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Original Article

Growing degree-days accumulation and phenological stages of the maize billbug [*Sphenophorus maidis* (Chittenden)] in eastern gamagrass [*Tripsacum dactyloides* (L.) L.]

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ABSTRACT

The maize billbug [*Sphenophoris maidis* (Chittenden)] feeds on eastern gamagrass [*Tripsacum dactyloides* (L.) L.] causing economic damage. The incidence of maize billbug was studied in a six-year-old eastern gamagrass field plot, and cumulative growing degree-days (cGDD) were calculated for the morphological stages of the pest for two years. The adult population was more abundant and distributed throughout the year compared to larvae and pupae. On the basis of growing degree-days, the 99% quantile for larvae, pupae, and adult maize billbug population was estimated between 1396-1908 cGDD. Very few pupae were recovered from field sampling, which may be due to its short pupation period and weekly sampling interval. Findings of this study will be helpful to formulate sustainable maize billbug management strategies.

KEYWORDS: maize billbug, eastern gamagrass, life-cycle, growing degree-days.

INTRODUCTION

Eastern gamagrass [*Tripsacum dactyloides* (L.) L., Poaceae] is a warm-season perennial C_4 bunchgrass distributed throughout the eastern, central, and southern United States [1, 2]. Eastern gamagrass was recognized by Magoffin (1831) for its productivity and high-quality palatable forage [3]. The grass is primarily used for forage and hay and is valued for its multiple ecosystem services [4]. The most recent eastern gamagrass cultivars include Pete, Iuka IV, Jackson, Medina, Highlander, and Verl [5, 6]. Recently, eastern gamagrass has attracted considerable attention among stakeholders in the forage and livestock industry. Since its production area has increased over the years, pests and diseases have also become more abundant and problematic [5]. Although eastern gamagrass is considered relatively free of insect pests and pathogens [7], the taxonomic proximity of eastern gamagrass to corn (*Zea mays* L.) makes it more susceptible to diseases and pests of corn [6, 8]. Eastern gamagrass was reported as a host plant of maize billbug by Satterthwait [9]. It was first described by Dr. F. H. Chittenden, and as early as 1854 it was reported to be very destructive to corn [10]. Springer *et al.* [5] estimated a potential Eastern gamagrass forage yield loss of 145 kg ha^{-1} due to maize billbug infestation, which could significantly reduce forage production and stand longevity. This is equivalent to a loss in eastern gamagrass hay production of 5.8 USD ha^{-1} (estimates based on 40 USD Mg^{-1}) [11].

Adult maize billbugs feed on young shoots of eastern gamagrass, leaving a transverse feeding pattern. Female maize billbugs feed at the base of the culm for ovipositioning and once the eggs hatch,

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the larvae feed voraciously producing a cavity at the base of the culm, thereby causing extensive damage to the culm base which results in the death of the culm [11]. Because so much remains unknown about eastern gamagrass pest population and life cycle dynamics, predicting outbreak is exceptionally challenging. Julian date models have proved to be inadequate in predicting insect outbreak when growing season conditions differ substantially from the normal. A site-specific degree-day model has been widely used in the published literature for improved prediction of insect phenology using air temperature data. Hence, research was conducted for a better understanding of the putative life stages of the maize billbug in eastern gamagrass. An overview of maize billbug ecology, with a focus on the extent of thermal requirements of the species in eastern gamagrass, is presented.

MATERIALS AND METHODS

Site description and weather conditions

This study was conducted at the USDA-ARS Southern Plains Range Research Station (SPRRS), Woodward, OK (36º 25'N 99º 24'W, elevation 615 m above sea level), during the year 2003 and 2004. Eastern gamagrass germplasm 'FGT-1' [12] were transplanted in the field in 1996. Plants were spaced on 1.1 m centers. The soil of the experimental plot was a Devol fine sandy loam (Thermic Typic Haplustalfs). Each year, the plants were burned in mid-March and atrazine (2-chloro-4-ethylamino-6-isopropylamino-1,3,5-triazine) was applied at the rate of 1.68 a. i. ha^{-1}, 7-14 days after burning for weed control. Nitrogen fertilizer in the form of urea was applied to the soil at 70 kg N ha^{-1}. No insecticides were used in the field. Beginning in January 2003, each week, four plant crowns were randomly selected and dug out throughout the year for maize billbug sampling. Plant shoots of the sampled materials were dissected to determine the presence of larvae, pupae, and adult maize billbugs (Figure 1). Detailed methods of sampling are published in Springer *et al*. [13]. Daily high and low temperatures and rainfall data were obtained from an automated weather station located approximately 1 km from the study site from which 30-year average climate normal was computed (Table 1).

Figure 1. Larvae of maize billbug [*Sphenophorus maidis* (top)] within a feeding cavity located at the base of eastern gamagrass [*Tripsacum dactyloides* (L.) L.] culm; adult and pupae in the inset (scale bar in *cm*). Photograph by David Maas.

Table 1. Monthly mean maximum and minimum temperatures, and monthly total rainfall in 2003 and 2004 in comparison with the 30-year mean (1981-2010) for Woodward, Oklahoma, USA.

Month	2003			2004			30-year mean		
	Max T (°C)	Min T (°C)	Rain (mm)	Max T (°C)	Min T (°C)	Rain (mm)	Max T (°C)	Min T (°C)	Rain (mm)
Jan	10	-4	2	10	-4	32	9	-6	13
Feb	8	-4	10	10	-3	34	12	-3	25
Mar	17	2	47	19	6	78	17	2	46
Apr	23	8	35	21	8	50	23	7	53
May	26	12	37	30	15	1	27	13	102
Jun	28	17	111	30	18	168	32	18	81
Jul	36	22	1	32	20	47	35	21	66
Aug	35	21	92	31	18	95	34	19	74
Sep	26	14	75	30	16	29	29	15	58
Oct	23	9	10	22	9	86	24	8	48
Nov	15	3	16	13	3	120	16	1	36
Dec	11	-2	17	13	-2	3	40	-4	20

Cumulative growing degree-days

Growing degree-days (GDD) is a commonly used measure of thermal accumulation. It serves as a proxy for growing conditions within a region and species phenology [14]. GDD explicitly constrains the thermal limits within which growth is possible. Equation (1) was used to calculate growing degree-days (GDD) for each year using the weather data collected locally.

$$GDD = \sum \left[\frac{T_{max} + T_{min}}{2} - T_{base} \right] \quad (1)$$

where T_{max} is the daily maximum air temperature, T_{min} is the daily minimum air temperature, and T_{base} is the temperature below which the processes of the species, such as growth and development do not progress and the organism remains in dormancy. Because the base minimum temperature threshold for maize billbug is unknown, a minimum threshold of 10 °C was used which is similar to the degree-day model developed for bluegrass billbug (*Sphenophorus parvulus* Gyllenhal) in Ohio, USA [15]. A maximum temperature threshold of 30 °C was used based on the Springer *et al*. [16] discussion of temperature requirements for eastern gamagrass. Cumulative growing degree-days was calculated with a biofix date of April 12 using the daily maximum and minimum ambient temperature recorded for the site. A biofix date of April 12 was used because it is reported as the last hard freeze date (minimum temperature ≤ -2.2 °C) for the study area. All analyses were conducted using SAS software, version 9.4 (SAS Institute Inc., Cary, NC, USA). PROC UNIVARIATE was used to obtain descriptive statistics for cumulative growing degree-days (cGDD) for each life stage.

RESULTS AND DISCUSSION

The first captures of maize billbug larvae, pupae, and adults were recorded as early as day of year (DOY) 169, 190, and 7 for 2003 and DOY 175, 189, and 14 for 2004 respectively. Adults captured early in the year are from the overwintering adult population. Larvae, pupae, and adults comprised 30.2, 8.3 and 61.4% of the total sampled population respectively. The 5% and 95% quantile for egg, larvae, pupae, and adult maize billbugs were estimated between 574-1868 cGDD and 1396-1868 cGDD, respectively (Table 2).

Table 2. Putative life-stages of the maize billbug [*Sphenophorus maidis* (Chittenden)] in eastern gamagrass at Woodward, OK. Cumulative growing degree-days (cGDD) computed based on a biofix of April 12.

Stage		*n*	Observed cGDD				Expected cGDD			
			1%	5%	95%	Range	1%	5%	95%	Range
Average	Eggs†	50	543	619	1457	838 (57) ‡	403	574	1396	822 (56)
	Larvae	128	618	719	1592	873 (60)	490	669	1533	864 (60)
	Pupae	23	923	923	1768	845 (58)	538	773	1908	848 (81)
	Adult	11	1050	1050	1674	624 (43)	912	1076	1868	792 (56)

† Based on maize billbug data published by Cartwright [15], Figure 10.

‡ Values inside parentheses are the average number of days between the 5th and 95th percentile population for each growth stages of maize billbug.

Since eggs were not sampled in this study, information on cGDD for eggs was acquired from maize billbug data published by Cartwright [17]. On average, eggs incubate somewhere between 8-12 days. Dry weather expedites egg development thereby shortening the incubation period, whereas wet weather prolongs the development time [18]. On the basis of the univariate analysis, eggs, larvae, pupae, and adult maize billbug population were observed at 985 ± 275 (mean ± SD), 1101 ± 263, 1340 ± 345, and 1472 ± 241 cGDD, respectively. Larval stage in maize billbug has been reported to range from 32-75 days depending upon the weather and host plants [19]. A three-year study in maize billbug under laboratory conditions reported varying larval stages (33-70 days), with an average larval period of 49.2 days [17]. In this study, fifth and 95th percentile larvae population were observed within 60 days (DOY 172-232). Estimated cGDD between fifth and 95th percentile larvae population ranged from 669-1533 (60 days, DOY 168-228). This is similar to that reported by Hayes [19] for corn in southern Kansas (June through early September) and Cartwright [17] in South Carolina.

Fifth and 95th percentile pupae were observed within 57 days (DOY 187-244). Estimated cGDD between fifth and 95th percentile pupae population ranged from 773-1908 (81 days, DOY 176-257). Depending upon the weather, the length of the pupation stage can vary annually, ranging between 9-30 days [19]. Pupation period is short in a dry season and extended in a wet season [19]. Similarly, Cartwright [17] reported a three-year average pupal period of 9.9 days (minimum eight days, maximum 15 days) under laboratory conditions. Hayes [19] reported maize billbug's pupae in corn from mid-July through early September. Also, Cartwright [17] mentioned finding maize billbug from mid-July through mid-October. In this study, the number of days for observed 5th and 95th percentile of pupae and adult population was approximately seven days. This resulted in lesser recovery of pupae population as sampling was performed on a weekly basis in this study. As stated earlier, pupation in corn varies between 9 and 30 days depending upon the weather; it may be possible that the pupation period is less for eastern gamagrass because our sampling interval was every seven days and very few pupae were recovered during sampling.

Adult maize billbugs were collected throughout the two-year period. Adults are active and vigorous, having a few natural enemies. During the dormant season, adults remain protected during most of their existence, either inside the plant crown or under the dead plant materials in the field. They can also survive underwater for several days in case of heavy rains and field flooding [18]. To account for the overwintering population, adults found prior to 900 cGDD were discarded from the study. Because of this, fewer adult samples (n = 11) were recorded during the active growing season, which resulted in lower observed cGDD in adults than in pupae. Fifth and 95th percentile adult population was found within

43 days (DOY 195-238). Estimated cGDD between fifth and 95th percentile adult population ranged from 1076-1868 (56 days, DOY 197-253). However, when data of adult population for both years are combined, the histogram of the cGDD shows that peak adult activity occurred (22% of the observed population) around 2200 cGDD (Figure 2).

The nutritive value of eastern gamagrass is superior to that of corn, with lipid and protein contents being 1.5 and three times greater than that of corn respectively [20]. The amount of total nonstructural carbohydrate (TNC) in eastern gamagrass is also highest during the winter dormant season and least during May and June [21]. A study conducted from 1993 through 1997 at the USDA-ARS SPRRS quantified the nutritive value of eastern gamagrass and found varying levels of nitrogen content, ranging from 2.3-3.1% (14.6-19.6% crude protein) in May to 0.8-1.2% (5.3-7.6% crude protein) in August [22]. It is known that high-protein diet allows for rapid development of larvae compared with larvae surviving on low-protein diet [23, 24]. Therefore, maize billbugs appear to time the onset of their larval stage and stabilize their relative growth rate when protein availability is relatively higher in eastern gamagrass.

Maize billbug control strategies may include preventive application of contact and systemic insecticides targeting overwintering adult population before they oviposit during the spring. Burning of the eastern gamagrass residue in the spring, followed by nitrogen fertilizer application could also be helpful in controlling maize billbug. Natural enemies of maize billbug include *Anaphoidea calandrae* Gahan that feed on their eggs, *Cerceris bicornuta*, a wasp, that preys on adult maize billbugs and takes them to its nest for feeding its larvae, and parasitic fungi that cause mortality at any stage of its growth [25]. Development of resistant eastern gamagrass cultivars with fine stems and leaves and tougher plant tissues, paired with integrated pest management (IPM) control strategies may be effective. Dupuy and Ramirez [15] did a review on the biology and control of billbugs and described several cultural, biological, and chemical control methods for billbug management, with most focus on turfgrass. It will be challenging to control maize billbug due to

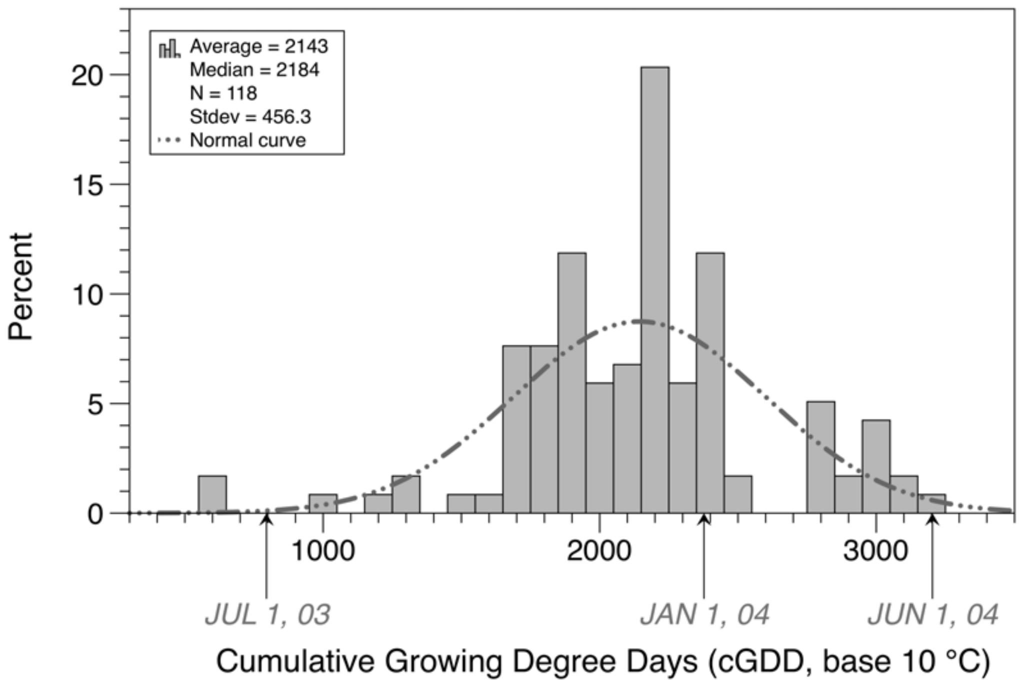

Figure 2. Histogram of cumulative growing degree-days (base 10 °C, biofix of April 12, 2003) based on occurrence of maize billbug (*Sphenophorus maidis*) adult population for 2003 and 2004 at Woodward, Oklahoma.

lack of systemic insecticides specifically labeled for eastern gamagrass and its sheltered feeding habit [26]. Application of pesticides would be cost prohibitive, and the cheapest and most effective means of maize billbug control is crop rotation [15].

CONCLUSIONS

This study associated cumulative growing degree-days with maize billbug phenological stages in eastern gamagrass. The developmental findings suggest that lower threshold temperatures in maize billbug are likely to restrict its larval and pupal population under current climatic parameters. Adult population occur throughout the year. A spatiotemporal analysis will be necessary to establish a sound understanding of billbug seasonal activity and development of optimal management strategy. In addition, novel methods for studying the development from egg to adult are imperative to fully understand the life-cycle of the pest and unravel information on sex ratio, female lifespan, and fecundity, as well as larval biology. This study is useful in improving the maize billbug's scouting efficiency and forecasting of the seasonal occurrence of maize billbug in eastern gamagrass. Further research is needed in order to enlighten the underinvestigated life-cycle stages and its activity at various phenological stages and for the development of control and management mechanisms that fit well with an IPM approach.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

REFERENCES

1. Barkworth, M. E., Anderton, L. K., Capels, K. M., Long, S. and Piep, M. B. 2007, Manual of Grasses for North America, University Press of Colorado.
2. Hitchcock, A. S. 1950, Manual of the grasses of the United States. 2nd Ed. Revised by A. Chase, USDA, U. S. Gov. Print Office, Washington DC.
3. Magoffin, J. 1831, Gama Grass. The American Farmer, Vol. XIII, 143-144.
4. Gilker, R. E., Weil, R. R., Krizek, D. T. and Momen, B. 2002, Soil Sci. Soc. Am. J, 66(3), 931-938.
5. Springer, T. L. and Dewald, C. L. 2004, Eastern Gamagrass and Other *Tripsacum* Species, American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison, WI.
6. Springer, T. L., Dewald, C. L. and Sims, P. L. 2006, Crop Sci., 46(1), 477-478.
7. Krizek, D. T., Solis, M. A., Touhey, P. A., Ritchie, J. C. and Millner, P. D. 2004, Rediscovery of the southern cornstalk borer: a potentially serious pest of eastern gamagrass and strategies for mitigation. In: Randall and J. C. Burns (Eds), Proceedings of the Eastern Native Grass Symposium. North Carolina Botanical Garden, Chapel Hill, NC, Oct. 1-3, 2002, Omnipress, Madison, WI. p. 277-283.
8. Maas, D. L., Springer, T. L. and Arnold, D. C. 2003, Southwest. Entomol., 28(2), 150-152.
9. Satterthwait, A. F. 1931, Ann. Entomol. Soc. Am., 24(1), 143-172.
10. Kelly, O. G. 1911, The Maize Billbug, Bulletin No. 95, U. S. Department of Agriculture, Bureau of Entomology, Washington, Government Printing Office.
11. Springer, T. L., Sims, P. L. and Gillen, R. L. 2006, Estimates of forage yield loss in

eastern gamagrass due to shoot boring insects, In Cassida, K. (Ed.), Proceedings of the 2004 Conference of the American Forage Grassland Council, Roanoke, VA, June 12-16, 2004, p. 333-336.
12. Dewald, C. L. and Sims, P. L. 1981, J. Range Manag., 34(4), 300-304.
13. Springer, T. L., Puterka, G. J., Maas, D. L. and Thacker, E. T. 2011, J. Kansas Entomol. Soc., 84(3), 209-216.
14. Higley, L. G., Pedigo, L. P. and Ostlie, K. R. 1986, Environ. Entomol., 15(5), 999-1016.
15. Dupuy, M. M. and Ramirez, R. A. 2016, J. Integr. Pest. Manag., 7(1), 6.
16. Springer, T. L., Gunter, S. A., Goldman, J. J. and Moffet, C. A. 2016, Agricultural Sciences, 7, 710-715.
17. Cartwright, O. L. 1929, The maize billbug in South Carolina (*Calendra maidis* Chittn.)] Clemson Agricultural College, Clemson College, South Carolina.
18. Hayes, W. P. 1920, The Maize Billbug or Elephant Bug (*Sphenophorus maidis*, Chittn.), Agricultural Experiment Station, Vol. 6, Kansas State Agricultural College, Manhattan, Kansas, Kansas State Printing Plant, Topeka, Kansas.
19. Hayes, W. P. 1916, J. Econ. Entomol., 9(1), 120-130.
20. Bargman, T. J., Hanners, G. D., Becker, R., Saunders, R. M. and Rupnow, J. H. 1989, LWT - Food Sci. Technol., 22, 208-212.
21. Dewald, C. L. and Bryan, K. 1996, Crop Sci., 36, 219.
22. Gillen, R. L., Berg, W. A., Dewald, C. L. and Sims, P. L. 1999, J. Range Manag., 52(6), 583-589.
23. Karowe, D. N. and Martin, M. M. 1989, J. Insect Physiol., 35(9), 699-708.
24. Woods, H. A. 1999, Physiol. Biochem. Zool., 72(4), 445-454.
25. Vaurie, P. 1951, Revision of the genus *Calandra* (formerly *Sphenophorus*) in the United States and Mexico (Coleoptera, Curculionidae)], Bulletin of the American Museum of Natural History, 31-186.
26. Kuhn, W. R., Youngman, R. R., Wu, S. and Laub, C. A. 2013, Journal of Integrated Pest Management, 4(3), 1-5.