

IMPACT OF MANAGEMENT PRACTICES ON POPULATION DYNAMICS OF
ATHERIGONA REVERSURA IN GEORGIA BERMUDAGRASS

by

CODY HALE BOWLING

(Under the Direction of William G Hudson)

ABSTRACT

The bermudagrass stem maggot (BSM; *Atherigona reversura* Villeneuve) is an invasive agriculture pest from Southeast Asia that has impacted the hay industry in the Southeast USA. In particular, the BSM has lowered the production and nutritive value of bermudagrass hay [*Cynodon dactylon* (L.) Pers.] for producers in Georgia and the Southeastern United States. Three bermudagrass hay fields and three pastures were surveyed to identify how management practices affect population dynamics of BSM. Mowing significantly reduced BSM damage hayfields compared to grazing in pastures ($P=2.937e-06$). Still, adult flies increased in population over the course of the season regardless of management ($P=0.0085$). There is strong correlation between damage levels and adult populations ($S_r=.3303$). With proper management and timely harvest, producers can lower the overall damage BSM causes to their hay crops.

INDEX WORDS: Bermudagrass, BSM, management practices, pupal stage,

Atherigona reversura

IMPACT OF MANAGEMENT PRACTICES ON POPULATION DYNAMICS
OF BSM IN GEORGIA BERMUDAGRASS

BY

CODY HALE BOWLING
BS, EASTERN KENTUCKY UNIVERSITY, 2018

A Thesis Submitted to the Graduate Faculty of The University of Georgia in
Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2020

© 2020

Cody Hale Bowling

All Right Reserved

Impact of Management Practices on Population Dynamics of BSM in Georgia

Bermudagrass

By

Cody Hale Bowling

Major Professor: William Hudson

Committee Members: Lisa Baxter

Keith Delaplane

Electronic Version Approved:
Ron Walcott
Dean of the Graduate School
The University of Georgia
December 2020

DEDICATION

I dedicate this work to the Georgia Beef Cattle Commodity Commission for their funding of this work and my education here at the University of Georgia. Also, I would like to thank my wife for her constant support and motivation.

ACKNOWLEDGEMENTS

I would like to acknowledge and thank my committee and producers who made this project possible: Dr. William Hudson (UGA-Athens), Dr. Lisa Baxter (UGA-Tifton), and Dr. Keith Delaplane (UGA-Athens). A special thanks to Chad Westmoreland (UGA Beef Cattle Research Station) and John Lovin (Lovins' Family Farms) for allowing me to collect samples on their property over the course of this study.

Table of Contents

	Page
ACKNOWLEDGEMENTS.....	v
LIST OF FIGURES.....	vii
LIST OF TABLES.....	viii
CHAPTER	
1. Introduction.....	1
a. References.....	3
2. Literature Review.....	4
a. References.....	10
3. Track the stem damage incurred by BSM in both hay production fields and pastures across Georgia.....	18
a. Abstract.....	19
b. Introduction.....	19
c. Material and Methods.....	21
d. Results and Discussion.....	23
e. Conclusions.....	26
f. References.....	30
4. Other biological and Behavioral Studies.....	31
a. Introduction.....	31
b. Material and Methods.....	32
c. Results and Discussion.....	33

List of Figures

Fig 2.1: A bermudagrass stem maggot revealed in the removed pseudostem of a bermudagrass sample.....	15
Fig 2.2: Adult BSM size and shape comparison, Left: Male, Right: Female.....	16
Fig 2.3: Overgrown grass makes it nearly impossible to collect sweep samples and creates an unsuitable habitat for adults.....	16
Fig 3.1: Preliminary study (2019) damage	21
Fig 3.2: Fig 3.2 BSM Damage seen in each test plot over a 12 week trial. Eatonton Location = EP1/EF1. Eatonton Location 2= EP2/EF2. Lexington = LP/LF.	27
Fig 3.3: BSM Adult Population counts from each test plot over 12 weeks, arrows indicate harvest. Eatonton Location 1=EP1/EF1. Eatonton Location 2=EP2/EF2. Lexington = LP/LF.....	28

List of Tables

Table 2.1: Comparison of varieties and their susceptibility to BSM damage.....	17
Table 3.1 : Analysis of Deviance Table (Type 3 Test) for damage.....	28
Table 3.2 Analysis of deviance Table for adult sweep counts.....	29
Table 3.3 Comparison of management between locations.....	29

Chapter 1

Introduction

The bermudagrass stem maggot, *Atherigona reversura* Villeneuve (BSM; Diptera:Muscidae) is an invasive fly from Southeast Asia. The first American findings were in Hawaii in the 1970's (Hardy, 1976) and California in 2009 (Holderbaum, 2009). The first report in Georgia did not come until 2010 from Pierce, Tift, and Jeff Davis counties (Hancock, 2012). The fly is now readily found throughout the Southeast US, from FL to NC to Texas and north to Kentucky, although there was a recent report in Canada (Savage, 2016). *Atherigona reversura* attacks bermudagrass and stargrass (*Cynodon* spp.) here in the United States with a variety of host plants reported elsewhere in the world (Pont, 1995).

The adult fly is a highly mobile, yet low flying insect that generally stays within the crop canopy. Mature adults lay their eggs on the terminal leaves of bermudagrass, favoring finer stem cultivars such as Alicia, Coastal, or Russell. When these eggs hatch, the maggots migrate down the leaf blade inwards to the terminal node and create a bacterial "soup" of the internal tissue by macerating the pseudostem with their mouth hooks. After several days of feeding in the stems, the maggot emerges and falls to the ground to pupate just beneath the soil surface.

The BSM damage halts the growth of affected tillers and reduces the yield potential of the grass. Studies have documented up to an 80% yield reduction in heavily infested harvests. *Atherigona reversura* will also infest home lawns and other managed or unmanaged bermudagrass. The adult flies will seek refuge in the perimeters and

neighboring fields and pastures when the hay is harvested, only to return to lay more eggs as the grass regrows.

In an attempt to understand the impact of forage management, specifically haying practices, on population dynamics of the BSM, data on the number of adults, damage levels and pupal numbers were compared in selected hay fields and nearby pastures. This project will add to the overall picture of how the harvest of hay, which results in the immediate loss of resources for the fly, affects the adult population of BSM.

The Objectives for the proposal are:

Objective 1: Track the stem damage caused by BSM in both hay production fields and pastures across Georgia, and monitor adult population changes over time.

Objective 2: Investigate the life cycle, adult life span and pupal stages of BSM

Objective 3: Tracking BSM Movement in Dry Conditions

References

- Hancock, D.W. 2012. Bermudagrass stem maggot. Georgia Cattlemen. 40:20.
- Hardy, D.E. 1976. Proceedings of the Hawaiian Entomological Society for 1974.
Hawaiian Entomol. Soc. Proc., Honolulu, Hawaii, 1974. Hawaiian Entomol. Soc.
22(2).
- Holderbaum, B. 2009. Orange Fly-Atherigona. IA State University Entomology.
<http://bugguide.net/node/view/312313/bgimage> (accessed 20 Nov 2020).
- Pont, A.C. and F.R. Magpayo. 1995. Muscid shoot-flies of the Philippine Islands
(Diptera: Muscidae, genus *Atherigona* Rondani). Bull. Entomol. Res. Supp. Ser.
3: 1-100
- Savage, J. (2016). FIRST CANADIAN RECORD OF THE BERMUDA GRASS STEM
MAGGOT, *ATHERIGONA REVERSURA* (DIPTERA: MUSCIDAE). *Journal
of the Entomological Society of Ontario*, 147, 3-6.

Chapter 2

Literature Review

In the summer of 2010, Georgia bermudagrass hay producers unfortunately began to see a new and different type of damage to their bermudagrass. A “bronzing” or “frosting” of the tops of their hay was starting to appear and create concern in South Georgia, beginning in Tift, Jeff Davis and Pierce counties (Hancock, 2012). The pest responsible for this damage would later be identified as an invasive fly, *Atherigona reversura* Villeneuve (Diptera: Muscidae). Commonly referred to as the bermudagrass stem maggot (BSM), the noticeable damage of the top leaves and characteristic separable tiller (Fig 2.1) damage is now common in bermudagrass fields across Georgia and other Southeastern states.

Origins and invasion

The BSM was first discovered in China on a Swedish-Chinese expedition and described by J. Villeneuve in 1936. After Dr. Villeneuve’s initial description, the fly was not mentioned again in western entomological literature until the 1970’s. Several BSM adults were collected in light traps in Hawaii by Dr. J.W. Beardsley in January of 1974 and sent to A.C Pont for identification (Hardy, 1976,1981). These adult flies were identified as *Atherigona reversura*, which was at that time found only in Asia.

Although the BSM is commonly described as an agricultural pest, the species will infest many different cultivars of bermudagrass, including common and turf-type

bermudgrass. This was first evident in the identification of BSM in one of the most metropolitan areas of America, Los Angeles (Holderbaum, 2009). By the summer of 2010, BSM was reported in three counties in Georgia (Hancock, 2012). It now infests all of the Southeastern United States where bermudagrass is a common hay and forage crop. The bermudagrass stem maggot made its way northward to Kentucky (Townsend et al., 2013) and eventually to Canada (Savage, 2016). The BSM has recently been discovered in Argentina (Patitucci, 2016) and Brazil (Ribeiro, 2016).

Morphology

BSM adults are relatively easy to capture and identify, especially in mature hay crops later in the season, using sweep nets. The adults are roughly 3 mm in size with a grey thorax and a yellow abdomen with at least a single pair of black spots (Fig 2.2). A.C Pont has a well-written anatomical description for both males and females (1995). To date there has been no internal morphology literature written; although a close relative, the Sorghum shoot fly (*Atherigona soccata*) does have an internal description cited in literature (Unnithan, 1981).

It should be noted that no adult has been observed laying eggs nor have eggs been found in the field. The eggs have been observed through micro-dissection, but further research is required to identify them in the field (Baxter, 2014). The pupae are brown and barrel shaped at approximately 3-mm long (Grzywacz et al, 2013). Maggots are white and cylindrical at roughly 3 mm in length (Grzywacz, 2013), and darken as they mature. They possess mouth hooks that they use to macerate the pseudostem and create the “bacterial soup” that is hypothesized as their source for nutrients. Maggots can be found

by splitting newly infected pseudostems with a razor blade. This can be a difficult task and should be performed over a solid, dark surface for better visibility.

Host Range

Most species within *Atherigona* are usually found in decaying plant matter, with a primary focus on infesting Gramineae (Pont, 1981). The BSM has a relatively wide range of reported host plants from around the world that include corn (*Zea mays*), finger millet (*Eleusine coracana*), white grass (*Schima nervosum*), tropical cupgrass (*Erichola procera*), and jungle rice (*Echinochloa colona*, Pont, 1981, Davies et al, 1981). They only damage *Cynodon* grasses here in the United States.

Nutritional requirements of the BSM remain largely unknown. Given only sugar water and raised under laboratory conditions of ~70 degrees, adult flies sometimes live 18-20 days (W. Hudson, Personal Communication). In nature however, it is believed that the adult BSM could be feeding on guttation water produced by the bermudagrass (Hancock, 2014). This liquid contains a combination of sugars and other ions released from the grass (Duell et al., 1977). It has also been noted that BSM damage is seen alongside other forms of damage such as bermudagrass leaf spot (*Bipolaris cynodontis*) and bermudagrass leaf rust (*Puccinia cynodontis*; Hancock et al., 2014). This combined with high levels of N fertilization are associated with higher amounts of guttation, which increases the proximity to and likelihood the adult BSM are feeding on this source of sugar.

BSM Damage vs. Other Stresses

There is a plethora of biotic and abiotic stressors that affect bermudagrass. These stresses can often times be confused with and misidentified as BSM damage. BSM damage can be recognized by the chlorosis of the top 2-3 leaves of a tiller, as well as the easy removal from the pseudostem (Hancock, 2012). When the larva feeds in the tiller, the distal portion will die, however the grass below that top node will remain alive and intact. Similar discoloration can come from drought stress, leaf spot, leafrust, and a number of nutrient deficiencies (Andrae et al., 2012, Havlin et al., 2004; Martinez et al., 2012; Read et al., 2012; Robinson, 1985), but those maladies usually affect more than just the 2 terminal leaves. BSM maggots are never found below the terminal node of a tiller.

Control Methods

Mowing as a form of mechanical control has been shown to suppress the close relative of BSM, the sorghum shoot fly, from building up large populations (Young, 1981). Sorghum is usually only harvested 1-2 times a year instead of 4-5 times like bermudagrass hay, so the mechanical control of harvesting may be more effective. For hay producers the current recommendations are to harvest as soon as conditions are favorable if damage is present within one week of the anticipated harvest date (Hancock, 2012). Unfortunately, damage seen earlier in the hay cycle will reduce overall production and the only recourse is to mow or graze the stand down to 3-4 inches to remove the damaged portion. This process will encourage regrowth, because if left alone the hay would be unlikely to develop any further. This process also limits the time adults

can produce maggots which is important to control the number of potential adults that will affect the following hay crops.

The trade-off from harvesting early and taking the yield loss is economically better than allowing the BSM population to expand. The economic impact of BSM has been estimated in Texas hay fields at roughly 8.9 lb. of lost forage per acre, per percent stem damage (Knutson, 2019). Once the hay is harvested, any maggots present in the stems will emerge. A portion of these maggots will be too immature to successfully pupate, leading to a lower population for the following cycle. Adult BSM, due to their high mobility, will escape to close by fields, yards and hedgerows near the field. The total distance that the adult BSM are willing to travel in the case of harvest is unknown.

The management protocol currently in place for BSM is using pyrethroid insecticides at the recommended rate after the bermudagrass begins to regrow roughly 7-10 days after harvest, followed by a second spray 7-10 days after the first application (Hudson, 2013). The only reason to use a chemical control is if the cost of two applications (~\$15/ac) falls below the value of lost yield. According to Baxter et al. (2019), the levels of damage rarely reach the threshold of economic impact to warrant chemical applications prior to the second or third hay harvest. For example, populations may not build up in USDA zones 9, 8a and 8b until July or August in the Southeastern United States, and even later in northern areas of bermudagrass production.

Cultivar Preference

The first demonstration of cultivar preferences in *Atherigona* spp. came from Blum (1967) and Soto (1974). The damage caused by the bermudagrass stem maggot was

shown to be negatively correlated to tiller diameter, length of internode and leaf blade width (Ikeda et al., 1991) and positively correlated with shoot density. Baxter et al. (2015) confirmed higher damage with higher shoot density in greenhouse trials. Certain varieties do show a substantial yield loss in test plots (Baxter, 2017), as shown in table 2.1.

References

- Andrae, J., A. Martinez, and R. Morgan. 2012. Leafspot diagnosis and management in bermudagrass forages. C 877. University of Georgia Cooperative Extension
- Baxter, L.L., D.W. Hancock, and W.G. Hudson. 2014. Bermudagrass stem maggot: An exotic pest in the Southeastern United States. Paper presented at: ASA-CSSA-SSA Annual Meetings, Tampa, FL. 4 Nov. Service, Athens.
- Baxter, L.L., D.W. Hancock, W.G. Hudson, and P.J. Moore. 2014. The difference in response of selected bermudagrass cultivars (*Cynodon dactylon*) to bermudagrass stem maggot (BSM, *Atherigona reversura* Villeneuve) damage. Paper presented at: American Forage and Grassland Conference, Memphis, TN. 13 Jan.
- Baxter, L.L., D.W. Hancock, W.G. Hudson, S.L. Dillard, W.F. Anderson, and B.M. Schwartz. 2015. Response of selected bermudagrass cultivars to bermudagrass stem maggot damage. *Crop Science* 55(6):2682. doi:10.2135/cropsci2015.12.0828
- Baxter, L.L., D.W. Hancock, and W.G. Hudson. 2014. The bermudagrass stem maggot (*Atherigona reversura* Villeneuve): A review of current knowledge. *Forage and Grazinglands* 12(1): 0. doi:10.2134/fg-2013-0049-rv
- Baxter, L.L., W.F. Anderson, W.G. Hudson, D.W. Hancock, C.G. Prevatt, and Z. Moore. 2019. Quantifying the damage potential of the bermudagrass stem maggot. *Crop Science* 59(5): 2280. doi: 10.2135/cropsci2019.04.0220

- Baxter, L.L., D.W. Hancock, W.G. Hudson, W.F. Anderson, and J.J. Tucker. 2017. Managing bermudagrass stem maggots. Bulletin 1484. UGA Cooperative Extension, Athens, GA.
- Blum, A. 1967. Varietal resistance of sorghum to the sorghum-shoot-fly (*Atherigona varia* var. *soccata*). *Crop Sci.* 7:461-462.
- Coleman, J.S. and C.G. Jones. 1991. A phyto-centric perspective of phytochemical induction by herbivores. In: D.W. Tallamy and M.J. Raupp, editors, *Phytochemical Induction by Herbivores*. John Wiley and Sons, Inc., New York. p.3-45.
- Davies, J.C. and K.V. Seshu Reddy. 1981. Shootfly species and their graminaceous hosts in Andhra Pradesh, India. *Insect Sci. Application.* 2(2): 33-37.
- Doharey, K.L., B.G. Srivastava, M.G. Jotwani, K. Dang. 1977. Effect of temperature and humidity on the development of *Atherigona soccata* Rondani. *Indian J. Entomol.* 39(3):211-215.
- Duell, R.W., and D.K. Markus. 1977. Guttation deposits on turfgrass. *Agron. J.* 69:891-894.
- Grzywacz, A., T. Pape, W.G. Hudson, and S. Gomez. 2013. Morphology of immature stages of *Atherigona reversura* (Diptera: Muscidae), with notes on the recent invasion of North America. *J. of Nat. History*, 47:15-16, 1055-1067.
- Hancock, D.W. 2012. Bermudagrass stem maggot. *Georgia Cattlemen.* 40:20.
- Hancock, D.W., W.G. Hudson, L.L. Baxter, and J.T. McCullers. 2014. What we have learned about the bermudagrass stem maggot. Paper presented at: American Forage and Grassland Conference, Memphis, TN. 14 Jan.

- Hardy, D.E. 1976. Proceedings of the Hawaiian Entomological Society for 1974. Hawaiian Entomol. Soc. Proc., Honolulu, Hawaii, 1974. Hawaiian Entomol. Soc. 22(2).
- Hardy, D.E. 1981. Genus *Atherigona* Rondani. In: D.E. Hardy and W. Henning (eds.) *Insects of Hawaii, Volume 14, Diptera: Cyclorrhapha IV*. University Press Hawaii, Honolulu. p. 68-72.
- Havlin, J.L., S.L. Tisdale, W.L. Nelson, and J.D. Beaton. 2004. *Soil Fertility and Fertilizers: An Introduction to Nutrient Management 7th Edition*. Prentice Hall. USA.
- Holderbaum, B. 2009. Orange Fly-*Atherigona*. IA State University Entomology. <http://bugguide.net/node/view/312313/bgimage> (accessed 15 May 2012).
- Hudson, W., D. Hancock, K. Flanders, and H. Dorough. 2013. *Biology and management of bermudagrass stem maggot*. Auburn Cooperative Extension System. Circular ANR-1462. Auburn, AL. <http://www.aces.edu/pubs/docs/A/ANR-1462/Anr-1462.pdf>
- Ikeda, H., M. Oyamada, and H. Ando. 1991. Varietal differences of bermudagrass in parasitic shoot ratio caused by bermudagrass stem maggot. (In Japanese). *Jpn. Soc. Grassland Sci.* 37(2): 240-245
- International Crop Research Institute for the Semi-Arid Tropics. 1978. *ICRISAT Annual Report, 1977-1979*. Hyderabad, India. p. 46-51
- Knutson, A. (2019). Economic Injury Level for Bermudagrass Stem Maggot (Diptera: Muscidae) in Bermudagrass Forage Production in Texas. *Journal of Economic Entomology*, 2215-2221.

- Martinez, A., M. Pearce and L. Burpee. 2012. Turfgrass diseases in Georgia: Identification and control. Bul. 1233. University of Georgia Cooperative Extension Service, Athens
- Mattson, Jr. , W.J. 1980. Herbivory in relation to plant nitrogen content. *Annu. Rev. Ecol. Syst.* 11: 119-161.
- Patitucci, L. (2016). First reports of the invasive pest Bermudagrass Stem Maggot, *Atherigona reversura* Villeneuve, 1936 (Diptera: Muscidae), in South America. *Check List*, 12(4), 1-5. doi:10.15560/12.4.1928
- Pont, A.C. 1981. Some new Oriental shootflies (Diptera: Muscidae, genus *Atherigona*) of actual or suspected economic importance. *Bull. Entomol. Res.* 71: 371:393.
- Pont, A.C. and F.R. Magpayo. 1995. Muscid shoot-flies of the Philippine Islands (Diptera: Muscidae, genus *Atherigona* Rondani). *Bull. Entomol. Res. Supp. Ser.* 3: 1-100.
- Read, J.J. and R.G. Pratt. 2012. Potassium influences forage bermudagrass yield and fungal leaf disease severity in Mississippi. *Forage and Grazinglands*. doi: 10.1094/FG-2012-0725-01-RS.
- Ribeiro, Leandro do Prado et al. “First Record of *Atherigona Reversura* Villeneuve (Diptera: Muscidae) Feeding on Bermudagrass (*Cynodon Dactylon* Cv. Jiggs, Poaceae) in Brazil: Morphological and Molecular Tools for Identification.” *Revista Brasileira de Entomologia*, vol. 60, no. 3, Sept. 2016, pp. 270–274. *EBSCOhost*, doi:10.1016/j.rbe.2016.04.001.
- Robinson, D.L. 1985. Potassium nutrition of forage grasses. In: Robert Munson, editor, *Potassium in Agriculture*. pgs. 895-914.

- Savage, J. (2016). FIRST CANADIAN RECORD OF THE BERMUDA GRASS STEM MAGGOT, *ATHERIGONA REVERSURA* (DIPTERA: MUSCIDAE). *Journal of the Entomological Society of Ontario*, 147, 3-6.
- Schoonhoven, L.M. 1968. Chemosensory bases of host plant selection. *Annu. Rev. Entomol.* 13: 115-136.
- Singh, S.K., S.S. Yazdani, S.F. Hameed, and D.N. Mehto. 1983. Bio-efficacy of spray applications of some newer insecticides against shoot fly *Atherigona* spp. on proso millet (*Panicum miliaceum* L.) in North Bihar. *Entomon.* 8(3): 239-244
- Soto, P.E. and K. Laxminarayana. 1971. A method for rearing the sorghum shoot fly. *Journal of Econ. Entomol.* 64(2): 553.
- Soto, P.E. 1974. Ovipositional preference and antibiosis in relation to resistance to a sorghum shoot fly. *Journal of Econ. Entomol.* 67(2): 265-267.
- Staedler, E. 1977. Sensory aspects of insect plant interactions. *Proc. Int. Congr. Entomol.* 15: 228-248.
- Talati, G.M. and V.R. Upadhyay. 1978. Status of shoot fly *Atherigona approximata* Malloch as a pest of Bajra *Pennisetum typhoides* crop in Gujarat State. *GAU. Res. J.* 4(1): 30-35.
- Townsend, L. and S. Osborne. 2013. Bermudagrass stem maggot found in Allen County. *Kentucky Pest News* No. 1363. University of Kentucky, Lexington, KY.
- Unnithan, G. C. 1981. Aspects of sorghum shootfly reproduction. *Insect Sci. Application.* 2(1): 87-92.
- Villeneuve, J. 1936. Schwedisch-chinesische wissenschaftliche expedition nach den

nordwestlichen Provinzen Chinas, unter Leitung von Dr. Sven Hedin und Prof. Su Pingchang. Insekten gesammelt vom schwedischen Arzt der Expedition Dr. David Hummerl 1927-1930. 52. Diptera. 16. Muscidae. Ark. Zool. 27 A 34: 1-13.

Young, W.R. 1981. Fifty-five years of research on the sorghum shootfly. Insect Sci. Application. 2(2): 3-9

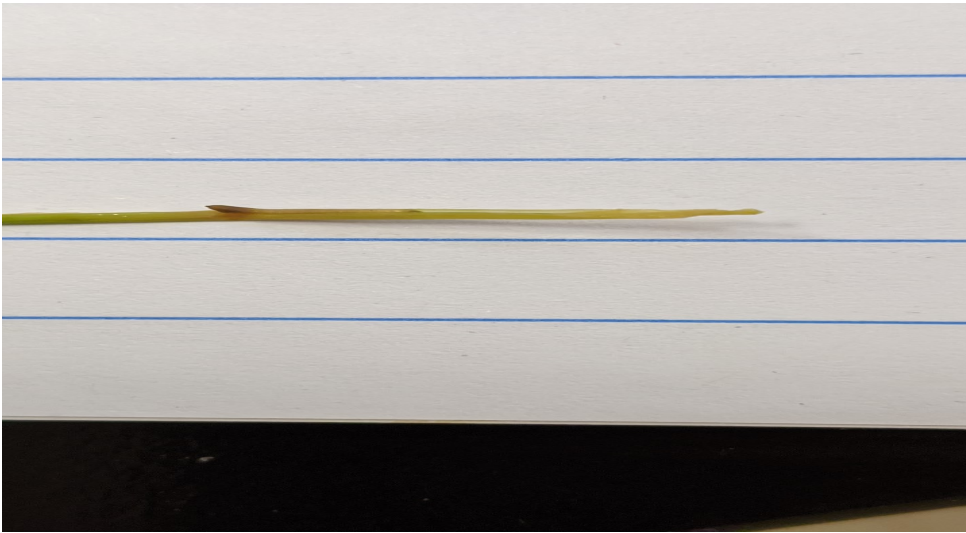


Fig 2.1) A bermudagrass stem maggot revealed in the removed pseudostem of a bermudagrass sample

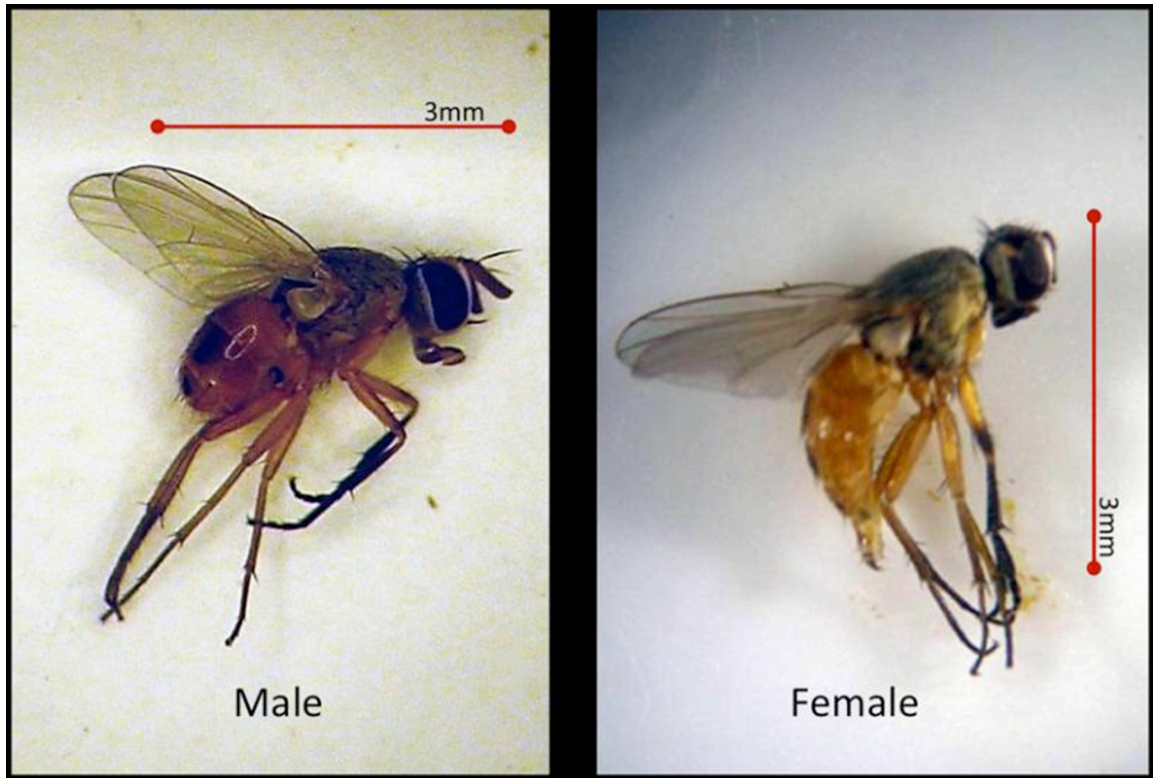


Fig 2.2) Adult BSM size and shape comparison, Left: Male, Right: Female



Fig 2.3) Overgrown grass creates an unsuitable habitat for adults, Young grass is more susceptible to yield loss

Variety	Yield loss %
Sprigged	
Alicia	30-60
Coastal	15-30
Coastcross II	0-15
Russell	20-40
Tifton 44	15-30
Tifton 85	0-20
Seeded	
Common	30-60
Various seeded	30-60

Table 2.1 Comparison of varieties and their susceptibility to BSM damage

Chapter 3

Impact of Management Practices on Population Dynamics of *Atherigona reversura* in Hayfields and Pastures as Measured by Damage Level and Number of Adults

¹C.H. Bowling, W.G. Hudson, K.S. Delaplane and L.L. Baxter
To be submitted to Journal of Economic Entomology

Abstract

There is currently no published information regarding any difference in damage caused by the bermudagrass stem maggot (BSM; *Atherigona reversura* Villeneuve) in bermudagrass [*Cynodon dactylon* (L.) Pers.] harvested as hay compared to being grazed in a pasture. The objective of this study was to determine whether harvesting forage impacted the development of adult BSM or resulting BSM damage when compared to grazing the forage. Six plots were used in a 12-week trial of stem sampling. Three pastures and three hay fields were surveyed weekly by gathering 10 grass samples and 10 insect sweep net samples to determine the average percent damage and number of adult flies, respectively. These weekly averages were tracked over the course of the study to build a damage curve to compare fields and pastures. Sites were separated into pairs for comparison of treatment versus no treatment. Overall there was a significant difference in the damage observed due to management (hay vs. grazing) ($P=2.937e-06$) and location (Eatonton vs. Lexington) ($P=2.2e-16$). Overall there is a significant correlation between damage and population ($r_s=.3303$). We also found a significant difference between management types ($p=.0085$). This suggests that harvesting has a significant effect on BSM populations, therefore reducing overall damage.

Introduction

The bermudagrass stem maggot (BSM) is an invasive species of Muscidae from Southeast Asia. It was first discovered in the United States in Hawaii in the 1970s (Hardy, 1976) and California in 2009 (Holderbaum, 2009). The first report in Georgia

was not documented until 2010 from Pierce, Tift, and Jeff Davis counties (Hancock, 2012). The fly is now readily found throughout the Southeast US, from Texas to Kentucky, although there was a recent report in Canada (Savage, 2016). *Atherigona reversura* attacks bermudagrass and stargrass (*Cynodon* spp.) here in the United States with a variety of host plants reported elsewhere in the world (Pont, 1995).

The adult fly is a highly mobile, yet low flying insect that generally stays within the crop canopy. Mature adults lay their eggs on the terminal leaves of bermudagrass, favoring finer stem cultivars such as Alicia, Coastal, or Russell. When these eggs hatch, the maggots migrate down the leaf blade inwards to the terminal node and create a bacterial “soup” of the internal tissue by macerating the pseudostem with their mouth hooks. After 2-3 weeks of feeding in the stems, the maggot emerges and moves to the ground to pupate just beneath the soil surface.

The BSM damage halts the growth of affected tillers and reduces the yield potential of the forage. Studies have documented up to an 80% yield reduction in heavily infested harvests. The current recommendations for spraying are to wait 7-10 days after cutting, followed by a second spray 7-10 days after the first application (Hudson, 2019). This timing is based on the phenology of the bermudagrass, which will initiate regrowth within a few days following a harvest or intense grazing event. The adult flies will seek refuge in the perimeters and neighboring fields and pastures when the forage is harvested, only to return to lay more eggs as the grass regrows. The flies will quickly re-infest the field once new tillers appear.

Material and Methods

Treatment locations

A total of 6 sampling locations were selected from two counties in Georgia. No hay production field or pasture received any insecticide treatment throughout the entire trial period. One hay field and one grazed pasture were selected on the Lovin Family Farm in Lexington, Georgia. Two hay fields and two pastures were also selected at the University of Georgia Beef Cattle Research Farm in Eatonton Georgia.

Sample Collection

Grass samples were collected on a weekly basis to monitor the amount of damage throughout the peak season (Jul 1-Aug 31 in 2019, Jun 8-Aug 25 in 2020). In 2019, 5 samples per field were collected on each sample date. In 2020 this was increased to 10 samples per field per sample date. On each sample date in 2020, 10 sets of 10 sweeps of a sweep net were used for the purpose of collecting adult BSM. At the end of each set the contents of the nets were placed in a mesh cage (12” Rearing and Observation Cube, BioQuip Products Inc.) for counting. In cases where more than ~20 adults were present, cages were returned to the lab, frozen overnight, and adults counted afterwards. Adults were released after each set and the same cubes would be utilized again. To ensure adequate representation, sweep samples were collected randomly throughout each field or pasture. Samples were collected at least 20 meters apart.

BSM damage is characterized by the “bronzing” of the top two leaves and also by the easy removal top two leaves from the pseudostem. A sample collection

consisted of one handful of stems, cut at the base of the grass. These samples consisted of 16-154 (avg. = 64.9) stems. Soil samples were also collected in 2019 at each sample date. These consisted of 5 samples, each 1 ft² by ~2" depth, which were returned to the lab and examined by careful sifting for pupae. This was changed to 10 samples, collected one week after harvest for each field and pasture pair for the 2020 study.

Statistical Analysis

Data was analyzed using R Studio (Ver. 1.3.1093, Boston, Ma). Aggregated Logistic regression models (Binomial Regression) were built to investigate the field damage data since the response is the damage percentage (count of damage/total count). Weeks were handled as continuous variable while Location and Event were categorical variables. All the variables were handled as fixed effects. Likelihood ratio test was performed to determine if reduced model was significantly different from full model.

Since the response variable is the count of adult sweeps from sample hay, Poisson regression was initially used to study the adult sweep data. The full model suggested a severe over dispersion problem, indicating that the data violates the assumption of Poisson Regression (this is likely due to the occurrence of a considerable amount of '0' counts in the data). Therefore, we chose the negative binomial model to analyze the adult sweep data. Finally, field damage and counts of adult sweeps were analyzed as paired data and the Spearman rank correlation test was conducted to investigate the relationship between count of adult sweeps and field percent damage.

Results and Discussion

Preliminary data

In 2019 the same fields and pastures were sampled for stem damage and also pupae population (Fig 3.1). Five soil and five stem samples were each collected each week over a period of seven weeks. The same methods of sweeping and soil collection were maintained in the 2020 collection period. This preliminary research laid the foundation which our main study would use and gave insight to what results we could receive. Using the lessons learned here, it was decided that more samples for damage were required to build a better picture of overall damage. Weekly soil samples were limited to 10 samples 1 week after harvest, for the hay field and its accompanying pasture.

Stem Damage

There is sufficient statistical evidence suggesting both management type ($P = 2.937e-06$) and location ($P = < 2.2e-16$) are significant. We can conclude there are differences between management types/locations over time for both damage and number of adults present (Table 3.1). Hay harvest events were significant ($P = 0.00026$) as well, which indicates that the action of harvesting hay would make a difference in field damage proportion and adult numbers. The harvesting did knock damage and adult populations to zero, but these levels rebounded quickly. The data shows us that although rebounding does occur, the damage levels never catch up to pastures (Fig 3.2).

During the 12 weeks of this study, EF1 was harvested only one time for hay (Fig 3.2) and otherwise was allowed to overgrow. Similarly, EP1 was only grazed for the first few weeks of the study and essentially allowed to go fallow. Lack of weed control and absence of grazing resulted in the proportion of bermudagrass in the stand being reduced to approximately 50% over the field with the rest consisting of other, non-forage grasses and broadleaf weeds. This under management contributed to the significance in differences between locations in the study.

The second pair of test plots from Eatonton was labeled as EP2 vs EF2. The story in these plots was somewhat similar to the first set of test plots. Cattle were removed from the pasture after the first 3 or 4 weeks and the plot was allowed to overgrow. EF2 was harvested twice (Fig 3.2) during our study, however the timing between cuts (9 weeks) still allowed for seed heads to form and was not an efficient form of management. As with EF1/EP1, this underutilization and infrequent harvest increased the variability between locations.

Lexington produced the most relevant set of data from the entire study. The management here was excellent and consisted of timely harvest, fertilization and herbicide applications to maintain weeds. Cattle and horses were allowed to graze the pasture freely for the entire length of the study. This grazing allowed for new growth and new resources for BSM throughout the study. Lexington Field (LF) was harvested twice (Fig 3.2) during the study, however in a more timely fashion than EF2 at a four week interval. This better overall management helped identify the interaction between harvest and overall damage (Table 3.3). Rains kept the producers from harvesting a third time during our study and there is a sharp increase in damage because of this. The field was a

prime cultivar, freshly weeded with herbicides, and when left uncut, the BSM showed a sharp increase in damage and population.

Adult populations

From the output of our final model, we can conclude there are significant differences between management types ($P = 0.008549$)/locations ($P = 6.645e06$) in adult sweep habitation preference, suggesting that harvesting has an impact on adult population (Table 3.1). The Spearman's Rank Analysis shows a correlation between field damage and adult population levels of $r_s = .3303$. A number closer to one signifies higher correlation between two inputs. This aligns with the hypothesis that higher adult populations lead to higher damage levels.

Over the course of 12 weeks the BSM adult population did grow in all fields and pastures. In the Eatonton plots (EF1/EF2/EP1/EP2), forage was underutilized resulting in an over mature stand with lower forage quality and severe weed invasion. Only when the fields were harvested and allowed to regrow were large numbers of adult found again (Fig 3.3). Pastures were allowed to grow and go to seed with no intervention, showing a similar adult build up as the hay fields. Due to Covid-19, funds were not available for staffing and production on the Eatonton Beef Cattle Research farm, resulting in greatly reduced management.

The Lexington plots were maintained properly throughout the study and gave a more realistic outlook on adult population build up (Fig 3.3). Here we observed proper grazing and harvesting that would be comparable to other commercial hay production operations. Overall, we determined a significant difference in adult populations between

locations ($P=2.685e-07$, Table 3.2) and we can potentially attribute it to that maintenance (Table 3.3).

Pupal Population Observations

Finding mature pupae has been a difficult process under field conditions. Using a soil sifter and timing the collection properly has led to in-field discoveries at depths of <3 inches. So few pupae were found that the research team decided that the effort (more than 1 hour per sample, 30 samples per week) was not productive. In 2020, soil samples were collected only after harvest when numbers of pupae should have been highest. Those maggots that were present at the time of harvest left the stems all at once as the cut grass dried. Even then, numbers were so low that the data were not useful. It is possible we are missing important information on the pupal stage of BSM. It seems that the adult populations and damage we see in fields is not represented by pupae in the soil. Perhaps BSM has naturally low pupation rates or pupates deeper in the soil. Further research is needed to answer these important biological questions.

Conclusion

In conclusion, we identified that higher adult populations lead to higher damage in bermudagrass hay fields. Harvesting the hay lowers the overall adult populations and damage when compared to pastures. When healthy fields are left untreated, BSM has a great ability to rebound and damage the hay severely. Proper management and timely harvest are key to controlling BSM and damage levels.

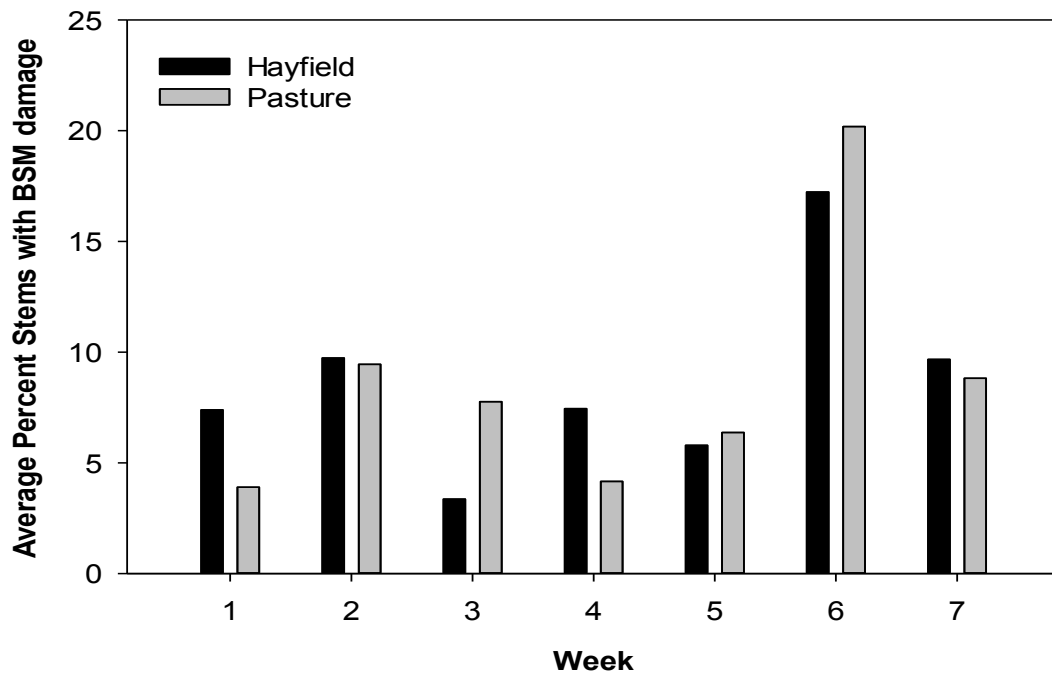


Fig 3.1 Preliminary data showing average damage among all hay fields and pastures over 7 weeks

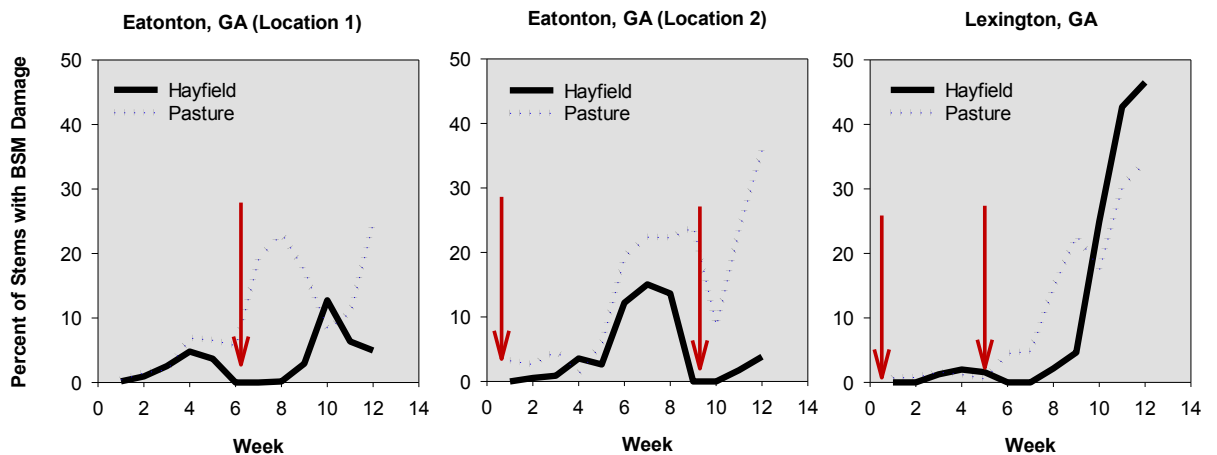


Fig 3.2 BSM Damage seen in each test plot over a 12-week trial. Eatonton Location = EP1/EF1. Eatonton Location 2= EP2/EF2. Lexington = LP/LF. Arrows indicate Harvest.

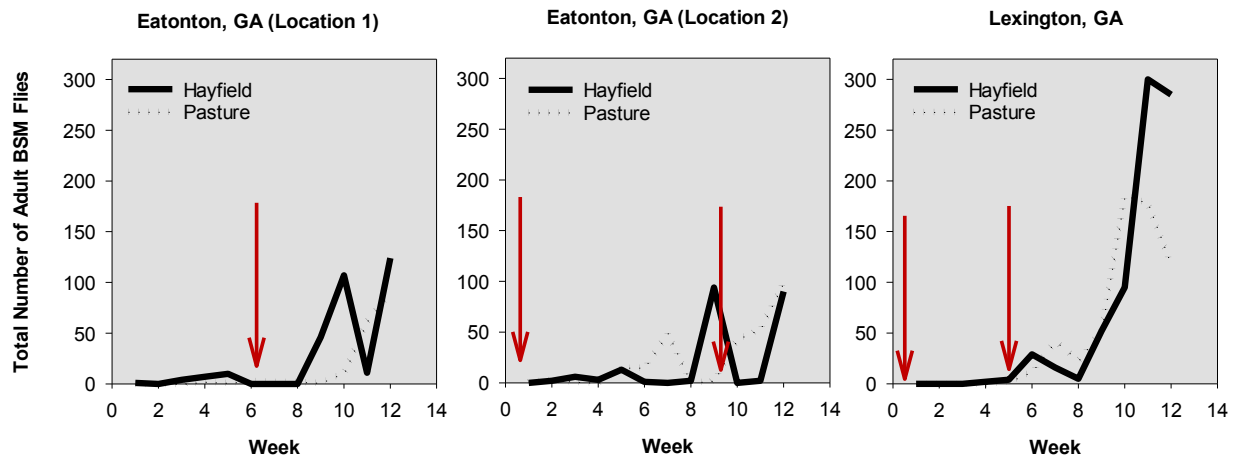


Fig 3.3 BSM Adult Population counts from each test plot over 12 weeks, arrows indicate harvest. Eatonton Location 1=EP1/EF1. Eatonton Location 2=EP2/EF2. Lexington = LP/LF

LR	CHISQ	DF	Pr(>CHISQ)
Event	13.32	1	0.0002***
Loc	219.71	2	<2.2e-16***
Type	21.86	1	2.937e-06***
Week:Event	21.74	1	3.128e-06***
Week:Loc	184.59	2	<2.2e-16***
Loc:Type	14.68	2	0.0006***
Event:Loc	48.64	2	2.748e-11***

Table 3.1 : Analysis of Deviance Table (Type 3 Test) for damage

LR	CHISQ	DF	Pr(>CHISQ)
Event	16.97	1	3.794e-05***
Loc	30.26	2	2.685e-07***
Type	6.91	1	0.008**
Week:Loc	23.71	2	7.101e-06***
Loc:Type	5.18	2	0.074*
Loc:Event	40.08	2	1.972e-09***

Table 3.2 Analysis of deviance Table for adult sweep counts

	HERBICIDES	WEEKS GRAZED	# OF HARVEST
EP1	NO	3	0
EP2	NO	3	0
LP	YES	12	0
EF1	NO	0	1
EF2	NO	0	2
LF	YES	0	2

Table 3.3 Comparison of management between locations

References

- Hancock, D.W. 2012. Bermudagrass stem maggot. Georgia Cattlemen. 40:20.
- Hardy, D.E. 1976. Proceedings of the Hawaiian Entomological Society for 1974. Hawaiian Entomol. Soc. Proc., Honolulu, Hawaii, 1974. Hawaiian Entomol. Soc. 22(2).
- Holderbaum, B. 2009. Orange Fly-Atherigona. IA State University Entomology. <http://bugguide.net/node/view/312313/bgimage> (accessed 15 May 2012).
- Hudson, W. G., Dr. (2019, June 24). Quantifying the Damage Potential of the Bermudagrass Stem Maggot. Retrieved from <https://www.aces.edu/blog/topics/forages-livestock/biology-and-management-of-bermudagrass-stem-maggot/?cn-reloaded=1>
- Pont, A.C. and F.R. Magpayo. 1995. Muscid shoot-flies of the Philippine Islands (Diptera: Muscidae, genus *Atherigona* Rondani). Bull. Entomol. Res. Supp. Ser. 3: 1-100.
- Savage, J. (2016). FIRST CANADIAN RECORD OF THE BERMUDA GRASS STEM MAGGOT, *ATHERIGONA REVERSURA* (DIPTERA: MUSCIDAE). *Journal of the Entomological Society of Ontario*, 147, 3-6.

Chapter 4

Other Biological and Behavioral Studies

Introduction

There is currently little information in the literature regarding the life cycle of bermudagrass stem maggot (BSM; *Atherigona reversura* Villeneuve). Previously, the life cycle of the sorghum shoot fly was used as a reference for a predicted life cycle. This study had a main objective of quantifying aspects of the life cycle for future studies. Also, during a previous field study (Bowling et al, in progress), it was observed that adult populations were at times scarcely found in the open fields and pastures. In the mid-summer Georgia heat, it is not uncommon to experience daytime temperatures well over 90°F with high humidity. It was under these conditions, while conducting adult sampling for BSM, large numbers of adults were discovered in shaded areas around trees. To better understand this observation, follow up sampling was conducted to compare sweep samples in shaded areas vs open portions of fields. This information may be useful in future studies to determine more practical pesticide application protocols.

Material and Methods

Pupal Stage Study

Maggots that emerged from grass samples from every site location each week were allowed to pupate in laboratory conditions. These pupae were held in petri dishes at ~75° F and examined daily until adults emerged. The maggots were monitored daily and their total pupal stage determined.

Adult Life Span Study

Flies that emerged from pupation in the laboratory were held in mesh cages and used to study the life span of adult *A. reversura*. The life span was tracked via daily monitoring and feeding. Flies were fed a simple honey and water mix of 1 part honey to 2 parts water from a small dish. Flies that emerged on the same day were held together and tracked. They were monitored from the day they emerged until the day they died.

Life Cycle Study

Duration of the entire life cycle was studied in cages in the greenhouse. Potted bermudagrass was placed in mesh cages, and flies were released and allowed to lay eggs for 48 hours. This timing was based on previous studies that found flies left for 24 hours in the cages produced no subsequent adults (W. Hudson, personal communication). The potted bermudagrass was watered and maintained throughout the study. The mesh cages

were monitored every day for 6 weeks to identify when a new fly emerged. This data was used to calculate an average time for a life cycle to be completed.

Shade Study

Adult samples were collected in sets of ten in both open portions and two steps inside shaded areas of the same plots at EP2 and LF. These samples consisted of ten sets of ten sweeps, where adults were counted and compared. In samples that contained over 20 adults, the sample was entered as 20+ instead of individually counting the adults. On the last week of sampling, grass samples were taken to compare the damage accumulated in these areas.

Results and Discussion

Pupal Stage

The pupal stage lasted an average of 12.6 days (n=34) in laboratory conditions with a temperature of ~75° F. The range was 11-14 days with a single outlier of 18 days. Obviously, pupal development and time to emergence are temperature dependent so the duration of the pupal stage would likely be shorter under field conditions in Georgia summers.

Life Span

Flies held in the laboratory and fed honey water lived anywhere from 1 to 20 days (average 9, n=38). There were several instances where flies drowned in the provided water/honey mix early into adulthood. These early deaths obviously affected the average life span witnessed in the laboratory setting. In a field environment where drowning is not an issue the average life span is likely to be longer.

BSM Life Cycle

Flies for the life cycle study were released into a cage containing bermudagrass on 27 July 2020. 48 hours later those adults were removed and the cages were left in the greenhouse. The grass was watered regularly and cages were observed every day for new adults. The first fly emerged 18 days after release and the last emerged after 33 days (average = 24, n=7). Given the 48-hour window when eggs might have been laid, the life cycle was found to be as short as 16 days in summer temperatures in the greenhouse, which averaged in the low 90's during the study, or as long as 31 days.

It should be noted that the cages were in the greenhouse setting with higher average temperature and humidity when compared to the laboratory. This may have led to a decreased pupation time compared to laboratory conditions.

To test this, newly emerged larvae and pupae were placed in the greenhouse to measure pupation time under more natural conditions. The results never came, as pupae were dehydrated and killed when not in the protection of soil under greenhouse conditions. The same containers used in the laboratory to hold pupae were not adequate for the greenhouse version of the study.

BSM Affinity for Shade

On the week of July 27, LF and EP2 were sampled for adult populations in open and shaded conditions. The EP2 was allowed to grow freely without grazing. This plot contained a grove of trees that provided roughly a 30x30 meter area of shade at any given time of day. On the first round of sweeping, open pasture provided a total of 0 adult

BSM, while the shaded grove provided 350+ adults. On the second sampling day, during the week of August 17, open pastures provided 53 adults. On this same plot, shaded areas provided 300+ BSM adults. These sweeps took place between 10 am and 1 pm.

The pasture and field pair located on our Lexington plot were sampled during the same weeks as EP2. On the first sampling, an average of 5 and 23 adults were found per 10 sweep samples from open areas in the hay field and pasture respectively. Shaded areas of the hay production field yielded a total of 137 adults in 10 sweeps, while the pasture provided 223. On the second sampling, the week of August 17, open areas and shaded areas provided equal numbers of adults - well over 200 from 10 sweeps. On this sampling day, the grass was wet which may have provided enough cover and water to negate the need for shade. More data is needed to determine a connection between the hot/dry weather and their affinity for shade.

The final week of sampling (August 24-28) provided a good opportunity to collect stem samples from both areas of the field at Lexington. These samples were gathered to investigate whether damage was higher in the shade. Open field samples had an average damage of 46.5% and shaded areas had an average of 60.9% damage. This equates to 1.31X more damage in shaded areas.

Future studies should pursue the observation that adult flies retreat to shade in hot, dry conditions. If a greater body of evidence is found to support the movement of adults to shaded areas, adjustments could be made to pesticide application recommendations. By increasing efficiency in targeting, producers could narrow their applications to shaded regions in highly populated fields to save time and money on BSM control.

