), which makes them much easier to see under the leaf tissue (Backus et al. 1988). The third technique is known as Simplified Leafhopper Egg Detection by Autofluorescence (SLEDA), in which a blue light is shone on the leaf and the eggs fluoresce a bright green color (Herrmann and Boll 2004). This method requires special equipment for its effectiveness and is limited because the fluorescent property of eggs decreases over time after oviposition.

Monitoring nymphs is the standard method for growers to estimate population density of eastern grape leafhopper in their vineyards (Martinson et al. 1994). It is recommended that growers inspect at least 50 leaves for nymphs during each sampling period, depending on vineyard size (Rebek 2016). Martinson and Dennehy (1995a) suggested monitoring efforts should start once 650 GDD have accumulated. This amount of heat unit accumulation corresponds to the midpoint of nymphal development of the first generation of leafhoppers in New York, which is usually when the population of first-generation nymphs reaches peak abundance. In Quebec vineyards, Bostanian et al. (2006) recommended starting leafhopper nymph monitoring efforts when 630 GDD have accumulated above a lower developmental threshold of 8°C (46.4°F) since 1 March. This amount of heat unit accumulation corresponds to the time at which the population of first-generation nymphs reaches 5% of its cumulative abundance across the entire season. Alternatively, rating stippling injury to leaves is an indirect way of assessing leafhopper injury in the vineyard, and it has been used in combination with monitoring of nymphs to make management decisions (Jubb et al. 1983).

Monitoring of adult leafhoppers does not sufficiently estimate the actual population density because sampling methods for adults are relative (e.g., sticky traps). A leafhopper population may be large (as seen from direct counts of nymphs), but the adults may be inactive due to cool weather and, thus, not fly into the traps. In this case, population density would be underestimated with this sampling method. On the other hand, warm weather or flight associated with mating or immigration may stimulate leafhopper activity, resulting in a higher number of adults trapped and a potentially overestimated population density. Martinson et al. (1994) observed lower catches of adults on sticky card traps mid-season compared with early-season catches, even though the population of adults was increasing. The authors speculated that two factors might be responsible for the reduction in adults captured: reduced leafhopper movement and decreased attractiveness of the traps compared to a dense canopy of foliage.

There are different treatment thresholds for eastern grape leafhopper depending on the marketable product (i.e., table grapes, raisins, or wine) and the phenotype of grape varieties (Varela et al. 2019). Lower thresholds are used for vines producing table grapes as well as for varieties ripening during mid- or late season. In the northeastern United States, some authors recommend a threshold of five nymphs per leaf and others a threshold of two nymphs per leaf, or when 15% of sampled leaves have stippling injury (Jubb et al. 1983, Martinson et al. 1997). Martinson et al. (1991) recommended using a treatment threshold of five nymphs per leaf in the third week of July and 10 nymphs per leaf in the final week of August. Moreover, the authors recommended insecticide application if stippling injury is evident throughout the vineyard 10 d after bloom because treatment at that time is likely to prevent feeding damage later in the season. In Oklahoma vineyards, treatment thresholds are five nymphs per leaf before 1 August and 10 nymphs per leaf after 1 August (Rebek 2016). Van Kirk et al. (1984) reported that grapevines can tolerate a population density as high as 15 leafhoppers per leaf. Similarly, management guidelines from the University of California report that grapevines can generally tolerate high leafhopper populations; however, the geographic region where vines are planted may make them more susceptible to injury by leafhopper feeding, particularly those located in coastal areas (Varela et al. 2019).

Chemical Control

From the time eastern grape leafhopper was first reported as a pest in the late 1820s to the early 1900s, treatments included applications of lime sulfur dust, fumigating vines with tobacco smoke, or spraying tobacco extract for control of nymphs (Johnson 1914). An extract of blackleaf tobacco containing 40% nicotine sulphate, mixed to a ratio of 3.8 liters of extract to 5,678 liters of water (or Bordeaux mixture, a fungicidal concoction), was highly effective in killing nymphs when sprayed early in the season. Specifically, this treatment was most effective when first-generation nymphs reached fourth instar, corresponding to the highest population density of first-generation nymphs (Johnson 1914). From 1865 to the early 1900s, it was also common for grape growers to use soaps and oils to control eastern grape leafhopper. Slingerland (1904) devised a method of managing eastern grape leafhopper with whale oil soap and kerosene in the spring prior to oviposition by overwintering adults. This involved spraying a mixture of 0.5 kg of whale oil soap in 22.7 or 26.5 liters of water onto the vines to dislodge adults and then spraying an oil-in-water emulsion containing 25% kerosene onto the ground where the leafhoppers had fallen to kill them. He argued that if one-half to three-quarters of the leafhoppers were killed in the spring, this would prevent damaging levels of this pest from building up over the course of the season. Additionally, a mixture of 0.5 kg of whale oil soap and 37.9 liters of water sprayed on the underside of leaves was very effective in controlling nymphs (Slingerland 1904).

From 1946 through 1970, eastern grape leafhopper was controlled with dichlorodiphenyltrichloroethane (DDT). For most of this period, the application rate was 0.7 kg of DDT wettable powder in 379 liters of water (Taschenberg 1973). As early as 1954, insufﬁcient control of eastern grape leafhopper with DDT was detected in some areas, and it was evident that this chemical was becoming largely ineffective by 1966 because much more active ingredient per
Biological Control

Certain species of parasitic wasps in the genus *Anagrus* (Hymenoptera: Mymaridae) are solitary endoparasitoids of eastern grape leafhopper eggs. In New York, *Anagrus* spp. attacking eastern grape leafhopper include *A. daenei* S. Triapitsyn, *A. epos* Girault, *A. erythroneurae* S. Triapitzin & Chiappini, *A. nigriventis* Girault, and *A. trettakoevae* S. Triapitsyn. These insects generally colonize the edges of vineyards during May and June, later moving to the interior in August and September, indicating a pattern of slow dispersal for these parasitoids (Williams and Martinson 2000). *Anagrus* spp. present in vineyards of the northeastern United States overwinter as larvae inside diapausing leafhopper eggs laid on host plants such as sugar maple, gray dogwood (*Cornus racemosa* Lam.), hawthorn, white ash (*Fraxinus americana* L.), eastern black walnut (* Juglans nigra* L.), apple, American hophornbeam (*Ostrya virginiana* [Mill.] K. Koch), black cherry (*Prunus serotina* Ehrh.), northern red oak (*Quercus rubra* L.), black locust (*Robinia pseudoacacia* L.), multilora rose (* Rosa multiflora* Thunb.), black willow (*Salix nigra* Marsh.), riverbank grape, and common prickly ash (*Zanthoxylum americanum* Mill.) (Williams and Martinson 2000). Refugia in which *Rosa* spp. and *Rubus* spp. hosts are available to *Anagrus* wasps may conserve and increase numbers of these parasitoids in nearby vineyards, thus facilitating biological control (Prischmann et al. 2007). Moreover, because of the overwintering strategy used by *Anagrus* spp., wasp populations may increase by completing a full generation on alternate hosts before they enter vineyards in the spring to attack eastern grape leafhopper eggs (Williams and Martinson 2000). Cate (1975) found that *Anagrus* spp. may parasitize 10–20% of first-generation eggs of western grape leafhopper (*Erythroneura elegans* Osborn) and 80–95% of second-generation eggs in California vineyards. In New York during the early part of the season, Williams and Martinson (2000) found that *Anagrus* spp. parasitize 20–41% of eastern grape leafhopper eggs on grapevines adjacent to wooded areas, whereas they parasitized 0–28% of eggs on grapevines in the interior part of the same vineyard. In late June, they found that the parasitism rate reached a high of 59% of eastern grape leafhopper eggs.

Eastern grape leafhopper is also attacked by nymphal-adult parasitoids in the family Dryinidae. Fenton (1918) described the parasitism of eastern grape leafhopper by *Aphelopus comesi* Fenton (now *A. albopictus* Ashmead), which produces a visible larval sac, known as a thylacium, on the leafhopper abdomen (Fig. 3). This parasitoid sterilizes its host by consuming its reproductive organs (Flaherty et al. 1992). Wilson et al. (1991) reported that *A. albopictus* parasitized up to one-third of western grape leafhopper adults captured in vineyards in the San Joaquin Valley of California. Furthermore, Cate (1975) discovered up to 77% parasitism of western grape leafhopper by *A. albopictus* in the same region.

In addition to parasitoids, eastern grape leafhopper may be controlled by predators. Mulder (2019) recommended augmentation and deployment of 3,000–8,000 green lacewings, *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae), eggs per acre to enhance predation of leafhopper nymphs. Other natural predators of eastern grape leafhopper include black hunter thrips, *Leptothrips mali* (Fitch), brown lacewings (Neuroptera: Hemerobiidae), a dance fly, *Hemerodromia superstitionis* Say, *Hyaliolepis vitripennis* (Say) (Hemiptera: Miridae), another mirid in the genus *Paraprola*, ladybird beetles (*Hippodamia* spp.), minute pirate bugs (*Orius* spp.), spiders [e.g., *Cheiracanthium inclusum* (Hentz), *Tegenaria domestica* (Clerck), and *Theridion* spp.], and the mite, *Arytis agilis* (Banks) (Johnson 1914, Varela et al. 2019). Also, adult leafhoppers may become trapped in spider webs and be eaten (Johnson 1914).
Under the right conditions, pathogens can also contribute to the suppression of eastern grape leafhopper. Unusually wet growing seasons may promote infection of leafhoppers by fungi in the genus *Entomophthora* in the late fall, including *E. sphaerosperma* Fresen., which can decrease the size of the overwintering generation of leafhoppers (Jubb 1976).

**Cultural Control**

Mulder (2019) and Wilson and Daane (2017) suggested that there may be an advantage in managing leafhoppers via the customary practice of removing leaves from grapevines, which growers do in order to give their plants healthy and well-formed canopies. This practice may be timed immediately after the period in which leafhoppers have laid most of their eggs on the leaves, so that the population of eggs may be reduced within the vineyard (Wilson and Daane 2017).

In addition to leaf removal, pruning practices can positively or negatively affect management of leafhoppers in vineyards. Three methods of pruning commonly implemented in vineyards are minimal pruning, balanced pruning, and pruning to a fixed number of 80 nodes per vine. Minimal pruning involves cutting off the previous year’s growth at the level of the lower trellis. Balanced pruning involves following a formula set forth by Shaulis et al. (1966) designed to accomplish vegetative balance. Jubb et al. (1983) found that balanced-pruned vines did not suffer a decrease in crop weight when heavily infested compared to lightly infested vines. However, vineyards that are mechanically hedged or undergo minimal pruning practices may be at risk of higher damage from leafhopper feeding because the resulting increase in crop load stresses the vine, leading to incomplete ripening and lower tolerance of leafhopper injury (Martinson et al. 1997). Martinson et al. (1997) found that balanced-pruned vines and vines pruned down to 80 buds experienced more leafhopper injury than minimally pruned vines.

The use of ground cover may reduce leafhopper abundance on grapevines. Costello and Daane (2003) noted a reduction in grapevine vigor, as measured by pruning weight and nitrogen content in leaf petioles, in the presence of ground cover composed of barley (*Hordeum vulgare* L.) and purple vetch (*Vicia benghalensis* L.) until May, and afterward an assortment of grasses (e.g., *Digitaria, Echinochloa,* and *Setaria* spp.) and common knotweed (*Polygonum aviculare* L.). The authors found lower densities of leafhoppers mid and late season in vineyard plots having cover vegetation compared with plots without ground cover. These differences were not associated with parasitism of leafhopper eggs or spider density, suggesting that reduced grapevine vigor resulting from competition with cover vegetation for nutrients and water led to reduced host plant quality for *Erythroneura* spp. leafhoppers (Costello and Daane 2003).

Regulated deficit irrigation, an agricultural practice designed to provide plants with less water than is required for optimal plant growth (Chai et al. 2016), is used in California vineyards for improved grape quality and vegetative balance. This technique has been shown to decrease grape leafhopper populations when implemented at the time between berry set and veraison (i.e., onset of ripening; Costello 2008). First-generation females of western grape leafhopper generally oviposit second-generation eggs during this timeframe. Costello (2008) observed a decrease in the abundance of second-generation nymphs by about one-half as a result of this practice. Abundance of leafhopper eggs was also reduced but was not consistent across the two sites monitored. Conversely, Flaherty et al. (1992) reported that well-irrigated grapevines were able to withstand heavy leafhopper infestation.

**Sanitation and Mechanical Control**

Sanitation practices are an important component of eastern grape leafhopper management. These practices may include removing debris such as pruned canes and dead leaves from the vineyard as well as burning grass strips or weedy ditches bordering the vineyard in the winter (Jubb 1976). Slingerland (1904) noted that eastern grape leafhopper adults overwintering along vineyard rows could be controlled by running a plow close to the vines, effectively burying the insects in the soil. Used increasingly as an alternative to herbicides, tillage has been shown to provide a level of control of grape berry moth when the overwintering pupae are buried at least 1 cm (0.39 in) under the soil (Matlock et al. 2017). Thus, tillage holds promise as a good mechanical control option for vineyards having both eastern grape leafhopper and grape berry moth.

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**Fig. 4.** Potato leafhopper, *Empoasca fabae*: (A) nymph and (B) adult. Both life stages were collected from an experimental vineyard located at the Cimarron Valley Research Station, Perkins, OK. Photograph credit: Kevin Jarrell, Oklahoma State University.
Historically, traps coated with adhesive substances have been used to capture leafhoppers that are flushed out from infested vines. Slingerland (1904) designed and recommended a “sticky shield” constructed of a light wooden frame measuring 2.4 m × 1.2 m (8 ft × 4 ft), overlaid with oilcloth covered in a mixture of 0.95-liter melted resin with 0.47-liter castor oil. Two of these shields, each carried by one person, could be moved along either side of a vine row while shaking the canes of the vine to dislodge the leafhoppers onto the oil-cloth. This method was effective for capturing thousands of the over-wintered generation of adults before oviposition (Slingerland 1904).

Other Leafhoppers Occurring in North American Vineyards

Other leafhoppers in the subfamily Typhlocybinae, which have been reported as vineyard pests in North America, include the following: potato leafhopper \([Empoasca fabae\) (Harris)] (Fig. 4A and B); \(Erasnomeura variabilis\) (Beamer); \(E. vulnerata\) (Fig. 5); \(E. bistrata\); \(E. coloradensis\) (Gillette); \(E. cymbium\) McAtee; western grape leafhopper; threebanded leafhopper \((E. tricincta\) Fitch); \(E. vitifex\); and Virginia creeper leafhopper \((E. tricincta\) Fitch). Several other leafhoppers in the tribe Erythroneurini occur in vineyards and feed on grape leaves but have not been reported as serious pests. These include but are not limited to \(E. delicata\) McAtee, \(E. octonotata\) Walsh, \(E. vitis\), and \(E. illinoiensis\) (Gillette).

The species composition of erythroneurine leafhoppers in vineyards varies across North America. The predominant species in vineyards in the western United States, especially in California and Washington, are western grape leafhopper and Virginia creeper leafhopper; California also has \(E. variabilis\) (Settle and Wilson 1990, Olsen et al. 1998). Vineyards in Michigan, New York, Ohio, and Pennsylvania are attacked mostly by \(E. bistrata\), eastern grape leafhopper, \(E. cymbium\), threebanded leafhopper, and \(E. vitifex\) (Runner and Bliss 1923, Van Kirk et al. 1984, Martinson and Dennehy 1995b, Ellis et al. 2004). Vineyards of Colorado and Texas are attacked primarily by \(E. vulnerata\), \(E. coloradensis\), and Virginia creeper leafhopper (Slingerland 1904, Paxton 1990, Zimmerman et al. 1996). Ontario, the Canadian province with the most acreage of vineyards, has eastern grape leafhopper, threebanded leafhopper, and \(E. vitifex\), whereas Quebec has \(E. vulnerata\), eastern grape leafhopper, threebanded leafhopper, \(E. vitifex\), \(E. vitis\), and Virginia creeper leafhopper (Bostanian et al. 2006, Saguez et al. 2014). \(E. elegantula\) and Virginia creeper leafhopper are dominant in British Columbia (Lowery 2010).

Some leafhoppers in the subfamily Cicadellinae, generally known as sharpshooters, are also pests in vineyards across North America. Glassy-winged sharpshooter \([Homalodisca vitripennis\) (Germar)], c.g., is responsible for transmitting the bacterium, \(Xylella fastidiosa\) Wells et al. 1987, the causative agent of Pierce’s disease of grape (Purcell and Saunders 1999). Other leafhoppers in the subfamily Deltocephalinae are pests of grape, including \(Scaphoideus titanus\) Ball. This leafhopper has been reported as a vector of phytoplasmas in the eastern United States and of the phytoplasma causing the grapevine disease, flavescence dorée, in the Mediterranean region of Europe (Prince et al. 1993).

![Fig. 5. Adult *Erasnomeura vulnerata*. This specimen was collected from an experimental vineyard located at the Cimarron Valley Research Station, Perkins, OK. Photograph credit: Kevin Jarrell, Oklahoma State University.](https://academic.oup.com/jipm/article-abstract/11/1/6/5837047/7)

![Fig. 6. Virginia creeper leafhopper, *Erythroneura ziczac*: (A) nymph and (B) adult. Both life stages were collected from an experimental vineyard located at the Cimarron Valley Research Station, Perkins, OK. Photograph credit: Kevin Jarrell, Oklahoma State University.](https://academic.oup.com/jipm/article-abstract/11/1/6/5837047/7)
Considering that many of these sucking pests share ecological niches, host plants, and geographic ranges, a comprehensive Integrated Pest Management (IPM) program for eastern grape leafhopper (or other erythroneurine leafhopper) can provide effective management for multiple insect pests and several associated grapevine diseases.

**Concluding Remarks**

Eastern grape leafhopper is a key vineyard pest in several grape-producing regions of North America. This insect pest reduces grape quality and yield indirectly by using its piercing-sucking mouthparts to puncture leaf mesophyll cells and feed on the contents. Eastern grape leafhopper has potential to outbreak, and for over a century, researchers have focused efforts on developing and refining chemical, biological, cultural, and mechanical control tactics including sanitation to keep this pest in check. Successful implementation of these IPM strategies relies on effective monitoring of eastern grape leafhopper populations. In turn, monitoring depends on predictive power derived from relevant degree-day models, which are driven by phenology data that vary considerably in different climatic zones across the geographic range of this pest (Jarrell 2019). Therefore, degree-day models should be developed that are specific to each growing region. Management of other leafhoppers and sharpshooters that co-occur with eastern grape leafhopper in vineyards may reduce populations of this pest because multiple species share ecological niches, host plants, and geographic ranges.

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