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Fifty Years of Cereal Leaf Beetle in the U.S.: An Update on Its Biology, Management, and Current Research

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ABSTRACT. Cereal leaf beetle, *Oulema melanopus* L., is an introduced insect pest of small grains first recorded in the United States in the early 1960s. Since its introduction from Europe or Asia into Michigan, cereal leaf beetle has rapidly spread and can now be found in most states. Cereal leaf beetle feeds on numerous species of grasses and is considered a major pest of oats, barley, and wheat. Although several studies have investigated cereal leaf beetle biology and population dynamics, numerous gaps remain in understanding the mechanisms that influence its spread and distribution, which makes predicting pest outbreaks difficult. Because of the difficulty in predicting when and where pest outbreaks will occur many growers in the southeast apply insecticides on a calendar basis rather than using a threshold-based integrated pest management approach. Our challenge is to develop new information and procedures that will encourage growers to reevaluate the way they are approaching spring-time insect control in wheat, and consider adoption of the integrated pest management approach. This article is a review of cereal leaf beetle biology, past and present management practices, and current research being conducted.

Key Words: *Oulema melanopus*; small grains; wheat; IPM; CLB

Cereal leaf beetle, *Oulema melanopus* L. (Coleoptera: Chrysomelidae), is native to Europe and Asia where it is a pest of small grains. The first record of cereal leaf beetle in the United States was in southern Michigan in the early 1960s but can now be found throughout much of North America (Castro et al. 1965, Haynes and Gage 1981). Early studies set thresholds of cereal leaf beetle at one larvae per stem (Webster et al. 1972, Haynes and Gage 1981), but more recent research has shown that substantial losses can occur when populations reach that level (Ihrig et al. 2001, Buntin et al. 2004). Despite the development of scouting procedures and economic thresholds (Herbert and Van Duyn 1999, Ihrig et al. 2001, Buntin et al. 2004, Herbert 2009), wheat growers in the mid-Atlantic states have predominantly adopted a calendar-based insecticide spray program for this pest. These sprays are often timed with plant phenology to correspond to the best time for a top-dressed nitrogen application and not for the management of cereal leaf beetle. Growers will often incorporate a fungicide at this time, in addition to an insecticide, independent of scouting and thresholds. To continue to effectively manage this pest it is imperative that we understand the population dynamics, as well as how and why populations fluctuate both spatially and temporally. This article is an overview of cereal leaf beetle biology as well as a description of management practices through time, and a glimpse at current research being conducted, with an emphasis on the eastern United States.

Pest Status

Cereal leaf beetle is considered a major pest of small grains in Europe, Asia, and the United States. Since its introduction into Michigan, it has rapidly spread and is now found in most states south and east of North Dakota, as well as in Montana, Idaho, Utah, Wyoming, Nevada, Oregon, and Washington (Herbert et al. 2007). It feeds on numerous species of wild and cultivated grasses although preferences are shown for including oats, barley, and wheat, possibly because of increases in survival and development time (Wilson and Shade 1966). Although adults feed on young small grain plants, their feeding typically does not affect yield. Larvae however, eat long strips of parenchyma tissue skeletonizing the leaf decreasing the plant's ability to photosynthesize (Grant and Patrick 1993, Buntin et al. 2004). Significant feeding injury in wheat gives the field a frosted appearance (Fig. 1). This loss of photosynthetic ability can cause significant losses in yield or grain quality (Wilson et al. 1964, Koval 1966, Merrit and Apple 1969, Webster and Smith 1983, Grant and Patrick 1993). Losses are highly variable, and depend on infestation levels as well as the crop and the region, with maximum losses of ≈40% (Buntin et al. 2004). In Virginia commercial wheat fields average ≈15% yield loss if cereal leaf beetle is left untreated (Herbert et al. 2007). One possible reason for these large populations is poor establishment of introduced biological control agents leading to limited or no control (Herbert et al. 2007). Poor establishment of these parasitoids may be attributed to several factors, including management practices, with a key reason being the unnecessary and poorly timed use of pesticides.

A considerable amount of research has been done on cereal leaf beetle population dynamics and control. Nevertheless, the underlying mechanisms that determine its spread and distribution remain unresolved (Haynes and Gage 1981). Because so much remains unknown about this insect pest's life history and population ecology, predicting outbreaks is extremely difficult.

Description of Life Stages and Life History

Cereal leaf beetle has one generation per year, although McPherson (1983b) reported a small second generation in Virginia. The entire life cycle can take from 10 to 90 days to complete depending on temperature, but generally requires ≈46 days at average spring-time temperatures in the Midwest and mid-Atlantic states (Guppy and Harcourt 1978, Metcalf and Metcalf 1993).

Adult. The adult is a small elongated chrysomelid beetle ≈5 mm long with a metallic, bluish-black head and wing covers (elytra) and rust red to burgundy legs and thorax (Fig. 2). Adults overwinter in debris in or near wooded areas often adjacent to the previous season's grain fields. Adults emerge from overwintering in the early spring when daytime temperatures consistently exceed 14°C (Helgesen and

Fig. 1. Cereal leaf beetle larval feeding damage to wheat, damaged area in the foreground, green protected area in the background. (D.A. Herbert).

Fig. 2. Adult cereal leaf beetle. (D.D. Reisig).

Haynes 1972, Gutierrez et al. 1974), and move into small grains and begin to lay eggs.

Eggs. Female cereal leaf beetles deposit eggs individually or in short chains along the midvein on the upper surface of leaves (Helgesen and Haynes 1972). A single mated female can deposit up to 50 eggs in her lifetime. Eggs are elongate, yellowish orange in color, and are ≈1 mm long (Fig. 3). Eggs darken as they develop. A minimum temperature requirement for immature cereal leaf beetle development is ≈9°C. Development time decreases with increasing temperature until a maximum of ≈25°C (Yun 1967, Helgesen 1969, Guppy and Harcourt 1978; Table 1). At optimal temperatures (between 22–32°C), eggs complete their development in about 5 days (Guppy and Harcourt 1978, Herbert et al. 2007).

Fig. 3. Cereal leaf beetle eggs. (D.D. Reisig).

Larva. Newly hatched larvae are slug-like and have grayish yellow bodies with heads and legs that are brownish– black (Fig. 4). However, body coloration is usually obscured by a black globule of mucus and fecal matter held on the body, giving them a shiny black, wet appearance, especially in later instars (Fig. 5). Larvae pass through four instars and typically develop in 10–14 days at optimal temperatures between 22–32°C, with the time divided equally between the four instars (Guppy and Harcourt 1978, Herbert et al. 2007). Upon reaching full size (≈5 mm), larvae drop to the soil surface and burrow down to ≈2 inches (5 cm) and pupate.

Pupa. This life stage is rarely encountered in the field, as pupae are small (≈5 mm) and enclosed in earthen cells underneath the soil surface. Pupae are exarate, yellow, and darken with time. Adults emerge after 17–25 days based on soil temperature. New adults emerge as cereal grains begin to senesce and feed on summer grasses and crops before moving to overwintering sites.

Historical Control Effort

Quarantine. Shortly after its discovery in the United States, large-scale quarantine and eradication efforts were implemented. Large areas of Michigan and Indiana were placed under quarantine and small grains had to be treated before transportation (Haynes and Gage 1981). Despite these efforts, the pest continued to spread. It was later discovered that the likely culprit was overwintering adults on conifers sold as Christmas trees (Hess 1971). Along with these quarantine efforts were large-scale attempts to eradicate cereal leaf beetle using pesticides (Castro and Guyer 1963, Haynes and Gage 1981). During this time, hundreds of thousands of acres of small grains were sprayed across Michigan, Indiana, and Illinois, but cereal leaf beetle still

Table 1. Development time (days) of immature cereal leaf beetle by temp, data from Guppy and Harcourt (1978)

Stage	Temperature °C										
	8	10	12	14	18	22	25	28	30	32	34
Egg	41.3	38.5	25.3	17.9	10.1	6.1	4.5	3.8	3.7	3.9	
Total larval	47.5	46.2	32.5	25.2	15.7	10.8	8.5	7	6.4	6.6	

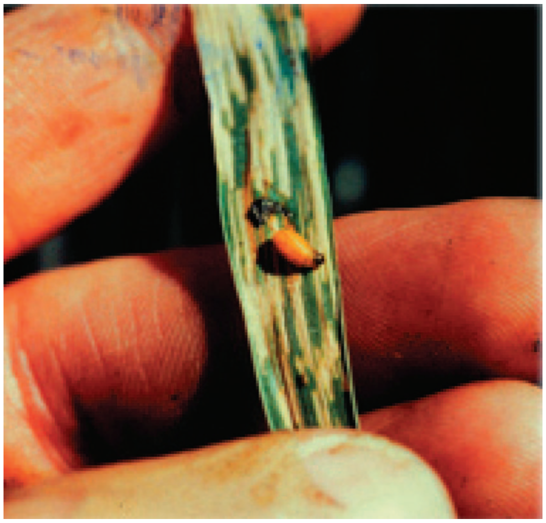

Fig. 4. Cereal leaf beetle larva with no mucus or fecal material. (D.A. Herbert).

Fig. 5. Cereal leaf beetle larva covered with mucus and fecal material. (D.D. Reisig).

continued to spread. By 1970, the decision was made to discontinue the cereal leaf beetle eradication programs in these states and attention was turned to other methods of control.

Host Plant Resistance. Resistance to cereal leaf beetle has been found in wheat, and is associated with leaf trichome density (Wellso 1973, Hoxie et al. 1975, Webster et al. 1972, Haynes and Gage 1981). The primary mechanism for control with pubescence is oviposition deterrence with high tricome densities reducing egg populations by 90% or more (Gallun et al. 1973). However, resistant varieties do not yield as well as other wheat varieties thus, using host plant resistance alone is likely not a long-term solution, but when used in conjunction with other control methods, it may prove to be a useful tool in the integrated pest management (IPM) toolbox for cereal leaf beetle (Haynes and Gage 1981).

Biological Control. Classical biological control efforts were also implemented in the United States From 1963–1967, five parasitoids were released in an attempt to control cereal leaf beetle. Four species, *Tetrastichus julis* (Walker) (Hymenoptera: Eulophidae), *Anaphes flavipes* (Förster) (Hymenoptera: Mymaridae), *Lemophagus curtus* Townes, and *Diaparsis temporalis* Horstmann have been reported as well established (Haynes and Gage 1981). Several of these species have been cultivated and released at various locations throughout the Midwest and mid-Atlantic states (Buntin et al. 2004). The two that appeared to be the most successful in control were the larval parasitoid *T. julis* and the egg parasitoid *A. flavipes*. Numerous studies have illustrated that these parasitoids have become well established in the Midwest with parasitism rates as high as 90% (Stehr 1970, Maltby et al. 1971, Gage 1974, Gage and Hanes 1981); however, little work has been done in recent years to evaluate the impact of these parasitoids on cereal leaf beetle. In 2010 the authors conducted surveys in Virginia and North Carolina, and no parasitoids were recovered from cereal leaf beetle eggs or larvae.

Current Management

Because cereal leaf beetle is a pest that can usually be managed with sound cultural practices it has not been the focus of much research in recent years. In areas where Hessian fly, *Mayetiola destructor* (Say) (Diptera: Cecidomyiidae), has not been a problem, cultural controls include avoiding late plantings and managing for early stands of thick-tillered wheat. If insecticides are needed, there are several pesticides registered for small grains that work well in controlling cereal leaf beetle if applied at the appropriate time. Currently, synthetic pyrethroids are typically used by growers because of their relatively low cost and effectiveness.

Treatment thresholds vary by state and region, but in recent years, an IPM program for cereal leaf beetle in wheat is being promoted in both Virginia and North Carolina with an economic threshold of 25 eggs or small larvae per 100 tillers (Herbert 2009, Herbert and Van Duyn 1999). Nevertheless, a majority of growers spray for cereal leaf beetle independently of scouting and thresholds (D.D.R., unpublished data). This approach is similar to the blanket sprays of the 1960s that ultimately were not effective in eliminating infestations or slowing the spread of cereal leaf beetle. The success of insecticide applications is heavily dependent on the timing in relation to cereal leaf beetle phenology; therefore, for effective management, we must improve our understanding of the biology and population dynamics to develop effective and accurate predictive tools that will allow for well-timed scouting and insecticide applications.

Current Research

To illustrate the importance of timing of insecticide applications, small plot studies were conducted that clearly demonstrated that residual activity of insecticides applied to correspond with plant phenology in terms of nitrogen applications, growth stage (GS) 30 (Zadoks et al. 1974), is too early in relation to the cereal leaf beetle population phenology and is ineffective for control. In the mid-Atlantic region, feeding by cereal leaf beetle larvae and adults generally does not peak until GS 45, $\approx$30–40 days after this GS 30 N application. Therefore, insecticides applied a month or more prior would be ineffective for control of cereal leaf beetle; however, they may be effective in controlling aphids if present. In 2010 and 2011 studies, Reisig (D.D.R., unpublished data) applied several pyrethroids, a spinosyn, and an organophosphate insecticide to coincide with the GS 30 nitrogen application $\approx$30 days before cereal leaf beetle reached threshold levels. In one location (Plymouth, NC, 2010) the cereal leaf beetle population greatly exceeded threshold (30 days after application). However, beetle abundances were not significantly different among the treatments or the untreated control. In another location

(Lumberton, NC) and in Plymouth, NC (2011), cereal leaf beetle populations never developed in either the treated or untreated wheat. Results in these studies were indicative of many cases where automatic insecticide applications are applied, either too early to be effective, or where cereal leaf beetle populations would never develop because of regional distribution patterns.

In addition to timing of insecticide applications, movement patterns and plant preferences of adult cereal leaf beetle after spring emergence are likely to play an important role in where beetles will be found, and these details have yet to be determined. Before experimental investigation, it was thought that emerging adults followed a succession pattern of host plants from wild grasses to cultivated grains (Ihrig 1998). However, Helgesen (1969) found that when grains were available they were the preferred host, and later studies illustrated clear preferences for wheat and oats over other potential hosts (Ruesink 1972, Gage 1974, Casagrande et al. 1977). While cereal leaf beetle may exhibit some level of host plant preference, the extent to which they prefer one host plant over another remains unclear. Cereal leaf beetle infestations can be sporadic and highly variable. According to some observations, the pest appears to prefer late-planted, thinly sown wheat or areas where there are conditions that lead to poor growth (McPherson 1983a, Grant and Patrick 1993). In contrast, Honek (1991) found that cereal leaf beetles prefer dense stands. Simulation models suggest that field edge, size, and habitat surroundings are the leading factors contributing to cereal leaf beetle infestations (Sawyer and Haynes 1986). What regulates when and where cereal leaf beetle infestations occur has yet to be determined.

To begin to understand when and where cereal leaf beetle outbreaks might occur, the interaction of various factors and populations within wheat fields must be considered. The main variables in the ecology of cereal leaf beetle are likely to be the interactions between temperature and field dynamics, such as host plant quality, and natural enemy populations. It is believed that the seasonal biology of cereal leaf beetle is driven by temperature. If the temperature correlation with population dynamics can be disentangled, it will make it much easier to predict cereal leaf beetle infestations. This may also lead to an understanding of what influences cereal leaf beetle distribution. Although data are sparse, some wheat fields have specific characteristics that may make them more susceptible to cereal leaf beetle infestations. These characteristics include planting date, stand thickness, soil characteristics, field size, and surrounding vegetation but adult beetles also appear to seek out less mature plants (Haynes and Gage 1981, McPherson 1983a). This may indicate that anything that limits stand growth also increases the likelihood of cereal leaf beetle infestations.

To improve the ability to predict cereal leaf beetle infestations, cereal leaf beetle distribution should be described; an understanding should be gained regarding why these infestations occur, and gaps should be filled in what we know about this insect's biology. Research is underway to evaluate all of these needs and preliminary results are promising. Recent studies in the southeastern United States show that cereal leaf beetle populations are spatially aggregated on a field, farm, and regional level (D.D.R. and D.A.H, unpublished data; Reay-Jones 2010), but the main contributing factors leading to this distribution remain unknown. Knowledge of these factors is needed to explain the spatial distribution of this pest.

Because cereal leaf beetle emergence from overwintering and the rates of egg and larval development are largely determined by spring temperatures, determining if degree-days can accurately predict when peak egg and larval densities occur may improve scouting efficiency and could encourage more growers to adopt an IPM approach. By building on an existing predictive degree-day model (Guppy and Harcourt 1978), we hope to determine when peak egg populations occur and correlate these egg densities to current thresholds. In 2010, we used this model to estimate the dates of peak egg populations of cereal leaf beetle in Virginia and North Carolina. With a lower development threshold of 8°C and upper development threshold of 25°C, a prediction for egg peak was made at 182 DD (degree-days). Four wheat fields, three in Virginia and one in North Carolina, were sampled weekly from the first emergence of adults, through the egg and larval stages, until newly emerged adults were found. Population peaks were plotted against calculated degree-days to evaluate population trends and to predict population peaks. Observed cereal leaf beetle egg population peaks occurred between April 6 and 12 at all four locations with an average of 8 April. This model predicted the calendar date of peak eggs within 2 days of the average, April 10. Data are also being collected on peak larval populations. These data together will be used to determine if a model can be developed to predict peak larval numbers based on the peak number of eggs. Similar studies are planned in the future to provide additional data to further develop these models. When optimized, these model should provide growers with a 'heads-up' as to when to expect to see cereal leaf beetle stages in their fields, thus limiting the need to scout to those important days and thereby saving growers time and money.

All of this collaborative research, when integrated, should allow us to predict what fields are at the greatest risk to cereal leaf beetle infestation, when they are at risk, and why. Better knowledge of when, why and where outbreaks will occur could improve sampling efficiency and accuracy reducing the number of unnecessary insecticide applications. Our challenge is to develop new information and procedures that will encourage growers to reevaluate the way they are approaching spring-time insect control in wheat, and reconsider adoption of the IPM approach.

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