2011

Stem-Boring Caterpillars of Switchgrass in the Midwestern United States

Jarrad R. Prasifka
University of Illinois, prasifka@illinois.edu

Jennifer E. Buhay
USDA-ARS, jennifer.buhay@ars.usda.gov

Thomas W. Sappington
USDA-ARS, tsapping@iastate.edu

Emily A. Heaton
Iowa State University, heaton@iastate.edu

Jeffrey Bradshaw
University of Nebraska-Lincoln, jbradshaw2@unl.edu

See next page for additional authors

Authors
Jarrad R. Prasifka, Jennifer E. Buhay, Thomas W. Sappington, Emily A. Heaton, Jeffrey Bradshaw, and Michael E. Gray

ARTHROPOD BIOLOGY

Stem-Boring Caterpillars of Switchgrass in the Midwestern United States

JARRAD R. PRASIFKA,[1,2] JENNIFER E. BUHAY,[1] THOMAS W. SAPPINGTON,[1] EMILY A. HEATON,[3] JEFFREY D. BRADSHAW,[4] AND MICHAEL E. GRAY[5]

Energy Biosciences Institute, Institute for Genomic Biology, Room 1117, University of Illinois, Urbana, IL 61801

Ann. Entomol. Soc. Am. 104(3): 507–514 (2011); DOI: 10.1603/AN10183

ABSTRACT Lepidopteran stem borers were collected from switchgrass, *Panicum virgatum* L., tillers showing symptoms of infestation at seven locations in Illinois and Iowa, with additional observations made on larval and adult activity. *Blastobasis repartella* (Dietz) (Coleophoridae), whose only known host is switchgrass, was common in plots grown for >5 yr, whereas the polyphagous stalk borer, *Papaipema nebris* (Guenée) (Noctuidae), was abundant in newly established (i.e., first- and second-year) switchgrass. *Haimbachia albescens* Capps (Crambidae) was collected from two locations in Illinois, making switchgrass the first known host for this species. Entry holes made by *B. repartella* and *H. albescens* were usually 1–2 cm above the soil surface, precluding discrimination between these species based on external appearance of damage. Although *P. nebris* often entered stems within 5 cm of the soil surface, they also seemed to move between stems and were the only species entering stems at heights >15 cm. Adults of *B. repartella* were active on and above the switchgrass canopy by 2130 hours, with peak activity at ≈0230 hours. Activity of *B. repartella* adults seemed greatly reduced on one night with relatively cool temperatures and low wind speeds. Data from switchgrass and giant ragweed, *Ambrosia trifida* L., suggest *P. nebris* larvae move out of switchgrass during July in search of hosts with larger diameter stems, although by then hosts such as corn, *Zea mays* L., or *Miscanthus* spp. may have outgrown the potential for serious damage. However, switchgrass could contribute to greater adult populations of *P. nebris* if thick-stemmed hosts such as giant ragweed are not managed.

KEY WORDS herbivores, biomass, bioenergy, nocturnal activity, *Chaetopsis* sp.

Perennial grasses such as switchgrass, *Panicum virgatum* L., are promoted as crops superior to corn, *Zea mays* L., grain for sustainable production of plant biomass (Varvel et al. 2008). Biomass crops act as sources of alternative energy through the production of liquid fuels (e.g., ethanol) or direct combustion and conversion to electricity. To meet national goals for renewable energy in the United States, the magnitude of land-use changes projected for perennial biomass crops (grasses and woody plants) has been estimated at 14–22 million ha (Perlack et al. 2005). Part of the potential advantage in sustainability for perennial biomass crops is a reduced need for off-farm inputs, including insecticides, relative to annual food and feed crops (Hohenstein and Wright 1994, Hill et al. 2006).

Some research has suggested switchgrass and other perennial grasses will require little or no management for insect pests (Parrish and Fike 2005, Semere and Slater 2007, Wang 2007). However, most food and feed crops are consumed by hundreds of herbivorous insects, with a handful of species acting as significant pests. Given the small areas currently dedicated to perennials such as switchgrass, it seems most accurate to state that the identity of insect herbivores in biomass crops and their effects on yields are simply unknown (Mitchell et al. 2008). Increased research into the herbivorous insects of perennial biomass crops has revealed species that were previously undescribed (Boe and Gagné 2010), described but without known host associations or other general biological information (Prasifka et al. 2010), and well-known pests of food and feed crops (Bradshaw et al. 2010).

A survey for one stem-boring caterpillar in switchgrass, *Blastobasis repartella* (Dietz) (Coleophoridae), showed a species distribution that included at least eight states in the north central United States (Prasifka et al. 2010). Although *B. repartella* only infested ≈4% of switchgrass tillers sampled across four states, there

Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture. USDA is an equal opportunity provider and employer.

[1] USDA–ARS, Corn Insects and Crop Genetics Research Unit, Ames, IA 50011.

[2] Corresponding author, e-mail: prasifka@illinois.edu.

[3] Department of Agronomy, Iowa State University, Ames, IA 50011.

[4] Panhandle Research and Extension Center, University of Nebraska–Lincoln, Scottsbluff, NE 69361–4939.

[5] Department of Crop Sciences, University of Illinois, Urbana, IL 61801.

are still reasons for concern. First, as insects that feed almost exclusively inside plants, stem borers are protected from most insecticides. Second, an orders-of-magnitude expansion of the area dedicated to switchgrass production could change the frequency with which *B. repartella* damages switchgrass tillers. Finally, because the survey for *B. repartella* revealed larvae of two additional species of stem-boring lepidopterans, *Haimbachia albescens* Capps (Crambidae) and *Papaipema nebris* (Guenée) (Noctuidae), the potential for damage to switchgrass or other grasses is significantly increased.

Little is known regarding the biology of *B. repartella* or *H. albescens.* Adults of *B. repartella* were first described a century ago (Dietz 1910), but no host was known until larvae were found infesting switchgrass (Nyoka et al. 2007). Observations in Illinois suggest after larvae overwinter, *B. repartella* tunnel into emerging switchgrass in the spring, pupate in stems at or below soil level, and eclose as adults after which females deposit eggs at the base of tillers in midsummer (Prasifka et al. 2010). Similarly, a description of *H. albescens* adults represents the only published information for this species (Capps 1965). However, stalk borer is a well-known pest found in hundreds of hosts, but it is often associated with corn (Rice and Davis 2010). Stalk borer overwinters as eggs, typically on weedy grasses (Levine 1985). After hatch, stalk borer larvae tunnel into a host, often outgrowing the stem diameter and moving to another, larger diameter plant. Pupae are found in the soil (or host stalks), with adults emerging from late summer to early fall (Bailey et al. 1985). Because of the association with noncrop hosts, stalk borer damage to cultivated crops usually occurs near field borders (Meyer and Peterson 1998) or in fields with high weed populations (Levine 1993).

To better understand the community of insects feeding on switchgrass grown for biomass, observations were made on stem-boring lepidopterans from switchgrass in two midwestern states. Tillers showing symptoms of infestation were dissected to characterize injury by stem-boring species in plots of varying size and age. Data on nocturnal activity were collected to facilitate collection of adult moths, which are well concealed during the day. Sampling also was conducted in an annual weed host preferred by *P. nebris* to determine the potential effect of switchgrass on populations of this polyphagous stem borer.

Materials and Methods

Efforts to characterize lepidopteran stem borers of switchgrass were made from three locations in Illinois and four locations in Iowa during 2010. Except for a single area of native vegetation adjacent to a farm in Iowa, all sites were plots of switchgrass used for biomass production research. Two locations in Illinois (SoyFACE, 40.04° N, 88.22° W; and Energy Farm, 40.06° N, 88.19° W) were located near one another, and the third (Dudley Smith, 39.44° N, 89.12° W) was ≈100 km to the southwest. All four locations in Iowa (Sorenson, 42.012° N, 93.746° W; Marsden, 42.016° N, 93.777° W; Hinds, 42.067° N, 93.623° W; and Woodruff, 41.986° N, 93.694° W) were located in the central part of the state within 15 km of each other. The plots were typically surrounded by turf (mowed), soybean [*Glycine max* (L.) Merr.], corn, and (at the Illinois sites) the perennial biomass crop *Miscanthus* × *giganteus* Greef and Deuter ex Hodkinson and Renvoize.

Larval Collections From Switchgrass. By 29 April, larvae of *B. repartella* were present in new growth of switchgrass in both Illinois and Iowa. However, larvae could be found only by dissecting tillers randomly or by carefully looking for very small holes at the base of emerging tillers; only in subsequent weeks were symptoms of infestation detectable in emerging leaves. Because dead or dying whorl leaves also may be caused by mechanical damage (e.g., from farm equipment or walking through plots) switchgrass tillers were considered to show symptoms of borer infestation only if a hole near the base of the stem also was visible.

In Illinois, collections focused on quantifying the proportion of tillers lost to stem borer species infesting switchgrass. From 10 May to 10 June, weekly collections were made at three locations. For each location, five points were randomly selected within a plot. At each point, a subsample of 100 tillers was searched and symptomatic tillers were cut below soil level. Tillers were later dissected by hand. The height of the hole in each stem (centimeters above soil level), and the location of the larva or pupa relative to the hole were noted. Larvae or pupae removed from stems were retained for identification. To test whether the species of borers infesting switchgrass could be determined without dissection, a Kruskal–Wallis (KW) test (SAS Institute 2007) was used to evaluate possible differences in the height of entry holes for species which were collected from >20 tillers; a category (vacant) also was included for stems in which no larva or pupa was found.

In Iowa, where only one of the locations was sampled in previous years, collections were made to obtain the greatest number of symptomatic tillers possible. Between 31 May and 15 June, each of four locations was sampled on two or three dates. At each location, tillers with dead or dying whorl leaves were identified by crawling or walking through plots; tillers that also had holes near the base of the stem were cut below soil level and dissected as described for the samples in Illinois. Tests regarding the height of holes made by stem borers also were made for the Iowa collections, but the greater total number of stems collected in Iowa allowed testing across multiple weeks. Consequently, tests for the effect of time on height of entry holes were made within a species to assess whether larvae moved into plots (or between tillers) over successive weeks.

Adult Activity. Attempts to collect adults of stem-boring caterpillars of switchgrass by using sweep-nets and vacuum samplers during the daytime have proven very inefficient, but *B. repartella* and *H. albescens* adults have been observed resting on switchgrass foliage and flying shortly after sunset. To facilitate collection of moths, two locations in Illinois were used to determine general patterns of adult activity. Using a headlight and sweep-net, moths were sampled without replacement from the perimeter of switchgrass plots; as many adult *B. repartella* and *H. albescens* as possible were collected during the last 30 min of each hour between 2100 and 0400 hours. The total numbers of moths and mating pairs collected were tracked using hand counters. To ensure a significant number of adults would be present, adult moths were sampled at Dudley Smith (17 June) and Soyface (24 and 26 June) farms ≈3 wk after the first *B. repartella* pupae were observed. Data from weather stations adjacent to switchgrass (<50 m) at each farm were examined for potential explanations of extremely low adult activity on 24 June. A chi-square test (SAS Institute 2007) was used to test whether observed activity of adult moths was distributed evenly during collection periods on 17 and 26 June.

Additional Observations. Because *P. nebris* is an occasional pest of several food and feed crops, the potential exists for switchgrass to indirectly affect nearby crops by increasing stalk borer populations. However, the life history of *P. nebris* implies that larvae eventually outgrow switchgrass and search for hosts with larger diameter stems. Consequently, after termination of sampling for other stem-boring caterpillars, switchgrass plots in Iowa and Illinois were occasionally sampled to determine whether stalk borers were departing for other hosts. During late June and early July, tillers that showed death of emerging leaves or panicles (i.e., witches' broom) and evidence of a large diameter hole in the stem were cut and dissected to determine the proportion of symptomatic tillers that contained *P. nebris* larvae. After sampling indicated few stalk borer larvae remained in switchgrass tillers, giant ragweed (*Ambrosia trifida* L.) plants were sampled to assess whether this weedy host may permit larvae abandoning switchgrass tillers to complete development. On 12 June, giant ragweed plants ($n = 12$) were removed from within a plot of switchgrass at the SoyFACE Farm in Illinois. Where large diameter entry holes were found, plants were split to assess the number of *P. nebris* per plant. A similar number of giant ragweed plants ($n = 15$) was collected from the border of an adjacent field 20–25 m away from the switchgrass. Because *P. nebris* larvae clearly did not share entry holes in giant ragweed, populations in the second sample were assessed by simply counting the holes characteristic of stalk borers; because some holes in the first sample did not contain *P. nebris* (or any other insect), simply counting the large holes probably produced a slight overestimate of larval numbers per plant in the second sample. To compare the numbers of *P. nebris* larvae from giant ragweed in switchgrass with giant ragweed from the adjacent field border, a *t*-test for groups with unequal variances was used. Also, based on reports of *P. nebris* injury to the introduced biomass crop *M.* × *giganteus*, stems of *Miscanthus* spp. in a nursery bordered by switchgrass at the Energy Farm were examined for *P. nebris* injury. In Iowa, stalk borer larvae also were collected from giant ragweed plants growing adjacent to switchgrass at the Woodruff farm, whereas apparent *P. nebris* injury to *M.* × *giganteus* was investigated at the Sorenson farm.

Table 1. Stem-boring caterpillars collected from switchgrass in three Illinois farms, 10 May–10 June 2010

Farm	Area (ha)	Age (yr)	Symptomatic tillers (%)[a]	*B. repartella*	*H. albescens*	*P. nebris*
SoyFACE	0.19	6	2.79	34	19	2
Dudley Smith	0.20	6	3.28	51	0	0
Energy	0.69	3	0.48	2	3	2

[a] From five 100-tiller subsamples each week for 5 wk (i.e., 2,500 tillers).

Results

Larval Collections From Switchgrass. Early-season damage by stem borers in Illinois was ≈3% for plots >5 yr old but was <1% for a single plot in its third year. Across all Illinois sites, relative abundance was *B. repartella* > *H. albescens* > *P. nebris*, although all species seemed equally uncommon in the youngest of the three fields surveyed (Table 1). Pupae for *B. repartella* were first found on 25 May, with most (≈75%) pupated by the second week of June. *H. albescens* pupae were not successfully collected from the field but were obtained by removing larvae from stems and confining them with sections of switchgrass stem tissue in the laboratory. Because host association and immature stages for *H. albescens* were previously unknown, larval, pupal, and adult specimens were deposited as vouchers at the U.S. Department of Agriculture's Systematic Entomology Laboratory (Beltsville, MD). Dipteran larvae also were occasionally found in tillers showing symptoms of damage by lepidopteran stem borers. Fly larvae reared to adulthood were identified as *Chaetopsis* sp. (Otitidae), possibly *Chaetopsis massyla* (Walker), which has been noted previously as a secondary invader of monocots damaged by stem-boring lepidopterans (Allen and Foote 1992).

The distribution of heights of entry holes differed among tillers containing *B. repartella*, *H. albescens*, and tillers that were vacant (symptomatic but with no lepidopteran larva inside the stem) (KW test: $\chi^2 = 42.0$, df = 2, $P < 0.001$), although considerable overlap occurred between the heights of *B. repartella* (median = 1 cm) and *H. albescens* (2-cm) entry holes. Heights of holes in vacant stems overlapped with those of *B. repartella* and *H. albescens* but also included outliers significantly higher than what was observed for either of those species; too few *P. nebris* (<10) were collected between 10 May and 10 June in Illinois to compare entry hole heights with those of the other stem-boring caterpillar species.

In Iowa, *P. nebris* was the most common species in collections of symptomatic switchgrass tillers, particularly in fields less than three years old and at a single mixed species grassland site (of unknown age). *H. albescens* was not collected in Iowa. However, as in Illinois, *B. repartella* was the most common stem-bor-

Table 2. Stem-boring caterpillars collected from switchgrass in four Iowa farms, 31 May 31–15 June 2010

Farm	Area (ha)	Age (yr)	Symptomatic tillers (no.)	*B. repartella*	*H. albescens*	*P. nebris*
Sorenson	0.05	7	152	65	0	15
Hinds[a]	1.16	Unknown	234	0	0	173
Marsden	3.24	3	123	12	0	64
Woodruff	7.28	2	245	0[b]	0	97

[a] Mixed species grassland adjacent to farm. Area not representative of switchgrass coverage.

[b] A single *B. repartella* larva was collected at the Woodruff farm on May 14 (before start of intensive sampling).

ing species collected in switchgrass >5 yr old (Table 2). Fly larvae resembling *Chaetopsis* sp. also were collected from tillers showing symptoms of lepidopteran damage but were not reared to adulthood. Dipteran larvae were generally found in stems categorized as vacant (16 of 328) rather than in stems containing *B. repartella* or *P. nebris* (1 of 426). The distribution of heights of *B. repartella* entry holes did not appear to change, but height increased by week for both tillers containing *P. nebris* ($\chi^2 = 82.1$, df = 2, $P < 0.001$) and those that were vacant ($\chi^2 = 47.0$, df = 1, $P < 0.001$) (Fig. 1).

Adult Activity. Moths were first seen on 11 June at SoyFACE, 11 d after pupae were first found at that location. Large numbers of adult *B. repartella* were collected by headlight and sweep-net, but almost no *H. albescens.* At Dudley Smith farm, just >10 adults could be collected per 30 min of sampling effort between 1 and 5 h after sunset, but significantly more adults were found starting at 0230 hours ($\chi^2 = 76.7$, df = 6, $P < 0.001$). Attempts to collect adults at SoyFACE on 24 June were mostly unsuccessful, with only seven adults obtained. Equal sampling effort at the same location on 26 June resulted in >100 adults collected, again with an increase after 0230 ($\chi^2 = 60.6$, df = 6, $P < 0.001$). Details of *B. repartella* adult collections are shown in Fig. 2, along with weather data that may relate to differences in adult activity between 24 June and the other sample dates. Only three mating pairs of *B. repartella* were seen over the three nights of observation, all after 0230 hours.

Additional Observations. Although *P. nebris* seemed uncommon in Illinois switchgrass plots from 10 May to 10 June, stems damaged by stalk borer (indicated by large-diameter holes, often >20 cm above soil level) were relatively easy to find in July. On 2 July, 18 stalk borer larvae were collected from 74 (24%) symptomatic tillers at the SoyFACE farm. By 9 July, only three of 59 (5%) symptomatic stems contained *P. nebris,* indicating most larvae had left switchgrass for larger stemmed hosts. Subsequent dissections of giant ragweed plants growing within a 0.19-ha switchgrass field revealed (mean ± SE) 8.9 ± 2.3 live *P. nebris* per plant; based on the number of entry holes, the level of *P. nebris* infestation in giant ragweed plants from the border of an adjacent soybean field was significantly lower (1.3 ± 0.3 holes per plant; $t = 3.2$, df = 11.3, $P = 0.008$). Partial dissection of a single giant ragweed plant adjacent to switchgrass at the Woodruff farm in Iowa also yielded several dozen stalk borer larvae in early July.

Previous observations of *P. nebris* infesting the "Illinois clone" of *M.* × *giganteus* were uncommon and larvae were sometimes found dead inside the stems, both implying *M.* × *giganteus* could have significant resistance (nonpreference or antibiosis) to stalk borer. However, reports of injury to *M.* × *giganteus* by stem-boring caterpillars at two Iowa locations prompted further examination of *Miscanthus* spp. in Illinois. In a nursery bordered by switchgrass at the Energy Farm, stems of *M. sinensis* and *M.* × *giganteus* 'Nagara' were found to contain *P. nebris* larvae on 28 June, but the proportion of stems infested appeared to

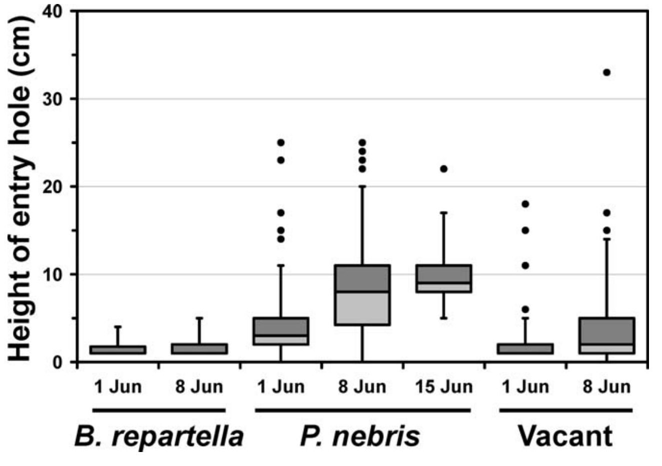

Fig. 1. Heights of entry holes (relative to soil level) for switchgrass tillers showing symptoms of stem borer infestation in Iowa. Data shown by collection week and contents of stems (*B. repartella*, *P. nebris*, or vacant). Box-and-whiskers plots shown with whiskers representing 3 times the range between the median and upper or lower quartile (because of asymmetric distributions). Outliers shown as filled circles beyond whiskers. Sample sizes (n) across columns = 50, 26, 108, 190, 50, 180, and 109.

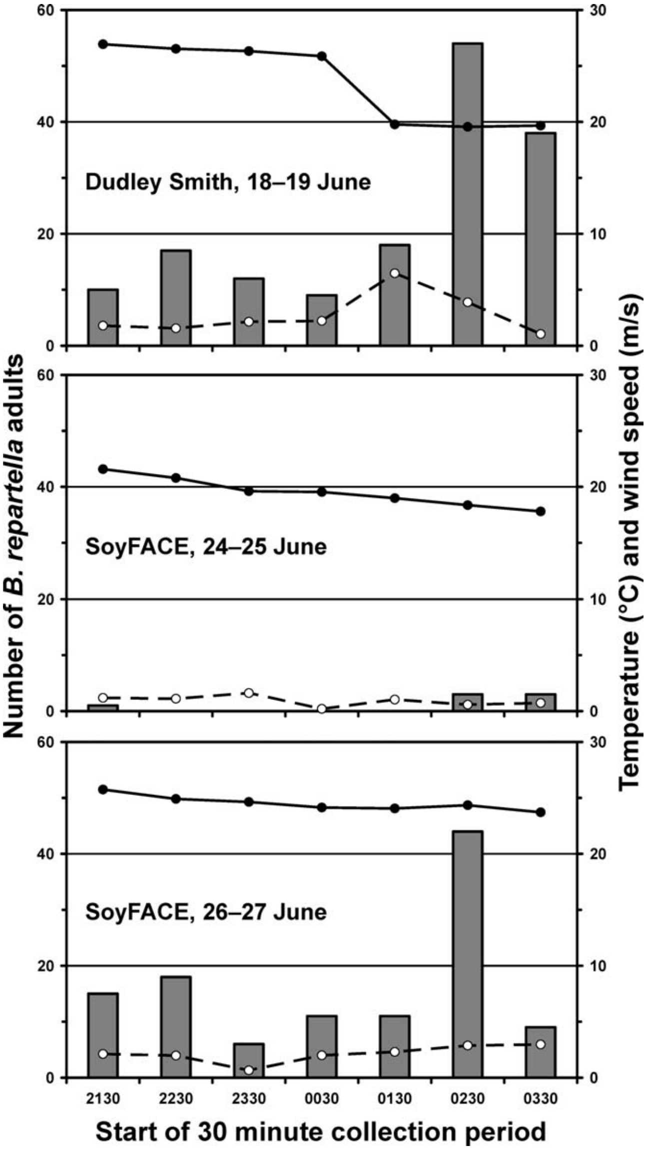

Fig. 2. Numbers of adult *B. repartella* collected using headlight and sweep-net during the latter 30 min of each hour between 2100 and 0400 hours. Data on temperature (solid line, closed circles) and wind speed (dashed line, open circles) from adjacent weather stations plotted as means over 30-min collection intervals. Relative humidity for each date, >90%.

be well <1%. On the same farm, other plots of *M.* × *giganteus* were apparently uninjured by *P. nebris* or other stem-boring lepidopterans. In Iowa, *M.* × *giganteus* stems with holes similar to those produced by stalk borer were collected at the Sorenson farm, where several small grains were planted with *M.* × *giganteus* during 2009 as a nurse crop. However, at the time of inspection (13 July), no lepidopteran larvae were found inside.

Discussion

Based on collections in Illinois and Iowa and the known distributions of *B. repartella* (Prasifka et al. 2010) and *P. nebris*, infestation of switchgrass by both species should be common throughout the midwestern United States. Although *B. repartella* was more abundant in older, well-established switchgrass, stalk borer was common in recently planted fields and switchgrass in one small, mixed species grassland (Tables 1 and 2). Large differences in the relative abundance of the two species between individual farms probably reflects their life histories; as an insect believed to be monophagous (or oligophagous) and with a small adult size, *B. repartella* may be slow to spread among small or isolated patches of suitable hosts. However, *P. nebris* larvae are found in hundreds of plant species, making adults more evenly distributed across the landscape and, along with their large size, more capable of moving into new switchgrass fields. Based on observations of newly established (i.e., first- and second-year) switchgrass, the abundance of weeds in new plantings may be attractive to ovipositing *P. nebris* and provide several potential larval hosts. It is unclear why *H. albescens* larvae were not collected from one location in Illinois or from any of the four locations in Iowa. Because the host plant for this species was previously unknown (Capps 1965), it may be a specialist that (as conjectured for *B. repartella*) is slow to colonize new plantings of switchgrass. Considering *H. albescens* adults have been collected in Iowa, New Jersey, and Virginia (Capps 1965), it seems this species may be widely distributed but relatively uncommon.

Data on the location of entry holes for *B. repartella*, *H. albescens*, and *P. nebris* were collected to test the idea that distribution of heights would reflect the time stems were colonized by borers, both between and within species. The location of holes does not provide a simple diagnostic where *B. repartella* and *H. albescens* are both present, because both often left holes 1–2 cm above the soil surface. However, for holes found >10 cm above soil level, all but one ($n = 103$) stem containing a lepidopteran larva contained *P. nebris* (Fig. 1). The increase in median hole location between weeks for stems containing *P. nebris* and vacant stems suggests stalk borers both move between stems and colonize plots over several weeks.

Observations of adult activity indicate that even with a low-level (≈3%) infestation, large numbers of *B. repartella* adults can be collected by one person on nights when moths are active (Fig. 2). Data from SoyFACE also show that 2 wk after the start of adult emergence, many moths may remain inactive beneath the canopy when conditions are unsatisfactory to *B. repartella.* Both temperature (Taylor 1963, Taylor and Shields 1990) and wind speed (Rojas et al. 2004, Bailey et al. 2007) can be important determinants of moth activity, but assigning a cause for *B. repartella* inactivity on 24 June is difficult because that night was both relatively cool and calm. However, because even the relatively cool temperatures on 24 June were ≥5°C over thresholds for flight in other species (Taylor 1963, Danthanarayana 1976, Taylor and Shields 1990), this seems an unlikely explanation. Furthermore, there are few instances where lower wind speed thresholds for moth flight have been established, although conditions on 24 June are close to what Danthanarayana (1976) suggested as a lower limit (0.8 m/s) for light brown apple moth, *Epiphyas postvittana* (Walker) (Tortricidae). Combined with the small number of nights on which *B. repartella* adults were quantitatively sampled, data on local weather conditions do not seem sufficient to determine the cause of differences in moth activity between dates.

B. repartella and *H. albescens* probably have little present impact on switchgrass production. Stunting of a small fraction (usually <5%) of tillers during the first few weeks of each growing season may permit plants to compensate by moving resources from the rhizomes into the remaining tillers, or by producing additional tillers. Even with occasional pest population outbreaks, perennial grasses may prove resilient in subsequent years (Johnson and Knapp 1996). However, collections from switchgrass in a mixed species area in Illinois produced no *B. repartella,* pointing to the possibility that production of larger, monospecific fields of switchgrass will provide conditions that promote increased problems with specialist herbivores.

Differences in the relative numbers of *P. nebris* collected in switchgrass were apparent between Illinois and Iowa. Stalk borer were initially uncommon in Illinois (≈0.1% infestation from 10 May to 10 June), though collections of *P. nebris* in switchgrass and giant ragweed (growing within switchgrass fields) indicated that larvae continued to move into switchgrass over a period of several weeks. In Iowa, the number of stalk borer larvae collected suggests some eggs may have overwintered within switchgrass, although it is unclear whether such eggs would have been laid on switchgrass or other weed species within the plots (Levine 1985). Relative to the *B. repartella* and *H. albescens,* potential for *P. nebris* to damage switchgrass may seem greater, as stalk borer larvae often move between stems, probably killing several tillers during the first 3 mo of growth. Furthermore, the density of tillers in switchgrass (400–800 tillers per m^2) means that a low frequency of infestation could produce relatively high incidence in adjacent food or feed crops. Interestingly, the large size of *P. nebris* may mitigate its damage potential, as switchgrass cultivars grown in the midwestern United States have diameters too small to permit stalk borers to complete larval development. Movement of *P. nebris* larvae out of switchgrass may present a risk to other crops grown nearby, but if the timing observed in Illinois (early-to-mid July) is typical, nearby corn usually will be too large to be affected by stalk borers (greater than six-leaf stage; Davis and Pedigo 1991). The low levels of stalk borers seen in *M. sinensis* and an *M. × giganteus* Nagara surrounded by infested switchgrass also imply that the varieties of *Miscanthus* spp. in the nursery may not be at risk from *P. nebris.* However, the increased number of stalk borers found in giant ragweed plants growing within switchgrass suggests the potential to support increased populations of *P. nebris.* This possibility is contingent on switchgrass fields containing one or more thick-stemmed weedy host of stalk borer, and perhaps provides an additional reason to be mindful of weed management during switchgrass establishment and maintenance.

Although none of the stem-boring lepidopterans collected in the midwestern United States seem to present serious, immediate threats to switchgrass or other crops grown nearby, their ready detection is a reminder of the potential for pests to complicate and limit agricultural production (Oerke 2005). Because the current area planted with dedicated biomass crops like switchgrass is orders of magnitude less than projected (Perlack et al. 2005), it may not be feasible to accurately predict the effects of insects and other pests before widespread planting of the crop (Bouton

2008, Perkins 2009). However, insect damage generally increases in large plantings of any crop, often due to greatly increased populations of one or more pests that are not significant in small or diverse plantings (Pimentel 1961, Root 1973). Forecasting the future effects of pests is even more difficult with regard to interactions between biomass and nearby food or feed crops (Perkins 2009, Spencer and Raghu 2009). Consequently, the best preparation is to continue to improve our understanding of the identities and biology of potential pests in candidate biomass crops.

Acknowledgments

We appreciate the help of Alma Solis and Allen Norrbom (USDA–ARS Systematic Entomology Laboratory), who identified *H. albescens* and *Chaetopsis* sp. adults, respectively. Megan Campbell (Mendel Biotechnology, Inc.) provided access to and information on plots within a *Miscanthus* spp. nursery. Andy VanLoocke (University of Illinois) provided data from local weather stations at SoyFACE and Dudley Smith farms. Patricia Prasifka (Dow AgroSciences) helped with the collection of adult moths. Saritha Muppa, Arielle Liebel, Angelique Howell, Jessie Dowding, Eric Hoffmeyer, Craig Marshall, Pat Alt, and Randy Ritland assisted with collections at the Iowa farms. Research funding was provided by the Energy Biosciences Institute.

References Cited

Allen, E. J., and B. A. Foote. 1992. Biology and immature stages of *Chaetopsis massyla* (Diptera: Otitidae), a secondary invader of herbaceous stems of wetland monocots. Proc. Entomol. Soc. Wash. 94: 320–328.

Bailey, W. C., G. D. Buntin, and L. P. Pedigo. 1985. Phenology of the adult stalk borer, *Papaipema nebris* (Gueneé) in Iowa. Environ. Entomol. 14: 267–271.

Bailey, R. I., D. Bourguet, A.-H. Le Pallec, and S. Ponsard. 2007. Dispersal propensity and settling preferences of European corn borers in maize field borders. J. Appl. Ecol. 44: 385–394.

Boe, A., and R. J. Gagné. 2010. A new species of gall midge (Diptera: Cecidomyiidae) infesting switchgrass in the northern Great Plains. BioEnergy Res. 4: 77–84 (doi: 10.1007/s12155-010-9102-6).

Bouton, J. 2008. Improvement of switchgrass as a bioenergy crop, pp. 295–308. *In* W. Vermerris (ed.), Genetic improvement of bioenergy crops. Springer Science+Business Media, LLC, New York.

Bradshaw, J. D., J. R. Prasifka, K. L. Steffey, and M. E. Gray. 2010. First report of field populations of two potential aphid pests of the bioenergy crop *Miscanthus* × *giganteus*. Fla. Entomol. 93: 135–137.

Capps, H. W. 1965. A review of the genus *Haimbachia* Dyar with descriptions of new species (Lepidoptera: Crambidae). Proc. U.S. Natl. Mus. 117: 629–654.

Danthanarayana, W. 1976. Flight thresholds and seasonal variations in flight activity of the light-brown apple moth, *Epiphyas postvittana* (Walk.)(Tortricidae), in Victoria, Australia. Oecologia 23: 271–282.

Davis, P. M., and L. P. Pedigo. 1991. Economic injury levels for management of stalk borer (Lepidoptera: Noctuidae) in corn. J. Econ. Entomol. 84: 290–293.

Dietz, W. G. 1910. Revision of the Blastobasidae of North America. Trans. Am. Entomol. Soc. 36: 1–72.

Hill, J., E. Nelson, D. Tilman, S. Polasky, and D. Tiffany. 2006. Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels. Proc. Natl. Acad. Sci. U.S.A. 103: 11206–11210.

Hohenstein, W. G., and L. L. Wright. 1994. Biomass energy production in the United States-an overview. Biomass Bioenergy 6: 161–173.

Johnson, S. R., and A. K. Knapp. 1996. Impact of *Ischnodemus falicus* (Hemiptera: Lygaeidae) on photosynthesis and production of *Spartina pectinata* wetlands. Environ. Entomol. 25: 1122–1127.

Levine, E. 1985. Oviposition by the stalk borer, Papaipema nebris (Lepidoptera: Noctuidae), on weeds, plant debris, and cover crops in cage tests. J. Econ. Entomol. 78: 65–68.

Levine, E. 1993. Effect of tillage practices and weed management on survival of stalk borer (Lepidoptera: Noctuidae) eggs and larvae. J. Econ. Entomol. 86: 924–928.

Meyer, S. J., and R.K.D. Peterson. 1998. Predicting movement of stalk borer (Lepidoptera: Noctuidae) larvae in corn. Crop Prot. 17: 609–612.

Mitchell, R., K. P. Vogel, and G. Sarath. 2008. Managing and enhancing switchgrass as a bioenergy feedstock. Biofuels Bioprod. Bioref. 2: 530–539.

Nyoka, B., P. Jeranyama, V. Owens, A. Boe, and M. Noechnig. 2007. Management guide for biomass feedstock production from switchgrass in the Northern Great Plains. SGINC2-07. South Dakota State University, Brookings, SD.

Oerke, E.-C. 2005. Crop losses to pests. J. Agric. Sci. 144: 31–43.

Parrish, D. J., and J. H. Fike. 2005. The biology and agronomy of switchgrass for biofuels. Crit. Rev. Plant Sci. 24: 423–459.

Perkins, J. H. 2009. Integrated pest management, biofuels, and a new Green Revolution: a case study of the American Midwest, pp. 581–607. *In* R. Peshin and A. K. Dhawan (eds.), Integrated pest management: dissemination and impact. Springer Science+Business Media, LLC, New York.

Perlack, R. D., L. L. Wright, A. F. Turhollow, R. L. Graham, B. J. Stokes, and D. C. Erbach. 2005. Biomass as feedstock for a bioenergy and bioproducts industry: the technical feasibility of a billion-ton annual supply. Oak Ridge National Laboratory, Oak Ridge, TN.

Pimentel, D. 1961. Species diversity and insect population outbreaks. Ann. Entomol. Soc. Am. 54: 76–86.

Prasifka, J. R., J. D. Bradshaw, A. A. Boe, D. K. Lee, D. Adamski, and M. E. Gray. 2010. Symptoms, distribution and abundance of the stem-boring caterpillar, *Blastobasis repartella* (Dietz), in switchgrass. Bioenergy Res. 3: 238–242.

Rice, M. E., and P. Davis. 2010. Stalk borer (Lepidoptera: Noctuidae) ecology and integrated pest management in corn. J. Integr. Pest Manag. 1: C1–C6.

Rojas, J. C., A. Virgen, and E. A. Malo. 2004. Seasonal and nocturnal flight activity of *Spodoptera frugiperda* males (Lepidoptera: Noctuidae) monitored by pheromone traps in the coast of Chiapas, México. Fla. Entomol. 87: 496–503.

Root, R. B. 1973. Organization of a plant-arthropod association in simple and diverse habitats—fauna of collards (*Brassica oleracea*). Ecol. Monogr. 43: 95–120.

SAS Institute. 2007. SAS 9.1.3, Help and documentation. SAS Institute, Cary, NC. (http://support.sas.com/onlinedoc/913/docMainpage.jsp).

Semere, T., and F. M. Slater. 2007. Invertebrate populations in *Miscanthus* (*Miscanthus* × *giganteus*) and reed canarygrass (*Phalaris arundinacea*) fields. Biomass Bioenergy 31: 30–39.

Spencer, J. L., and S. Raghu. 2009. Refuge or reservoir? The potential impacts of the biofuel crop *Miscanthus x giganteus* on a major pest of maize. PLoS ONE 4: e8336.

Taylor, L. R. 1963. Analysis of the effect of temperature on insects in flight. J. Anim. Ecol. 32: 99–117.

Taylor, P. S., and E. J. Shields. 1990. Flight thresholds of the armyworm (Lepidoptera: Noctuidae). Environ. Entomol. 19: 1410–1417.

Varvel, G. E., K. P. Vogel, R. B. Mitchell, R. F. Follett, and J. M. Kimble. 2008. Comparison of corn and switchgrass on marginal soils for bioenergy. Biomass Bioenergy 32: 18–21.

Wang, M. 2007. The greenhouse gases, regulated emissions, and energy use in transportation (GREET) model, version 1.8c. 0. University of Chicago Argonne LLC, Argonne, IL.

Received 19 November 2010; accepted 14 March 2011.