Millet Preference, Effects of Planting Date on Infestation, and Adult and Larval Use of Proso Millet by Ostrinia nubilalis (Lepidoptera: Crambidae)

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Abstract
The interaction between millet and European corn borer, Ostrinia nubilalis (Hu¨ bner), was investigated to gain insight into whether millet could serve as a refuge or trap crop for O. nubilalis management. In 1995, 1996, and 1999, millet selection studies were conducted in North Dakota and New York with four millet species. Proso millet, Panicum milliaceum L., had the highest infestation and widest distribution of O. nubilalis developmental stages, indicating the presence of both univoltine and bivoltine ecotypes. Siberian foxtail millet, Setaria italica (L.) Beauvois, harbored the greatest number of adults, followed by German foxtail millet, Setaria italica (L.) Beauvois. These two millets appeared to serve as better aggregation sites than proso millet. In North Dakota in 1997, proso millet planting date studies showed later planting dates were more heavily infested than earlier dates; in 1998, the trend was reversed. The change in trends between years was probably a result of differences in the respective growing seasons and subsequent differences in O. nubilalis flights. Adult sampling showed that both old and young females aggregated in proso millet during the day; however, at night, it appeared that young females moved out of millet to oviposit, whereas old females remained in millet. Egg masses were detected in proso millet over a 7-d period in 1997 and a 4-d period in 1998. Larval sampling showed planting proso millet between late May and mid-June may maximize the presence of individuals from both O. nubilalis ecotypes. Once the optimal combination of planting date, plant density, and millet type is found, millet may serve as an effective refuge or trap crop for O. nubilalis management.

Keywords
European corn borer, Ostrinia nubilalis, millet, trap crop, refuge

Disciplines
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Millet Preference, Effects of Planting Date on Infestation, and Adult and Larval Use of Proso Millet by *Ostrinia nubilalis* (Lepidoptera: Crambidae)

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ABSTRACT  The interaction between millet and European corn borer, *Ostrinia nubilalis* (Hübner), was investigated to gain insight into whether millet could serve as a refuge or trap crop for *O. nubilalis* management. In 1995, 1996, and 1999, millet selection studies were conducted in North Dakota and New York with four millet species. Proso millet, *Panicum miliaceum* L., had the highest infestation and widest distribution of *O. nubilalis* developmental stages, indicating the presence of both univoltine and bivoltine ecotypes. Siberian foxtail millet, *Setaria italica* (L.) Beauvois, harbored the greatest number of adults, followed by German foxtail millet, *Setaria italica* (L.) Beauvois. These two millets appeared to serve as better aggregation sites than proso millet. In North Dakota in 1997, proso millet planting date studies showed later planting dates were more heavily infested than earlier dates; in 1998, this trend was reversed. The change in trends between years was probably a result of differences in the respective growing seasons and subsequent differences in *O. nubilalis* flights. Adult sampling showed that both old and young females aggregated in proso millet during the day; however, at night, it appeared that young females moved out of millet to oviposit, whereas old females remained in millet. Egg masses were detected in proso millet over a 7-d period in 1997 and a 4-d period in 1998. Larval sampling showed planting proso millet between late May and mid-June may maximize the presence of individuals from both *O. nubilalis* ecotypes. Once the optimal combination of planting date, plant density, and millet type is found, millet may serve as an effective refuge or trap crop for *O. nubilalis* management.

KEY WORDS  European corn borer, *Ostrinia nubilalis*, millet, trap crop, refuge

*Ostrinia nubilalis* (Hübner), an insect pest of corn, *Zea mays* L., infests many agronomic crops and weedy species (Bergman et al. 1985). Some noncorn hosts also serve as aggregation or actions sites for adult moths (Showers et al. 1976, 1980, Hellmich et al. 1998). Adults rest in aggregation sites during the day because of the moist microclimate (DeRozari et al. 1977). Weedy species such as foxtails, similar to some millet species, act as *O. nubilalis* aggregation sites (Showers et al. 1976, 1980, Hellmich et al. 1998). While evaluating millet as an alternative crop for the northern Great Plains at North Dakota State University, injury by *O. nubilalis* to various millet species was observed.

In 2001, 550,000 acres of proso millet, *Panicum miliaceum* L., was planted in the United States compared with 76.1 million acres of corn (USDA NASS 2001). Although millet is currently a minor crop, its acreage is increasing (USDA NASS 2001). As acreage increases it is likely that insect problems will increase. *O. nubilalis*, with its wide host range, could pose a threat to millet. Understanding how *O. nubilalis* uses millet as a host may help in designing future management programs in millet. Depending on how millet is used by *O. nubilalis*, it could have potential as a trap crop or a refuge in transgenic corn resistance management. Aggregation of a large number of *O. nubilalis* adults or small larvae into millet could be followed by application of a chemical or biological agent (Showers et al. 1980). This trap cropping strategy could have economic and environmental benefits by reducing the number of treated acres. In transgenic resistance management programs, random mating of resistant and susceptible individuals in millet aggregation sites could suppress fixation of resistance alleles (Ostlie et al. 1997). If millet also could support growth of susceptible larvae, it may be valuable as a refuge in re-
sistance management. In the northern Great Plains, selecting a millet species that attracts individuals from both the univoltine and bivoltine ecotypes and supports the largest number of larvae would be most useful as a trap crop or refuge.

It is also important to look for ways to manipulate millet to attract more *O. nubilalis*. Understanding the dynamics between millet and *O. nubilalis* could increase populations in millet used as a trap crop or refuge or decrease populations in millet that is grown for profit. Previous research has shown that ovipositing *O. nubilalis* females are attracted to taller corn plants (Neiswander and Huber 1929, Hervey and Hartzell 1932, Patch 1942, Beard 1943, Everly 1959, Chiang and Hodson 1963). By altering the planting date, growers may be able to control the number of *O. nubilalis* in millet. Characterizing *O. nubilalis* adult and larval use of millet may provide insight into whether millet could be used as a trap crop or refuge as well as have important implications for the management of *O. nubilalis* in millet.

The objectives of this study were to (1) determine which millet species had the highest adult aggregation and infestation levels; (2) determine whether planting date of proso millet had a significant effect on infestation; and (3) examine aggregation, oviposition behavior, and egg mass and larval distribution of *O. nubilalis* in proso millet.

Materials and Methods

**Millet Selection and Planting Date Effects.** Studies were conducted at the North Dakota State University Carrington Research and Extension Center, Carrington, ND, between 1995 and 1998. Additional *O. nubilalis* millet selection studies were conducted at Cornell University Experimental Farm, Freeville, NY, in 1999.

**Millet Selection Studies.** In 1995 and 1996, two experiments, an early planting (25 May 1995; 27 May 1996) and a late planting (15 June 1995; 14 June 1996), were conducted in North Dakota. Each experiment contained four types of millet: proso millet; pearl millet, *Pennisetum americanum* (L.) Leeke; and German and Siberian foxtail millet, two landraces of *Setaria italica* (L.) Beauvois. Experimental units were 6.7 m in a randomized complete block design (RCBD) with four replicates. In 1999 at Freeville, proso, pearl, and Siberian millet were planted 21 May, 7 and 21 June in 6- by 6-m plots arranged in an RCBD with five replications and 4.5-m spaces between plots.

To estimate the number of adult *O. nubilalis* aggregating in each type of millet, a flush-bar technique (Derrick and Showers 1990) was used. The number of adults flushed per 10 m² was recorded for each plot. Sampling was conducted on 20 and 28 July 1995 and 24 July 1996 in North Dakota and on 19 and 28 July and three and 9 August 1999 in New York.

**Effects of Planting Date in Proso Millet.** Experiments were conducted in 1997 and 1998 with four planting date treatments (27 May 1997, 6, 16, and 25 June; 27 May, 4, 15, and 25 June 1998). Experimental units were 6.7 by 3.1 m arranged in an RCBD with four replicates.

In North Dakota, for each year and for both the millet selection and planting date studies, a 1-m² sample of plants was removed from each plot in late August. The number of stems was counted and 25 stems were randomly selected, split longitudinally, and examined for *O. nubilalis* larvae and evidence of injury (frass, shot holes in the stem, and stem tissue feeding or tunneling). Counts from the 25-stem sub samples were converted to meter squared based on total number of plants in the meter square. Larvae were preserved in 70% ethanol. Instar was determined by measuring head capsule width and body length (Hudon and LeRoux 1986). In the New York study, millet was sampled as described above, except all stems harvested were dissected. Thirty plants per plot also were examined weekly for *O. nubilalis* egg masses.

**Analysis.** Counts from North Dakota millet selection and planting date studies were each subjected to a one-way analysis of variance (ANOVA; *P* < 0.05; SAS Institute 1990). The following were compared: number of millet plants per m² (plant density), percentage of plants with injury per m², number of larvae per m² (larval density), and number of adults flushed per 10 m². Treatment means were separated using f-protected least significant difference (LSD) tests (*P* < 0.05; SAS Institute 1990). A square-root transformation was performed on the larval density data from the 1997 planting date study to normalize variances (SAS Institute 1990). For the New York data, SAS general linear model procedure was used instead of ANOVA because five plots were excluded from sampling because of poor plant emergence.

**Population Sampling in Proso Millet.** To have ample proso millet for destructive sampling and to ensure a preferred phenological millet stage was present for *O. nubilalis* oviposition, large millet plots were planted on three dates between the last week in May and the second week in June. Two 12.2- by 12.2-m plots of proso millet were planted on each date in 1997 and three on each date in 1998.

**Adult Sampling.** On 15, 17, and 22 July 1997, and 8, 10, and 11 July 1998, all adult *O. nubilalis* present in each 12.2- by 12.2-m plot were collected between 1000 and 1200 hours (CST) with a sweep net. Samples from each plot were bagged separately and females were dissected and categorized into reproductive classes: class 1, virgin; class 2, newly mated (spermatophore and ovaries full); class 3, spermatophore and ovaries partially depleted; and class 4, spermatophore and ovaries depleted (Showers et al. 1974).

Night sampling of *O. nubilalis* adults was conducted on 22 and 29 July and on six and 27 August 1997. A 14-m² drop net (Kmec 1996) was thrown over plants in the plot with the highest concentration of egg masses, as determined by egg mass sampling during the day. Collections were alternated between plots with the same planting date every hour from 2200 to 0200 hours (CST), which allowed adults to return to the disturbed area. *O. nubilalis* moths captured under the drop net were put into individual cloth bags and
females were dissected and classified as described above. In 1998, sweep nets were used because maneuverability under the drop net was difficult because of the height of the millet plants. Night sampling was conducted on 9 and 10 July 1998. Twenty pendulum sweeps were taken in each of the nine proso millet plots with a 38 cm sweep net (total area sampled 1.5 m²) every hour from 2230 to 0230 hours (CST). Females were dissected and classified as described above.

O. nubilalis flights from 1995 to 1998 were monitored with a blacklight trap located ∼500 m from the proso millet experimental plots. On the dates when night sampling was successful (22 July 1997 and 9 and 10 July 1998), female moths were removed from the blacklight trap, dissected, and classified as described previously to compare the percentages of each reproductive stage present in the environment to the percentages of each stage found in proso millet.

Egg Mass Sampling. Egg mass sampling was initiated in each planting date when the majority of plants had three or four leaves exposed (Cardenas et al. 1983). In 1997, three 0.09-m² samples per plot were examined weekly for egg masses from 8 July to 29 August. In 1998, four to five 0.09-m² samples were examined in each plot every 2–3 d from 7 July to 25 August. Egg masses were circled with a permanent marker and plants were tagged with survey tape. Egg masses were checked on subsequent dates for visible evidence of predation, parasitism, and desiccation (partially eaten, discolored, or shriveled eggs). In 1998, the mean height of plants with an egg mass was measured and compared with the mean height of other plants in the plot.

Larval Sampling. Millet samples were dissected in 1997 and 1998 to observe instars and numbers of O. nubilalis larvae in proso millet over time. In 1997, three 0.09-m² randomly selected samples were cut from each plot approximately every 10 d from 21 July to 29 August. In 1998, three to five 0.09-m² samples, depending on the date, were taken from each proso millet plot at least twice a week. All samples were bagged separately and plants were examined for O. nubilalis larvae or evidence of injury, as described previously. Larvae were classified to instar as described previously and in 1998, the location of larvae within the stem was noted.

Results

Millet Selection and Planting Date Effects. Millet Selection Studies. In 1995 and 1996, there were significant differences in plant density among treatments for early- and late-planted millet species in North Dakota (1995 early: F = 6.66; df = 3, 15; P = 0.005; 1995 late: F = 13.20; df = 3, 15; P = 0.001; 1996 early: F = 36.07; df = 3, 15; P = 0.0001; 1996 late: F = 6.33; df = 3, 15; P = 0.014; Table 1). German and Siberian foxtail millets had the greatest plant densities followed by proso and pearl millet, respectively. In New York, Siberian foxtail had significantly greater plant densities than proso or pearl millet (Table 2).

Early- and late-planted proso millet in 1995 had a significantly higher percentage of plants with injury than the other three early-planted millet species (early: F = 11.77; df = 3, 15; P = 0.002; late: F = 11.48; df = 3, 15; P = 0.002; Table 1). The 1996 late-planted proso millet had a significantly higher percentage of plants with injury than the other three millet species (F = 19.65; df = 3, 15; P = 0.001; Table 1). Early-planted proso millet in 1996 had the highest percentage of plants with injury, significantly higher than Siberian and German foxtail, but not significantly higher than pearl millet (F = 6.78; df = 3, 15; P = 0.011; Table 1). In New York, proso millet had a significantly higher percentage of plants with injury for all plantings (F = 13.41; df = 8, 26; P = 0.0001; Table 2). Comparing the New York early and mid-plantings to the North Dakota early and late plantings, results were consistent. Although O. nubilalis leaf feeding and stem boring were consistently observed in New York, few egg masses were located.

There were significant differences in larval densities among treatments for 1995 early-planted millet spe-
In North Dakota, there were no significant differences in number of adults flushed among treatments on any sampling date (Table 3). On 20 July 1995, *O. nubilalis* moths were flushed from all four millet types; however, on 28 July 1995, adults were only flushed from German and Siberian foxtail. In 1996, adults were only flushed from the early-planted German foxtail millet (Table 3). In New York, significantly greater numbers of moths, 5–20 times more, were flushed from early and mid planted Siberian than proso or pearl millet (*F* = 9.06; *df* = 2, 132; *P* = 0.0002; Table 3).

**Effects of Planting Date in Proso Millet.** There were significant differences in plant densities among planting date treatments in 1997 (*F* = 7.65; *df* = 3, 15; *P* = 0.006), but not in 1998 (*F* = 2.11, *df* = 3, 15; *P* = 0.152; Table 4). There were no significant differences in percentage of proso millet plants with injury in 1997 (*F* = 2.84; *df* = 3, 15; *P* = 0.082) but there were significant differences in 1998 (*F* = 11.10; *df* = 3, 15; *P* = 0.001; Table 4). There were significant differences in the mean larval density in 1997 (*F* = 5.18; *df* = 3, 15; *P* = 0.016) and 1998 (*F* = 4.21; *df* = 3, 15; *P* = 0.030; Table 4). An increasing percentage of plants with injury and increasing larval density with later planting dates was observed in 1997 (Table 4). The trend in 1998 was an increasing percentage of plants with injury and increasing larval density with earlier planting dates (Table 4).

In 1997, second through fifth instars and pupae were recovered from proso millet (Table 5). Only second

### Table 2. Mean (± SE) Plant density (no. of millet plants/m²), percentage of plants with injury per m², and larval density (no. of *O. nubilalis* larvae/m²) in three millet species planted on three dates, Freeville, NY, 1999

<table>
<thead>
<tr>
<th>Millet types</th>
<th>Plant density (Early)</th>
<th>Plant density (Mid)</th>
<th>Plant density (Late)</th>
<th>Percentage of plants with injury (Early)</th>
<th>Percentage of plants with injury (Mid)</th>
<th>Percentage of plants with injury (Late)</th>
<th>Larval density (Early)</th>
<th>Larval density (Mid)</th>
<th>Larval density (Late)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proso</td>
<td>102.5 ± 5.7b</td>
<td>87.0 ± 12.1b</td>
<td>220.0 ± 27.7b</td>
<td>22.2 ± 5.5a</td>
<td>41.2 ± 5.5a</td>
<td>19.0 ± 5.5a</td>
<td>22.8 ± 5.1a</td>
<td>35.7 ± 9.1a</td>
<td>41.5 ± 17.1a</td>
</tr>
<tr>
<td>Pearl</td>
<td>91.5 ± 12.7b</td>
<td>110.0 ± 18.5b</td>
<td>114.0 ± 12.7c</td>
<td>1.5 ± 0.5b</td>
<td>1.2 ± 0.5b</td>
<td>1.3 ± 0.5b</td>
<td>1.4 ± 0.5b</td>
<td>1.3 ± 0.7b</td>
<td>1.5 ± 0.9b</td>
</tr>
<tr>
<td>Siberian foxtail</td>
<td>210.5 ± 26.4a</td>
<td>271.9 ± 26.4a</td>
<td>289.5 ± 46.8a</td>
<td>5.4 ± 1.9b</td>
<td>2.3 ± 1.0b</td>
<td>2.1 ± 1.1b</td>
<td>11.4 ± 3.8b</td>
<td>6.2 ± 2.1b</td>
<td>6.3 ± 2.3b</td>
</tr>
</tbody>
</table>

Means within a column followed by the same letter are not significantly different (ANOVA, *P* ≤ 0.05; LSD, *P* = 0.05).

### Table 3. Mean number (± SE) of *O. nubilalis* moths per 10 square meters for four millets in North Dakota, 1995–1996, and three millets in New York, 1999

<table>
<thead>
<tr>
<th>Treatment*</th>
<th>Proso</th>
<th>Pearl</th>
<th>Siberian foxtail</th>
<th>German foxtail</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early planted/NY/1 date</td>
<td>0.0 ± 0.0a</td>
<td>0.0 ± 0.0a</td>
<td>0.5 ± 0.3a</td>
<td>0.8 ± 0.5a</td>
<td>0.088</td>
</tr>
<tr>
<td>Late planted/NY/1 date</td>
<td>1.0 ± 0.4a</td>
<td>1.5 ± 0.9a</td>
<td>1.3 ± 0.3a</td>
<td>1.8 ± 1.1a</td>
<td>0.915</td>
</tr>
<tr>
<td>Early planted/NY/2 date</td>
<td>0.0 ± 0.0a</td>
<td>0.0 ± 0.0a</td>
<td>0.3 ± 0.3a</td>
<td>0.0 ± 0.0a</td>
<td>0.436</td>
</tr>
<tr>
<td>Late planted/NY/2 date</td>
<td>0.0 ± 0.0a</td>
<td>0.0 ± 0.0a</td>
<td>0.0 ± 0.0a</td>
<td>0.3 ± 0.3a</td>
<td>0.436</td>
</tr>
<tr>
<td>Early planted/NY/3 date</td>
<td>0.0 ± 0.0a</td>
<td>0.0 ± 0.0a</td>
<td>0.0 ± 0.0a</td>
<td>0.0 ± 0.0a</td>
<td>—</td>
</tr>
<tr>
<td>Late planted/NY/3 date</td>
<td>0.3 ± 0.18a</td>
<td>0.20 ± 0.11a</td>
<td>1.06 ± 0.31b</td>
<td>NA</td>
<td>0.0002</td>
</tr>
<tr>
<td>Mid planted/NY/4 date</td>
<td>0.07 ± 0.07a</td>
<td>0.33 ± 0.16a</td>
<td>1.44 ± 0.34b</td>
<td>NA</td>
<td>0.0002</td>
</tr>
<tr>
<td>Late planted/NY/4 dates</td>
<td>0.00 ± 0.00a</td>
<td>0.17 ± 0.05a</td>
<td>0.11 ± 0.08a</td>
<td>NA</td>
<td>0.0002</td>
</tr>
</tbody>
</table>

*NA, not applicable. German foxtail was not tested at the New York site.*

New York means within a column and row followed by the same letter are not significantly different (ANOVA, *P* ≤ 0.05; LSD, *P* = 0.05). Interaction term millet × planting date, *P* = 0.0312. North Dakota means within a row followed by the same letter are not significantly different (ANOVA, *P* ≤ 0.05; LSD, *P* = 0.05).

*Time of planting/state conducted/sampling date (ND date 1, 20 July 1995; ND date 2, 28 July 1995; ND date 3, 24 July 1996; NY 4 dates, mean over 4 dates, 19 and 25 July and 3 and 9 August 1999).*
and third instars were recovered from the first planting date. All instars were recovered from the second, third, and fourth planting dates. Pupae were only recovered from the third planting date. In 1998, third, fourth, and fifth instars and pupae were recovered from proso millet (Table 5). All four of these developmental stages were recovered from the first planting date. Fourth and fifth instars, and pupae were recovered from the second planting date. All three of the instars were recovered from the third planting date. Only fourth and fifth instars were recovered from the fourth planting date.

### Population Sampling in Proso Millet

#### Adult Sampling
In 1997 and 1998, all four developmental stages of adult female *O. nubilalis* were captured. On each date that adults were sampled during the day in 1997 and 1998, at least 60% of females captured were either class 1 or 2 (virgin or newly mated) (Fig. 1).

#### Larval Sampling
Pupae were only recovered from the third planting date. In 1998, third, fourth, and fifth instars and pupae were recovered from proso millet (Table 5). All four of these developmental stages were recovered from the first planting date. Fourth and fifth instars, and pupae were recovered from the second planting date. All three of the instars were recovered from the third planting date. Only fourth and fifth instars were recovered from the fourth planting date.

#### Table 4. Mean (± SE) plant density (no. of proso millet plants/m²), percentage of proso millet plants with injury per m², and larval density (no. of *O. nubilalis* larvae/m²), Carrington, ND, 1997–1998

<table>
<thead>
<tr>
<th>Planting date</th>
<th>Plant density</th>
<th>Percentage of plants with injury/m²</th>
<th>Larval density</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>180.0 ± 13.9a</td>
<td>261.5 ± 31.6a</td>
<td>1.0 ± 1.0a</td>
</tr>
<tr>
<td>2</td>
<td>200.3 ± 13.9a</td>
<td>206.3 ± 8.3a</td>
<td>33.0 ± 8.5a</td>
</tr>
<tr>
<td>3</td>
<td>120.0 ± 6.1c</td>
<td>274.0 ± 10.4a</td>
<td>35.0 ± 14.4a</td>
</tr>
<tr>
<td>4</td>
<td>148.3 ± 17.0bc</td>
<td>303.5 ± 44.3a</td>
<td>44.0 ± 14.7a</td>
</tr>
</tbody>
</table>

Means within a column followed by the same letter are not significantly different (ANOVA, P ≤ 0.05; LSD, P = 0.05).

#### Table 5. Number of each *O. nubilalis* developmental stage found in four proso millet planting dates in late August, Carrington, ND, 1997–1998

<table>
<thead>
<tr>
<th>Year</th>
<th>Planting date</th>
<th>2nd instars</th>
<th>3rd instars</th>
<th>4th instars</th>
<th>5th instars</th>
<th>Pupae</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>5</td>
<td>30</td>
<td>17</td>
<td>2</td>
<td>0</td>
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<tr>
<td></td>
<td>3</td>
<td>1</td>
<td>29</td>
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*Planting date 1, 27 May; 2, 6 June; 3, 16 June; 4, 25 June.*

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**Fig. 1.** Percentage of each reproductive status of female *O. nubilalis* adults captured during daytime sampling, Carrington, ND, 1997 and 1998. Class 1, virgin female; class 2, newly mated; class 3, spermatophore and eggs partially depleted; and class 4, spermatophore and ovaries fully depleted.
samples from the same two nights showed all four classes of females (Fig. 2). On 9 July 1998, 35% of females in the blacklight trap were class 1 or two and on 10 July 25% of females in the blacklight trap were class 1 or two (Fig. 2).

**Egg Mass Sampling.** In 1997, 17 egg masses were found in proso millet (Fig. 3). Nine were found in 1998 (Fig. 3). They were found between 15 and 21 July 1997 and eight and 11 July 1998. Oviposition appeared to peak ≈17 July 1997 and ≈10 July 1998. No egg masses were found in proso millet after 21 July 1997 and 11 July 1998. No evidence of egg predation, parasitism, or desiccation was observed either year.

In 1997, 21% of plants that had an egg mass were in stage 1.0 of development (seedling stage; Cardenas et al. 1983). Another 21% of plants that had an egg mass

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**Fig. 2.** Percentage of each reproductive status of female *O. nubilalis* adults captured during night sampling and in a blacklight trap, Carrington, ND, 1997 and 1998. Class 1, virgin female; class 2, newly mated; class 3, spermatophore and eggs partially depleted; and class 4, spermatophore and eggs fully depleted.

**Fig. 3.** Number of egg masses collected in Proso millet and estimates of the first generation biovolteine egg-laying period, Carrington, ND, 1997–1998.
were in stage 2.0 (tillering and growing point initiation). Twenty-nine percent of plants that had an egg mass were in stage 2.5 (panicle development). The remaining 29% of plants with an egg mass were in stage 3.0 (flag-leaf stage). In 1997, 20% of egg masses were on plants that were less than average height, 70% on plants of average height, and the remaining 10% on plants taller than average.

In 1998, 57% of plants that had an egg mass were in stage 1.0, 29% were in stage 2.0, and 14% were in stage 2.5 (Cardenas et al. 1983). In 1999, the average height of plants with an egg mass was 35 cm. The average height of other plants within the plots was 39.7 cm. With only one exception, each plant with an egg mass was either average height or shorter than other plants in the plot.

**Larval Sampling.** Results from 1997 and 1998 larval sampling support those from the 1997 and 1998 planting date studies, showing reversed trends of increased infestation levels with later planting in 1997 and increased infestation with earlier planting in 1998. In 1998, 17% of first instars recovered from proso millet were found on the stem and 83% were found in a leaf axis (n = 6). Of the second instars recovered, 74% were in the stem, 7% were on the stem, 7% were on a leaf, and 12% were in a leaf axis (n = 68). Ninety-eight percent of third instars recovered in 1998 were found in the stem, 1.4% were on the stem, and 0.6% were on a leaf (n = 147). All fourth and fifth instars were found in the stem (n = 185 and 28, respectively).

**Discussion**

In the millet selection studies, a strong preference for proso millet by *O. nubilalis* was observed. Proso millet was highly infested with *O. nubilalis* compared with other millet species. These high infestation levels warrant concern that *O. nubilalis* could become a serious pest on proso millet. They also indicate that proso millet has potential for use as a trap crop or refuge insofar as it contained high numbers of *O. nubilalis* larvae. The presence of varying *O. nubilalis* developmental stages in millet samples probably represents the presence of more than one ecotype. Proso millet, each planting date for both years, contained the widest distribution of *O. nubilalis* instars; therefore, it appeared to attract both ecotypes present in the northern Great Plains. Attracting all ecotypes present in an area is another favorable quality of a potential trap crop or refuge.

In New York, Siberian millet had significantly greater numbers of adults flushed, whereas in North Dakota, most moths were flushed from either Siberian or German foxtail millet. These two millets appeared to serve as better aggregation sites for *O. nubilalis* adults compared with the other millet species. Hellmich et al. (1998) showed a positive correlation between canopy area (a measure of density) and adult *O. nubilalis* aggregation in stands of dense oat (*Avena* spp.) and standard planted oats. Siberian and German foxtail millets did have greater plant densities so there may be a similar relationship in millet, with more densely planted millets attracting greater numbers of *O. nubilalis* adults. However, the foxtail millets tested did not contain high numbers of larvae or injury at the end of the season. Adults aggregated and possibly mated in densely planted foxtail millet during the day; however, oviposition or larval survival appeared to be low in these millets. Proso millet contained some aggregating adults and also contained several times more larvae at the end of the season than the foxtail millets, indicating a higher rate of oviposition by *O. nubilalis* or higher survival of larvae. In addition to manipulating plant density to alter aggregation behavior in millet, combining different types of millet may create an environment that is conducive to both aggregation and oviposition.

In corn, females prefer tall corn (early-planted) for oviposition (Neiswander and Huber 1929, Hervey and Hartzell 1932, Patch 1942, Beard 1943, Everly 1959, Chiang and Hodson 1963). Therefore, it could be hypothesized that early-planted proso millet may attract the most ovipositing *O. nubilalis*, and consequently, have higher infestation levels. In 1998, a trend of increasing infestation with earlier planting date was seen. The opposite trend was seen in 1997. For the earliest planting date in 1997 (27 May) plants were stunted and yellow because of low moisture early in the season and a high weed infestation. These plant conditions were probably the cause of low infestation levels in the first planting date. For the remaining three planting dates (6, 16, and 25 June 1997), a trend of increasing infestation with later planting dates was indicated. It is uncertain why the trend in infestation changed between years, but it is probably a result of differences in the respective growing seasons and subsequent differences in the *O. nubilalis* flights. Because of cool weather in the spring and fall of 1997, the growing season was compressed. In 1998, insect degree-days started accumulating 23 d earlier; consequently, adult *O. nubilalis* began emerging 5 d earlier and each flight peak occurred approximately a week earlier than in 1997. Differences in timing of adult emergence and available stages of millet are probably the cause of differences between years.

The larval sampling of *O. nubilalis* in proso millet at the end of the season as well as throughout the season may indicate which ecotypes oviposited on each planting date. Sampling suggested that late-planted proso millet (25 June) might not attract sufficient bivoltine individuals to be an effective trap crop or refuge. Planting proso millet between late May and mid-June (planting dates 1–3) may maximize the number of individuals from both *O. nubilalis* ecotypes present in the northern Great Plains.

Daytime adult sampling from both years confirmed young, as well as old, females were using proso millet as an aggregation site. A trap crop should attract young females, those who have not yet laid all their eggs, to effectively reduce the population after the application of a chemical or biological agent. Attracting young *O. nubilalis* to a common aggregation site may increase the likelihood of random mating between resistant
and susceptible individuals, which is essential for resistance management.

The 1997 night sampling was inconclusive. When repeated in 1998, all the adult females captured in proso millet were old, either class 3 or four (spermatophore and ovaries partially or fully depleted). Captures from a nearby blacklight trap for the same nights showed all four reproductive classes were present, but not all classes were present in the proso millet during peak ovipositional hours. It appeared that both old and young females aggregated in proso millet during the day; however, at night, young females moved out of millet to oviposit, whereas old females remained in millet. The age of the females ovipositing in proso millet could affect its use as a refuge, especially if progeny from old females are less fit or asynchronous with progeny from younger females ovipositing in corn.

In corn, the average egg-laying period for *O. nubilalis* is ≈20 d (Calvin 1985). Oviposition in corn starts when the first females are collected in a nearby blacklight trap or 3 d before egg mass detection in the field (Calvin 1985). On 14 June 1997, the first females were collected in the blacklight trap, which gave a projected end to the oviposition period 20 d later, ≈3 July (Fig. 3). Egg masses were first detected on proso millet on 15 July; therefore, it is unlikely that they were laid by first-generation bivoltine *O. nubilalis* (Fig. 3). The same phenomenon was seen in 1998 (Fig. 3). However, in the larval sampling in late August 1998, pupae were found in proso millet, indicating the presence of first-generation bivoltine *O. nubilalis*. First-generation bivoltine females may have oviposited in proso millet, but at levels that were not detectable by egg mass sampling. Egg mass detection in proso millet may be more difficult than in corn. Perhaps oviposition began >3 d before first detection in the field. Data from North Dakota and New York showed large infestations of larvae in proso millet at the end of the season, yet few egg masses were detected early in the season. These data support the hypothesis that egg masses may be more difficult to detect or that survival of larvae could be higher in proso millet than it is in corn.

Oviposition on proso millet was observed for a 7-d period in 1997 and a 4-d period in 1998. *O. nubilalis* may not use proso millet for oviposition for the entire 20-d egg-laying period or the difficulty in detecting egg masses may make the oviposition period appear to be shorter in proso millet. The phenology data from the egg mass sampling did not show an ovipositional preference for a particular stage of millet or for increased plant height.

In corn, larvae normally do not bore into the stem until the third instar. In proso millet, 74% of second instars were found in the stem. The ability to bore into the stem earlier may provide protection and increase larval survival in proso millet. The location of third, fourth, and fifth instars in proso millet was similar to that in corn (Mason et al. 1996). In North Dakota, on average, 30% of the proso millet stems had entry/exit holes but no larvae. Because of a smaller diameter, late instars may need to move between millet plants more frequently to acquire adequate nutrients to complete development. Increased movement between plants may lead to increased mortality. Depending on how a millet refuge is planted, it also may increase the chances of late instars moving into Bt corn, where they would be subjected to a sublethal dose of Bt, and potentially confer resistance to subsequent generations. This scenario could be detrimental to a resistance management program.

Among the millets tested, proso millet showed the highest consistent larval infestation and presence of all *O. nubilalis* ecotypes. With high infestation levels, *O. nubilalis* has a strong potential to become a major pest on proso millet. Although German and Siberian foxtail millets appeared to serve as better aggregation sites for *O. nubilalis* adults, proso millet also was used for aggregation to some degree. Planting proso millet between late May and mid-June appeared to maximize the number of individuals from both ecotypes present in the northern Great Plains. Altering the plant density of proso millet also may affect the level of infestation and aggregation by *O. nubilalis*. The possibility of using combinations of different types of millet to maximize aggregation and oviposition should be considered if proso millet is to be used as a trap crop or refuge. Questions remain about the fitness of *O. nubilalis* developing on proso millet and the movement of larvae in millet; however, if these questions can be resolved, proso millet may be able to serve as an effective, low-input refuge or trap crop.

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