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**Abstract**

The wheat stem maggot (*Meromyza americana* Fitch) (WSM) is a minor pest of wheat, rye, and other grasses. In 2017, growers in Nebraska reported dead center whorls and excessive tillering in early-season cornfields that followed wheat or rye terminated after planting corn. A survey was conducted to evaluate the risk factors for this insect in cover crop to corn transition systems. In each field, management practices and the percentage of injured plants were recorded. Symptomatic corn plants were collected from each field and dissected to determine larval and plant characteristics. In a few cases, small patches of a field were planted to a cover crop to manage soil erosion, and injured plants were only found where the cover crop was present. From these observations, the hypothesis is that terminating a cover crop after planting corn allowed the WSM larva to move from the dying cover crop to corn to complete its development. Cornfields infested with WSM had a

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frequency of injured corn plants from 0 to 60% with yield losses estimated at 30 bushels/acre. This paper provides the first detailed documentation of WSM injury in corn and addresses important management practices that may have influenced this uncommon situation.

**Keywords:** wheat stem maggot, cover crop, termination, corn

Cover crops have continued to increase in acreage across the United States as a sustainable means of improving soil health and reducing runoff from fields to surface waters and as an alternative to managing resistant weed species (CTIC 2017). By increasing the biodiversity of the landscape, cover crops can attract both pest and beneficial insects (Bugg 1991; Dunbar et al. 2016, 2017; Koch et al. 2012; Landis et al. 2000; Lundgren and Fergen 2010; Tillman et al. 2004). Increasing the abundance of natural enemies and beneficial arthropods could lead to a reduction in pesticide use while increasing production sustainability (Cardina et al. 1996; Dunbar et al. 2017; Landis et al. 2000; Shearin et al. 2008). In contrast, cover crops also have the potential to create new insect problems for subsequent cash crops (Dunbar et al. 2016). The potential damage and benefits of these arthropods in the following cash crop vary based on a number of factors such as cover crop species, timing of cover crop establishment or termination, number of years with a cover crop, and weather conditions (Dunbar et al. 2017; Koch et al. 2012; Smith et al. 1988; Tillman et al. 2004). A number of cover crop species can be used depending on the goals of the grower. In 2017, cereal rye (*Secale cereale* L.) was the most used cover crop, followed by oats (*Avena sativa* L.), annual ryegrass (*Lolium multiflorum* L.), and winter wheat (*Triticum aestivum* L.) (CTIC 2017).

## The Wheat Stem Maggot (WSM)

WSM is known to infest rye, oats, and winter wheat, and it is assumed to be native to North America with the first description occurring in 1821 (Gilbertson 1925). Larvae of WSM are typically found feeding between the shoot and the last sheath, later entering into the center whorl of the tiller. Larval feeding can sometimes result in the death of a tiller. Gilbertson (1925) observed larvae moving between plants to seek out a healthy host or feeding site. There are no published reports

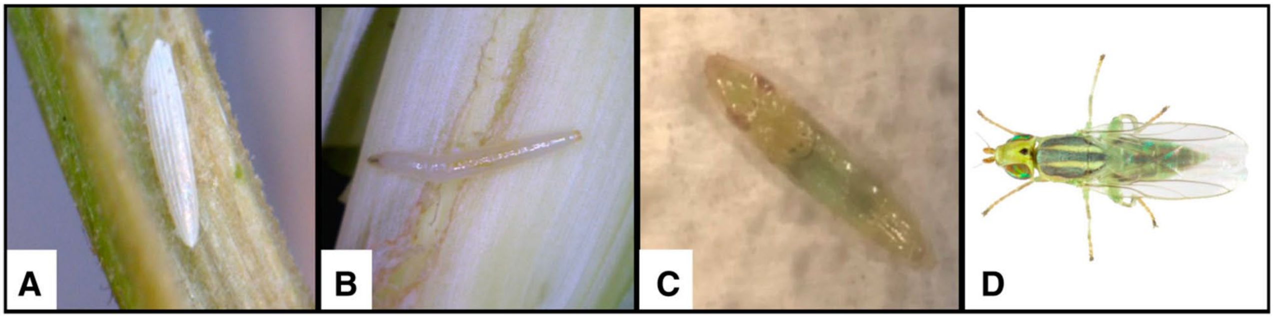


**Figure 1** Wheat stem maggot life stages: egg (A), larva (B), pupa (C), and adult (D). Photo credit: University of Nebraska Department of Entomology.

showing how far the larvae can migrate. In wheat fields, signs of WSM infestations are initially identified based on premature whitening of random wheat heads. These infestations are typically low in wheat fields but might cause significant economic losses (Allen and Painter 1937; Gilbertson 1925; Kieckhefer and Morrill 1970).

Wheat stem maggot flies lay eggs singly, which are placed parallel to the long axis of the leaves or on the base of the stems of the host plant. The eggs are fusiform-cylindrical in shape, snow white, and vary from 1 to 1.16 mm in length and from 0.17 to 0.2 mm in width (Figs. 1A and 2) (Gilbertson 1925). The maggots are cylindrical with 13 segments, legless, and headless. The maggots pass through three instars, with the first instar measuring about 1 mm in length and 0.1 mm in width; the second instar is approximately 3.2mm in length and 0.5mm in width, and the third and final instar varies from 6 to 7 mm in length and 0.8 to 1.3 in width (Figs. 1B and 2). The pupa has 10 clearly defined divisions, is yellowish-green, and is about 5 mm long and 1.4 mm in width (Figs. 1C and 2) (Allen and Painter 1937; Gilbertson 1925). The flies are about 4.5 mm long by 2 mm wide, pale yellowish-green. The thorax is marked by three broad longitudinal black bands, occupying the greater part of the posterior surface (Figs. 1D and 2). The oviposition period is 14 to 21 days, with each female fly laying approximately one to four eggs per day. Gilbertson (1925) indicated that the WSM can complete two and a half generations per year in South Dakota, and Allen and Painter (1937) found three and a half generations per year in Kansas. In both studies, the WSM overwintered as larvae in volunteer wheat or grasses.

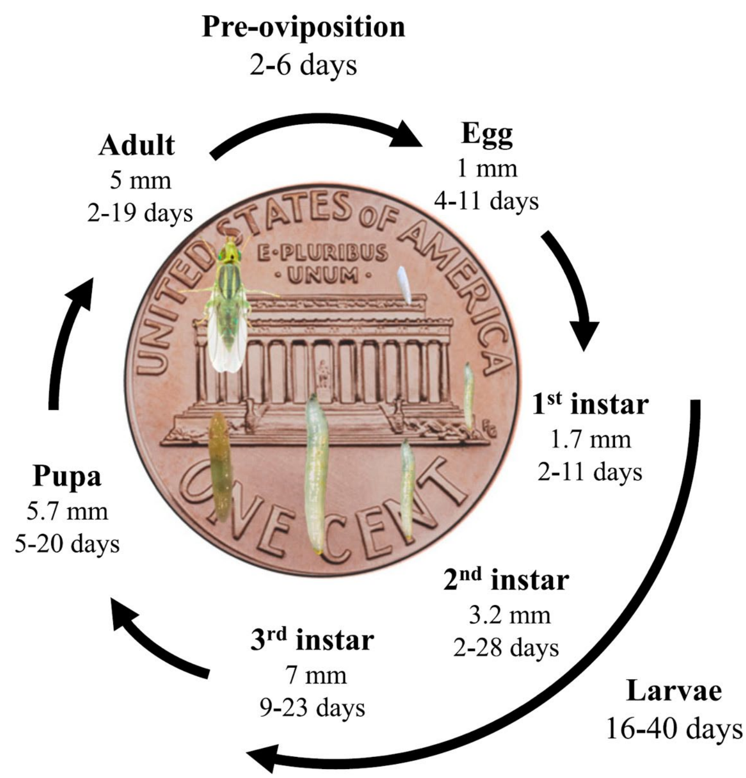


**Figure 2** Wheat stem maggot life cycle description (Gilbertson 1925).

## Management Practices to Control the WSM

Limited information is available regarding management practices to control WSM. McBride et al. (1989) stated that crop rotation with non-susceptible crops and plowing under volunteer host wild grasses reduces populations of this insect. In addition, they indicated that chemical treatment is not effective. However, Knodel et al. (2009) found that a foliar application of lambdacyhalothrin at the four- to six-leaf stage in wheat in combination with a low rate of thiamethoxam seed treatment significantly decreased the white head numbers in wheat, but such practices resulted in no significant yield differences. Hesler et al. (2005) studied the effect of wheat planting dates on insect infestations and incidence and found that a late planting date did not favor WSM infestations. Kieckhefer and Morrill (1970) reported a number of hymenopterous parasites on WSM, such as *Bracon meromyzae* Gahan (Gahan 1913), *Coelinidea ferruginea* Gahan (Gahan 1913), *C. meromyzae* (Forbes) (Forbes 1884), *Bubekia fallax* Gahan (Gahan 1933), and *Halticoptera patellana* (Dalman) (Gahan 1933).

## WSM in Corn: The Situation in Eastern and Central Nebraska

Reports of WSM affecting corn (*Zea mays* L.) are rare (Sloderbeck et al. 2013). In 2005 and 2015, isolated incidents of WSM infestations occurred in a few Nebraska cornfields (Ohnesorg 2016). Little is known about the agronomic characteristics of these situations. In 2017, a number of growers were forced to delay their cover crop terminations, resulting in corn being planted into a living cover crop. Some growers chose to delay cover crop terminations owing to successful outcomes in previous years. Others may resort to this practice as a result of a cold, wet spring that limits field activities and reduced herbicide efficacy following an application. Delayed cover crop terminations in combination with planting corn in living wheat or rye cover crops coincided with WSM causing injury to a number of cornfields across eastern and central Nebraska. Early-stage corn plants that were infested with WSM exhibited dead center whorl symptoms followed by excessive tillering as a result of a loss of the main stem (Fig. 3). The first report of field injury was made on 23 May 2017, followed by several reports in counties throughout eastern and south-central Nebraska. On 31 May 2017, a field survey was initiated to evaluate the impact and determine risk factors for WSM on early-season affected cornfields.

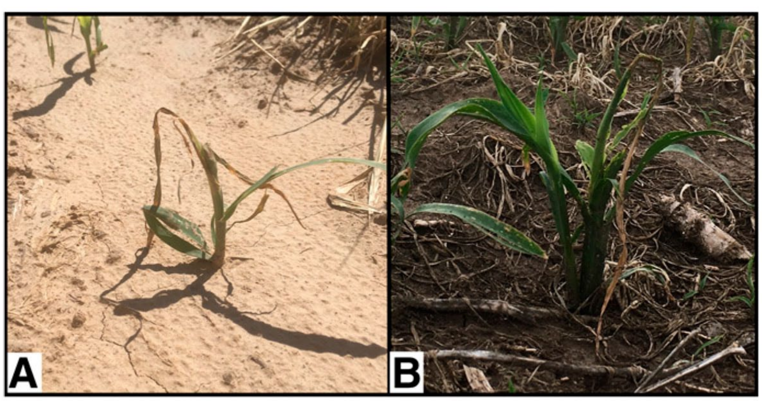


**Figure 3** Wheat stem maggot injury in early-season corn: A, dead center whorl symptom; and B, excessive early tillering owing to the feeding injury to the corn growing point.

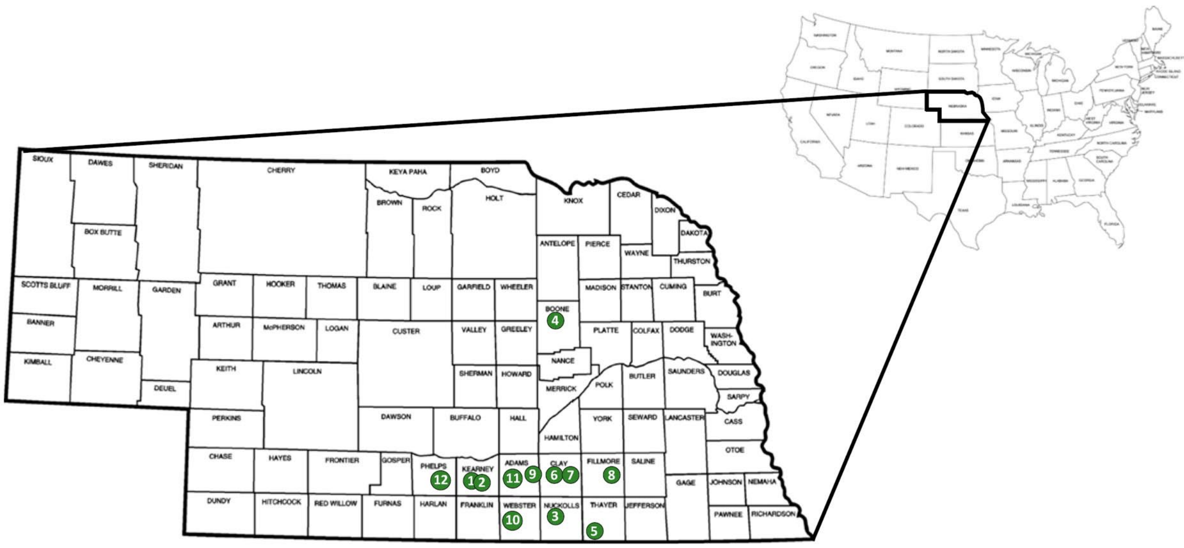


**Figure 4** Fields sampled for wheat stem maggot in Nebraska during the 2017 growing season. Numbers correspond with the field sampled.

## Observational Methods and Sampling

**Management practices.** Twelve WSM-injured cornfields were sampled in nine counties across eastern and central Nebraska from 31 May to 9 June 2017 (Fig. 4). Management practices such as cover crop species, cover crop planting and termination dates, cover crop termination method, and corn planting dates were collected through communications with farmers, Nebraska Extension Educators, and crop consultants from the region. The percentage of WSM-symptomatic plants was recorded on 100 consecutive corn plants in four randomized locations of each field. In addition, wheat plants were collected from nearby fields exhibiting white heads to compare with the WSM sampled from cornfields.

**Plant assessment.** In each field, a total of 20 to 30 symptomatic corn plants suspected to be infested with WSM (Fig. 3) were sampled in five locations of each field. Surveyed fields were sampled during early corn stages of development, between V2 and V7 across all the fields surveyed.

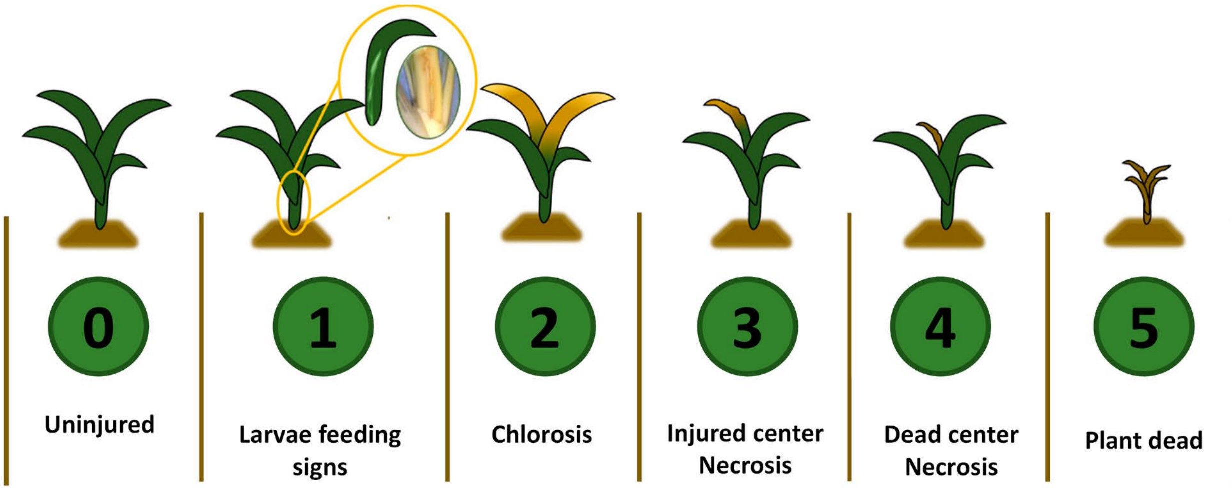


**Figure 5** Categories used for analyzing wheat stem maggot injury. Symptomatic plants are rated 1 to 5, and 0 represents an uninjured corn plant. Excessive tillering was observed in categories 2, 3, and 4.

The following data were assessed from the field-collected corn plants: percentage of plants with tillers, number of tillers per plant, plant stage, plant height, and plant injury. Plant injury was recorded based on an injury scale (Fig. 5) from 0 to 5, where 0 = uninjured plant, 1 = larval feeding signs inside the corn plant, 2 = plant with chlorotic leaves, 3 = plant showing an injured center and necrosis on leaves, 4 = plant with dead center and leaves with necrosis, and 5 = plant is dead.

**Insect assessment.** Plants sampled from cornfields were dissected, and the larvae were isolated when present. When WSM larvae were found, the percentage of plants infested per field, insect life stage, insect size, and insect location in the plant were recorded. Isolated larvae were stored in vials with 70% ethanol. Plant injury scores and larval size data were checked for normality before analyzing the data. Larval size and plant injury scores were compared using SAS 9.4 PROC CORR (version 9.22) using Spearman rank-order correlation. Only samples containing larvae were used in the analysis.

**Insect identification and emergence.** In each of the first five fields, an additional 25 symptomatic corn plants were dug up and transplanted to small containers. These plants were caged to capture emerging adults for species identification, because larvae are difficult to identify to species. Caged plants were maintained in a growth chamber at 80°F (27°C) with 14 h of light from 7 a.m. to 9 p.m. Plants were monitored for adult emergence each day. WSM fly emergence date and the number of flies per corn plant were recorded.

### Risk Factors for WSM Injury in Corn

**Management practices.** A total of 12 cornfields suspected to have WSM injury were surveyed in nine Nebraska counties from 31 May 2017 to 9 June 2017 (Fig. 4). All cornfields were previously planted to a rye or wheat cover crop. These cover crops were planted between mid-October and mid-November in 2016 and terminated between 8 April and 7 June 2017 (Table 1). In a few cases (fields 4, 10, and 12), growers made two applications of glyphosate owing to a lack of herbicide efficacy (Table 1). Corn was planted into these fields from 14 April to 28 April 2017 (Table 1). In all cases, corn was planted into a

**Table 1** Management practices and characteristics of wheat stem maggot-affected fields sampled in 2017

| *Field* | *County (NE)* | *Cover crop (CC)* | | | *Corn planting date (2017)* | *CC termination – corn planting*[a] |
|---|---|---|---|---|---|---|
| | | *Species* | *Planting date (2016)* | *Termination date (2017)* | | |
| 1 | Kearney | Rye | Mid-October | May 2 | April 22 | +10 |
| 2 | Kearney | Rye | Mid-October | May 2 | April 24 | +12 |
| 3 | Nuckolls | Wheat | Fall | April 19 | April 14 | +4 |
| 4 | Boone | Rye | October 22 | May 4 and 5 | April 23 and 24 | +14 |
| 5 | Thayer | ... | ... | ... | ... | ... |
| 6 | Clay | Wheat | November 5/11 | April 18 | April 17 | +1 |
| 7 | Clay | Wheat | October 20 | April 18 | April 17 | +1 |
| 8 | Fillmore | Rye | November | April 24 | April 22 | +2 |
| 9 | Adams | Rye | October | April 13 | April 22 | –9[b] |
| 10 | Webster | Wheat | Fall | April 8 and May 10 | April 27 | +13 |
| 11 | Adams | Wheat | Fall | April 24 | April 18 | +6 |
| 12 | Phelps | Wheat | Fall | April 28 and June 7 | April 28 | +9 |

a. Days between cover crop termination and planting corn. Positive sign (+) represents green planting or cover crop termination after planting corn.
b. Presence of live cover crops at the time of corn planting.

**Figure 6** Corn field with patch planting of cover crop. Orange lines indicate the border between an area with and without cover crop. Injured corn plants were confined to where cover crops were planted (field 3).

green cover crop with terminations occurring from 9 days before to 14 days after planting corn (Table 1). Fields 3 and 5 had patch plantings of cover crops to control soil erosion on slopes and low-lying areas of the fields. In both of these situations, WSM-injured corn plants were confined to an area within a few feet of where the cover crop was growing at the time of planting corn (Fig. 6). WSM-injured corn plants varied from 0 to 4%(field 12) to 50 to 60% (field 3) within a field. Seven of the 12 fields (58%) surveyed had more than 20% occurrence of WSM-injured corn plants (Table 2).

**Plant injury assessment.** From the 12 sampled fields, a total of 250 plants were analyzed with an average of 21 plants per field. The percentage of early-stage corn plants sampled with more than one tiller as a WSM feeding symptom varied from 20 to 100% (Table 2). Corn plants with one tiller were the most abundant in five of the 12

**Table 2** Sampled plant characteristics for each corn field surveyed with wheat stem maggot injury with rye or wheat as a cover crop in 2017

| Field | Symptomatic plants (%)[a] | Plant stage | Plants with tillers (%) | Percentage of tillers per plant | | | | | Percentage of plants with symptoms (injury score)[b] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 0 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 5 |
| 1 | 4–25 | V5 | 20 | 80 | 20 | 0 | 0 | 0 | 20 | 37 | 6 | 37 | 0 |
| 2 | 0–8 | V5 | 25 | 75 | 25 | 0 | 0 | 0 | 10 | 16 | 0 | 74 | 0 |
| 3 | 50–60 | V6 | 75 | 25 | 35 | 20 | 20 | 0 | 20 | 25 | 10 | 45 | 0 |
| 4 | 1–3 | V3 | 60 | 40 | 47 | 13 | 0 | 0 | 0 | 7 | 33 | 60 | 0 |
| 5 | 30–40 | V4 | 48 | 48 | 52 | 33 | 14 | 0 | 4 | 32 | 46 | 18 | 0 |
| 6 | 7–29 | V7 | 100 | 0 | 33 | 38 | 27 | 0 | 85 | 0 | 0 | 10 | 5 |
| 7 | 1–5 | V6 | 79 | 21 | 38 | 38 | 4 | 0 | 25 | 50 | 0 | 25 | 0 |
| 8 | 8–33 | V6 | 85 | 15 | 50 | 30 | 5 | 0 | 0 | 35 | 45 | 0 | 20 |
| 9 | 2–11 | V6 | 85 | 15 | 40 | 15 | 25 | 5 | 20 | 60 | 0 | 20 | 0 |
| 10 | 4–27 | V5 | 67 | 33 | 27 | 33 | 7 | 0 | 27 | 46 | 0 | 27 | 0 |
| 11 | 28–40 | V6 | 77 | 23 | 32 | 36 | 9 | 0 | 41 | 50 | 0 | 9 | 0 |
| 12 | 0–4 | V5 | 47 | 53 | 35 | 12 | 0 | 0 | 41 | 50 | 0 | 9 | 0 |

a. Range of percentage of symptomatic plants sampled across four different locations in the field.
b. Injury scores: 1 = larval feeding signs inside the corn plant; 2 = plant with chlorotic leaves; 3 = plant showing a damaged center and necrosis on leaves; 4 = plant with dead center and leaves with necrosis; and 5 = plant is dead (see Fig. 5 for illustration).

surveyed fields (42%). This was followed by corn plants with no tiller being the most common in four fields (33%), and corn plants with two tillers were observed in three surveyed fields (25%) (Table 2). At the time of sampling, corn plants were between V2 and V7 stage (Table 2). All plants that were sampled showed some signs of WSM injury (Fig. 5; Table 2), with the greatest percentage of the sampled plants showing signs of necrosis on the main stem and/or tillers (injury score 2). Sampled plants with a dead center whorl (injury score 4) were the second most frequent symptom (Table 2).

**Insect assessment.** A total of 74 WSM larvae were isolated from the 250 dissected. WSM field infestations varied from 12% (field 12) to 80% (field 3) (Table 3). In most cases, a single larva was found per plant, with the exception of a few corn plants containing two larvae. Larvae were most often found in the corn stalk between 0 and 5 cm from the growing point (Table 3) (Fig. 7). During plant dissection, injury from WSM larvae was observed by a tunnel that started just below the whorl and increased in diameter down to the growing point

**Table 3** Wheat stem maggot injury in corn following rye or wheat as a cover crop in 2017

| Field | Infested plants per total sampled | Insects per infested plant (%) | | Insect life stage (%) | | | | Percentage of larvae location (cm) above growing point | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Instar[a] | | | | | |
| | | 1 | 2 | First | Second | Third | Pupa | 0–5 | >5 |
| 1 | 9/30 | 100 | 0 | 12.5 | 62.5 | 25 | 0 | 88.8 | 11.2 |
| 2 | 8/21 | 87.5 | 12.5 | 0 | 33.3 | 66.7 | 0 | 100 | 0 |
| 3 | 12/15 | 100 | 0 | 0 | 50 | 50 | 0 | 100 | 0 |
| 4 | 4/25 | 100 | 0 | 0 | 100 | 0 | 0 | 100 | 0 |
| 5 | 7/25 | 100 | 0 | 0 | 71.4 | 14.3 | 14.3 | 100 | 0 |
| 6 | 4/20 | 100 | 0 | 0 | 100 | 0 | 0 | 100 | 0 |
| 7 | 4/21 | 100 | 0 | 25 | 75 | 0 | 0 | 75 | 25 |
| 8 | 5/20 | 100 | 0 | 0 | 40 | 40 | 20 | 100 | 0 |
| 9 | 10/20 | 88.9 | 11.1 | 0 | 55.6 | 33.3 | 11.1 | 88.8 | 11.1 |
| 10 | 2/15 | 100 | 0 | 0 | 0 | 100 | 0 | 100 | 0 |
| 11 | 7/21 | 100 | 0 | 0 | 42.9 | 14.2 | 42.9 | 100 | 0 |
| 12 | 2/17 | 100 | 0 | 0 | 50 | 0 | 50 | 50 | 50 |

a. First instar from 1 to 3 mm, second instar from 3.1 to 5 mm, and third instar from 5.1 to 7 mm.

(Fig. 7). In five fields (fields 5, 8, 9, 11, and 12), WSM pupae were found in injured plants, but the majority were second-instar larvae (8/12 fields). First-instar larvae were found in only two fields (fields 1 and 7) (Table 3). No significant correlation was found between larval size and injury scores (adjusted $R^2 = -0.005$; df = 38; $P = 0.3720$) (Fig. 8).

**Insect identification and emergence.** Confirmation of the WSM (*Meromyza americana* Fitch) species was made by University of Nebraska–Lincoln insect diagnostician James Kalisch, based on Fedoseeva (2003), in which the distinguishing characteristic was the anterior gonites being not sickle-shaped but more quadrangular. Voucher specimens were deposited in the systematic Research Collections in Entomology at the University of Nebraska State Museum, Lincoln, NE.

The emergence of WSM adults from caged plants varied between fields, with an average of 22 days after the field collection (SD ±3.4 days). Adults emerged 16 days after the field collection in field 2, followed by 19, 20, 21, and 22 days after being caged in field 3, 5, 4, and 1, respectively (Fig. 9). A total of 54 flies emerged from the 125 caged

**Figure 7** Wheat stem maggot larva feeding inside an early-stage corn plant. Solid line indicates corn growing point, and arrow indicates wheat stem maggot larva.

plants. A single fly emerged per corn plant from 50 of the cages, and two flies were collected from the same corn plant in only two of the cages. The percentage of WSM adult emergence varied from 16% (field 5) to 60% (field 1) from caged plants (Fig. 9).

## Summary of WSM Incidence and Management Recommendations

Cornfields surveyed for WSM injury were not randomly selected but were based on problem calls and Extension Educator reports. In all cases, corn was planted into a living wheat or rye cover crop. Both

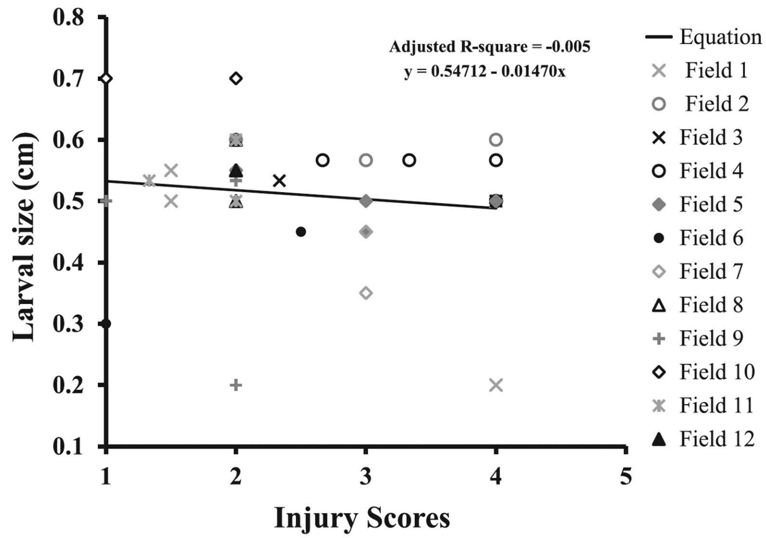


**Figure 8** Correlation between wheat stem maggot larval size and corn injury score for side within each field location where larvae were recovered.

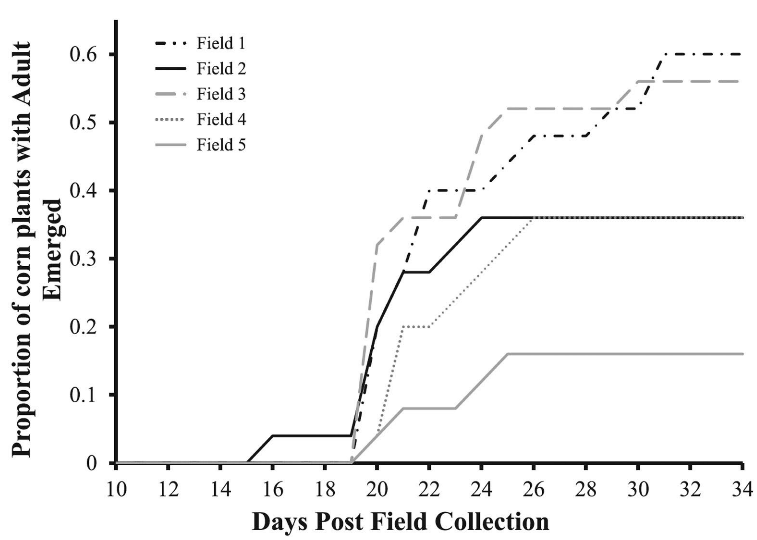


**Figure 9** Wheat stem maggot adult emergence in days after field collection, expressed as a proportion of the total plants caged from the fields 1, 2, 3, 4, and 5.

wheat and rye are preferred hosts for the WSM (Allen and Painter 1937; Gilbertson 1925; McBride et al. 1989). Patch planting of cover crops occurred in two fields, and in both cases the injury was confined to within a few feet of the cover crop. This distributional dependence of WSM injury based on the presence of cover crop suggests that larvae may have been the primary means of movement between the cover crop and corn (Fig. 6). Rotating to a nonpreferred host crop such as corn has been described as a pest management strategy for WSM (McBride et al. 1989). The results from this survey suggest that this strategy should be done in separate fields or with enough time for the spring wheat or rye as cover crop to die before planting corn.

Cover crop planting dates from this survey suggest that adults may have infested the cover crop in the spring before the cover crop termination. In two cases (field 6 and 8), cover crops were planted in November, a period outside of expected adult WSM movement in the fall (Allen and Painter 1937) (Table 1; Fig. 10). Allen and Painter (1937) found that the first adult WSM emerged in Kansas on 15 April, potentially allowing for a narrow window for infestation before the death of the cover crop during the spring of 2017.

Infestation of corn from the cover crops is suspected to have occurred as a result of larvae migrating from the dying cover crop to corn. This assumption is based the spatial distribution of plant injury when patch plantings of cover crops occurred (Fig. 6) and a lack of correlation between plant injury and larval size. If adult WSM laid eggs directly on corn plants, we would expect some relationship between larval development stage and plant injury as well as a wider distribution of injury around patch plantings of cover crops.

Excessive tillering in the early stages of corn is expected to reduce corn yield (Downey 1972; Frank et al. 2013). As a result, significant yield impacts would be anticipated from severe WSM infestations. Yield impacts on a per plant basis were not recorded in this survey; therefore, additional studies are needed to evaluate this relationship. In some cases, growers who planted cover crops in patches (field 3 with 50 to 60% symptomatic plants) reported a 30 bushels/acre (2,000 kg/ha) yield loss in these patches compared with other areas of the field with no cover crop. Such results are confounded by the presence or absence of the cover crop and the location within the field.

## WSM Potential in Corn and Future Directions

Maximizing cover crop biomass is a primary goal for growers in order to maximize benefits such as soil erosion control, soil health improvement, and weed suppression. As a result, green plantings have

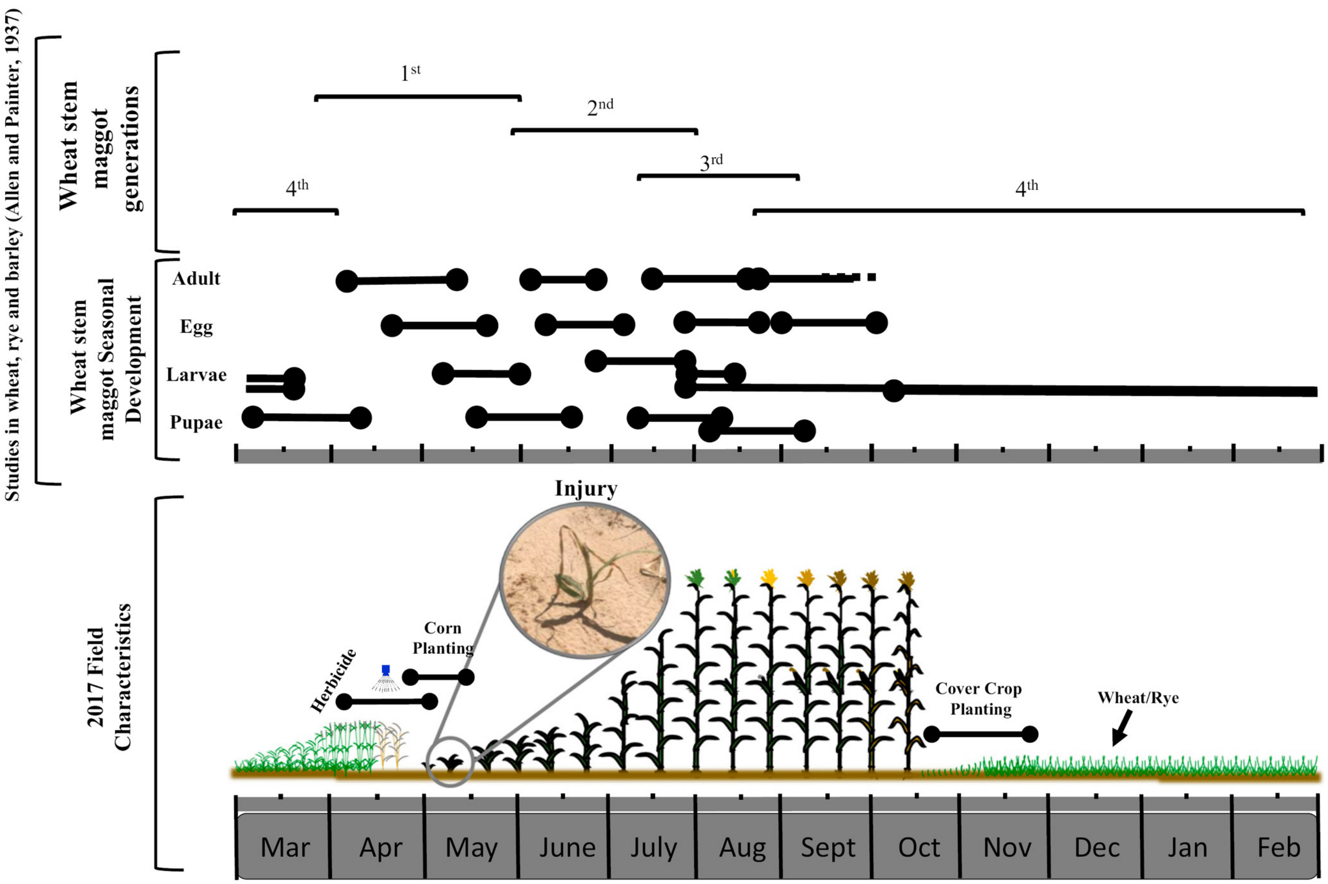


**Figure 10** Wheat stem maggot seasonal development overlapping the 2017 sampled field characteristics.

increased in recent years as a compromise with a need for early planting dates to maximize the yield of the cash crop (CTIC 2017). This survey provides evidence that cover crop termination time relative to corn planting date was likely the primary factor for WSM injury in cornfields in 2017. Although it is difficult to predict the conditions under which this would occur again, risk of WSM movement from the cover crop to the subsequent corn crop should ensure that the cover crop is completely dead at least 10 days before the cash crop emerges.

This survey is the first documentation of WSM as a pest of corn in a cover crop to corn transition system. Growers planting cover crops, especially wheat and rye followed by corn, should be aware of the potential occurrence of WSM in early corn stages.

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**Conflict of interest** The authors declare no conflict of interest.

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