# Effect of Greenbugs (Homoptera: Aphididae) on Yield Loss of Winter Wheat

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**ABSTRACT** The effect of greenbug, *Schizaphis graminum* (Rondani), feeding on the yield of four winter wheat cultivars commonly grown in Oklahoma was studied. Cultivars tested were 'Karl', a recent derivative 'Karl-92', and '2163', all greenbug-susceptible cultivars; and 'TAM-110', a cultivar with resistance to biotype E greenbugs. The objectives were to determine the effect of different greenbug densities during fall and spring on yield of winter wheat, and to develop mathematical models to quantify the effect of greenbugs on yield loss. The intensity of greenbug infestations achieved in plots by artificial infestation varied among years and growing seasons within a year, but was generally sufficient to cause a reduction in yield. Among yield components, the number of heads per square meter and the number of seeds per head were frequently negatively correlated with the accumulated number of greenbug-days per tiller. Seed weight was rarely affected by greenbug infestation. A regression model estimated yield loss for greenbug-susceptible cultivars at 0.51 kg/ha loss of yield per greenbug-day in years with near normal precipitation, and a loss of 1.17 kg/ha under severe drought conditions. The susceptible winter wheat cultivars exhibited similar yield loss in relation to the intensity of greenbug infestation, as indicated by a common slope parameter in the regression model. Results suggest that the model is robust for predicting yield loss for susceptible cultivars.

**KEY WORDS** *Schizaphis graminum, Triticum aestivum,* economic injury, economic threshold

OVER 2.2 MILLION ha of winter wheat, *Triticum aestivum,* are planted annually in Oklahoma. The greenbug, *Schizaphis graminum* (Rondani), is the most important insect pest of winter wheat in Oklahoma and is often the most significant factor limiting profitable winter wheat production (Starks and Burton 1977, Webster 1995). When greenbugs reach high numbers, which may occur during fall, but more frequently during late winter or early spring, they can kill plants or inhibit plant growth, thus reducing yields and net returns (Burton et al. 1985, Royer et al. 1997). Annual losses in winter wheat in Oklahoma from greenbugs vary from $0.5 to $135 million (Webster 1995).

Current recommendations for greenbug control in Oklahoma involve counting the number of greenbugs per 0.3 m of row, and treating the winter wheat field with an insecticide if there are 25–50 greenbugs per 0.3 m of row in seedling wheat, 100–300 per 0.3 m in wheat 7.5–15.0 cm tall, 200–400 per 0.3 m in wheat 10.0–20.0 cm tall, and 300–800 per 0.3 m in wheat 20.0–40.0 cm tall (Royer et al. 1997). These nominal threshold ranges are ambiguous with respect to what actually constitutes a damaging population. For example, there is no consideration of the number of wheat plants contained in 0.3 m of row. Thus, the threshold does not consider the number of greenbugs in relation to the biological unit that suffers damage as a direct result of greenbug feeding.

Sampling methods for greenbugs in Oklahoma involve estimating the number of greenbugs per tiller (Royer et al. 1997), an easily measured quantity that is related to the number of plants per unit area. Thus, economic injury levels based on this plant unit are desirable for use in integrated pest management (IPM) programs. A related issue in developing economic injury levels for the greenbug in Oklahoma is simultaneous consideration of yield loss, price of wheat, and cost of insecticide application. These factors are not considered in current recommendations. Also, numerous factors that are known to affect the level of injury to winter wheat caused by greenbugs are not considered in current thresholds. For example, injury varies depending on the density and feeding duration of greenbugs, and the growth stage of the crop (Wood and Henderson 1965, Pike and Schaffner 1985, Burton et al. 1985, Kieckhefer and Kantack 1988). Plant growth stage is only crudely accounted

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for in current thresholds. Further research is needed to define economic injury levels for greenbugs on winter wheat in Oklahoma.

Previous studies to determine yield loss of winter wheat caused by greenbug infestation (Dahms and Wood 1957, Ortman and Painter 1960, Harvey and Wilson 1962, Wood and Henderson 1965, Burton et al. 1985) do not provide sufficient information from which to determine economic injury levels for the greenbug. However, these studies suggest ways to efficiently approach the problem of developing economic injury levels that will be applicable for several wheat cultivars with varying levels of resistance to damage caused by greenbugs. First, all wheat cultivars that have been investigated appear to show a greater loss in yield from feeding during fall than they do for similar levels of greenbug feeding in spring (Burton et al. 1985, Kieckhefer and Kantack 1988). Second, greenbug infestations that establish at jointing or later stages of plant growth appear to have minimal impact on wheat yield (Dahms and Wood 1957, Wood and Henderson 1965, Burton et al. 1985, Kieckhefer and Kantack 1988). Therefore, it is reasonable to focus two periods during the winter wheat growing season: autumn, after plants have emerged but before winter freeze; and late winter through spring, from wheat regrowth to head emergence.

We studied the effects of greenbug feeding on the yield of winter wheat cultivars commonly grown in Oklahoma: 'Karl', a recent derivative 'Karl-92', and '2163' (all greenbug susceptible cultivars), and 'TAM-110' a greenbug-resistant cultivar. The objectives were to determine the extent to which greenbugs reduced yield of these wheat cultivars in response to an infestation that occurred during fall or during late winter to early spring; and to develop models which quantify the effect of greenbugs on yield loss for fall and spring infested wheat.

## Materials and Methods

The study was repeated for 4 yr in a field located 7.5 km west of Stillwater, OK. Each year, a 0.4-ha planting of Karl (1994) or Karl-92 (1996, 1997, and 1998) winter wheat was made during the recommended planting interval (October 1–15) for central Oklahoma (Cuperus et al. 1985). In 1997, an identical planting of the greenbug resistant cultivar 'TAM-110' was made, and in 1998, a planting of the susceptible cultivar 2163 was made. Wheat was planted at a rate of 67 kg/ha in rows spaced 17.8 cm apart. Fertilizer requirements were based on soil tests for available nitrogen made each year before planting. Enough 20-10-10 (N-P-K) fertilizer was applied before planting to bring available nitrogen to sufficient level to achieve a yield potential of 5,400 kg/ha. Forty experimental units (1 by 1-m plots) were established in four rows (10 plots per row) within each planting. All plots were sprayed with malathion insecticide (1.1 kg/ha (AI)) 7–10 d before infesting with greenbugs.

A colony of biotype-E greenbugs was used to infest plots. These greenbugs were reared in a greenhouse on seedling wheat plants (≈20 seedlings per pot) grown in a mixture of fritted clay and peat moss (3:1 ratio) in plastic pots (15 cm diameter). The greenbug infestation period (fall or spring) and infestation intensity were randomly assigned to plots. Two greenbug infestation time-interval treatments were assigned to each of 20 plots: (1) plots infested with greenbugs in fall when wheat was in the three- to four-leaf growth stage [growth stage 1.4–1.5 (Zadoks et al. 1974)], with greenbug infestations allowed to grow until freeze, after which plants were kept free of greenbugs; and (2) plots infested with greenbugs in late-winter during tillering (growth stage 2.1–2.2), with greenbug infestations allowed to persist until plants headed (growth stage 5.0), after which plants were kept free of aphids. To achieve a range of greenbug densities within each infestation time-interval treatment, five infestation intensity treatments were established within each infestation time-interval treatment (four plots per infestation size treatment): (1) no greenbugs (uninfested); (2) greenbugs from approximately one-half of the foliage from a pot of heavily infested wheat seedlings; (3) greenbugs from one pot of heavily infested wheat seedlings; (4) greenbugs from two pots of heavily infested wheat seedlings; and (5) greenbugs from four pots of heavily infested wheat seedlings. Using this approach, we were usually able to achieve a wide range in greenbug infestation levels. However, in some cases, mainly due to untimely rainfall, it was necessary to further manipulate greenbug infestations in plots to obtain an appropriate range of infestation levels. When this was necessary, plots were infested with greenbugs a second, and sometimes a third, time to try to produce an appropriate range of greenbug densities.

Greenbug infestations in plots were sampled at 10- to 14-d intervals starting ≈7 d after the initial infestation and contining throughout the designated time interval. Each time the greenbugs in a plot were sampled, 10 randomly selected tillers were carefully cut at ground level, placed in a labeled paper bag, and returned to the laboratory where the greenbugs were counted. Uninfested plants were kept free of greenbugs by periodically treating them with malathion at the above-mentioned rate.

When the grain crop ripened, yield samples were taken from each 1-m$^2$ plot by dividing the area within the plot into four quadrants and clipping all tillers (standing and lodged) in a 0.3-m section of row per quadrant. An additional 0.3-m section of row was cut from near the center of the plot. Tillers from each 0.3-m section of row were placed in a labeled paper bag and returned to the laboratory. Each 0.3-m subsample was hand threshed and the number of heads, number of sterile heads, number of seeds per head, seed weight, and yield were measured and recorded. Yield for the plot was estimated as the average yield for the five subsamples, and was transformed to units of kg/ha.

Greenbug-days (Kieckhefer et al. 1994) over the growing season (a measure that integrates greenbug density and the duration of an infestation) were cal-

Table 1. Range of values of greenbug-days and maximum number of greenbugs per tiller in 1-m$^2$ plots of winter wheat infested with several levels of greenbugs during fall or spring of four growing seasons, and correlations of maximum number of greenbugs per tiller with greenbug-days

| Growing season | Cultivar | Fall infestation | | | Spring infestation | | |
|---|---|---|---|---|---|---|---|
| | | Max greenbugs | Greenbug-days | *r* | Max greenbugs | Greenbug-days | *r* |
| 1993–94 | Karl | 0.7–13.4 | 26–1554 | 0.82 | 0–8.8 | 0–365 | 0.97 |
| 1995–96 | Karl-92 | 0–43.0 | 0–1711 | 0.98 | 0.1–13.8 | 4–431 | 0.93 |
| 1996–97 | Karl-92 | 0–5.7 | 0–104 | 0.96 | 0–40.9 | 0–774 | 0.99 |
| | TAM-110 | 0–3.3 | 0–60 | 0.92 | 0–70.0 | 0–1318 | 0.98 |
| 1997–98 | Karl-92 | 0.1–34.8 | 1–3414 | 0.76 | 0–95.3 | 0–2240 | 0.99 |
| | 2163 | 0–40.0 | 0–1406 | 0.96 | 0–84.9 | 0–2077 | 0.99 |

culated for each plot using a Fortran program. The program for calculating greenbug-days was written in Digital Visual Fortran 6.0. The program estimated the area under the observed time series curve of greenbug infestation per plot by fitting an interpolation polynomial to the time series using the Lagrangian method and calculating the area under the resulting polynomial using the trapezoidal method (Bixel 1986).

Linear least squares regression was used to relate yield loss to cumulative greenbug-days for fall and spring infestations each year. This was accomplished by constructing a heterogeneity of slopes regression model (Neter and Wasserman 1974) to relate yield loss and greenbug-days for fall and spring infestations each year. The heterogeneity of slopes model had the form:

$$\text{yield (kg/ha)} = a_i + b_i \cdot \text{greenbug days/tiller}, \quad [1]$$

where the intercept, $a_i$, represents wheat yield in the absence of greenbugs for a particular cultivar infested during a particular growing season and year (designated by the subscript $i$), and the slope, $b_i$, represents the corresponding reduction in yield caused by greenbugs. After fitting the heterogeneity of slopes model, *F*-tests that particular regression coefficients equaled zero were constructed using a general linear test procedure (Neter and Wasserman 1974) to search for a parsimonious yield loss model. All statistical analyses were accomplished using appropriate procedures from the Statistical Analysis System (SAS Institute 1996).

## Results and Discussion

**Greenbug Infestations.** The intensity of greenbug infestations achieved in plots by artificial infestation varied among years and growing seasons within a year. For example, greenbug-days per wheat tiller ranged from 26 to over 1,554 in Karl wheat during fall of 1994, but from 0 to only 365 greenbug-days per tiller in the spring of 1994 (Table 1). The maximum number of greenbugs per tiller was similarly variable among years and seasons. Reasons for the variable success in achieving high, sustained greenbug infestations were not determined but probably included variation in rainfall and cold weather among seasons and years. The maximum number of greenbugs per tiller was highly correlated with greenbug-days in every case, ranging from 0.76 for Karl-92 in fall of 1998 to 0.99 in Karl-92 in spring of 1997 (Table 1); this indicates that if greenbug-days or the maximum number of greenbugs per tiller is correlated with yield, both variables will be correlated with yield.

**Effect of Greenbugs on Yield.** In spite of the variable success in establishing a consistently broad range of greenbug infestations, we were able to achieve a broad enough range of infestation levels among plots in most cases to observe a reduction in yield of winter wheat compared with plots without greenbugs (Figs. 1 and 2). Correlations of yield components with greenbug-days and the maximum number of greenbugs per tiller were frequently significant, but correlations of yield with greenbug-days were usually greater in magnitude and more frequently significant than correlations with the maximum number of greenbugs per tiller (not shown). Therefore, we present only analyses comparing yield to greenbug-days.

Yield components and yield of winter wheat were generally negatively correlated with greenbug-days, but correlations were not always significant (Table 2). For the greenbug-susceptible cultivars Karl, Karl-92, and 2163, correlations of yield with greenbug-days were significant in all cases in which infestations of $\approx$400 greenbug-days or more were achieved in the most heavily infested plots. Among yield components, the number of heads per 0.3 m was usually negatively correlated with greenbug-days, and was most frequently correlated with greenbug-days among components measured, with a total of 5 out of 10 possible correlations significant. The number of seeds per head was also negatively correlated with greenbug-days, with 3 out of 10 correlations significant. Seed weight was the least frequently affected yield component with only one significant correlation. Our results are consistent with those of Kieckhefer et al. (1994) in spring wheat in that head formation and the number of seeds per head most frequently suffered declines due to greenbug infestation, whereas seed weight was less frequently affected. Our results and those of Kieckhefer et al. (1994) suggest that reduced seed weight is not the main cause of reduced yields associated with greenbug damage, and that reduced tillering and seed number are more likely to contribute to reduced yields. As suggested by Kieckhefer et al. (1994), this may occur because the number of heads per plant and the number of seeds per head are de-

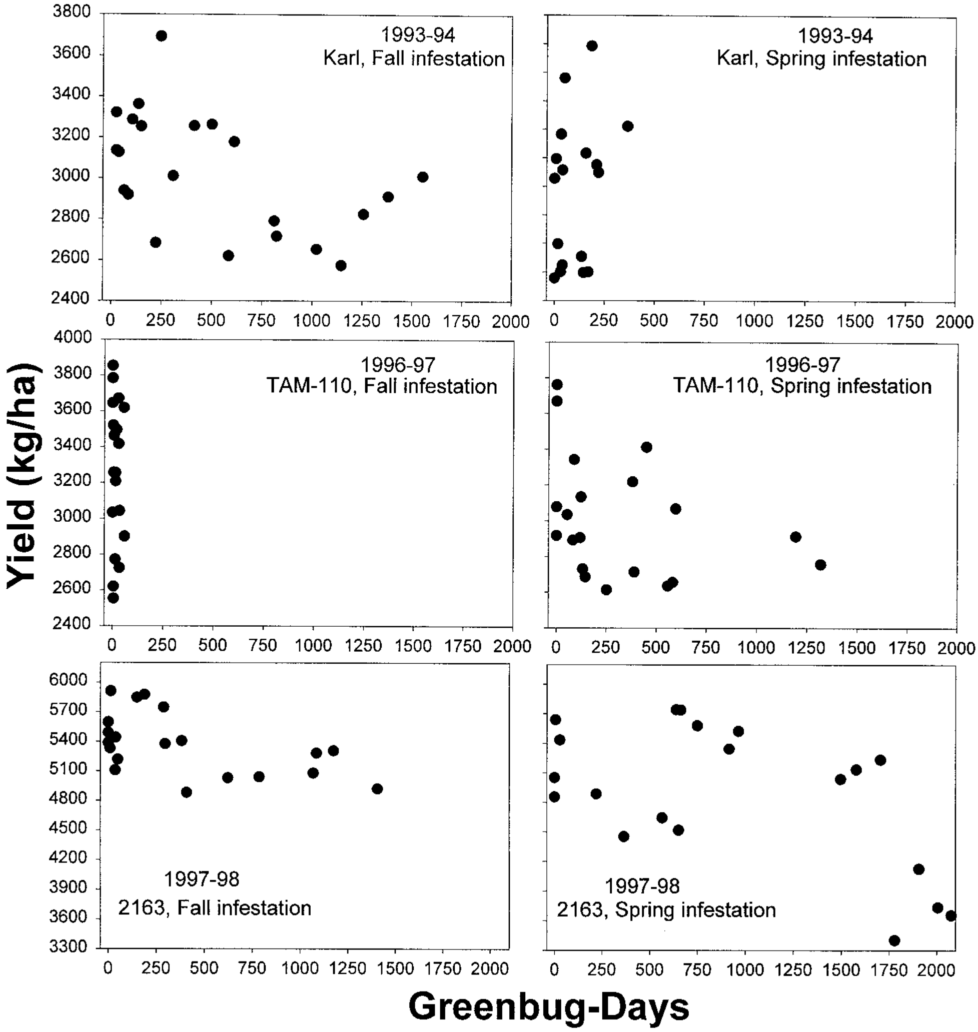


**Fig. 1.** Relationship between yield and greenbug-days for Karl, Tam-110, and 2163 winter wheat cultivars.

termined by anthesis, whereas seed weight is determined primarily after anthesis (Teng and Gaunt 1980), by which time greenbug infestations have usually disappeared. However, Burton et al. (1985), in a study conducted during a single growing season, found that all yield components were reduced by greenbug infestations. The physiological and structural damage to wheat plants caused by greenbug feeding, which persists after greenbugs are gone (Al-Mousawi et al. 1983), may be responsible for the reduced seed weight sometimes observed, even though greenbugs typically are absent from plants by the grain-filling stage.

For the greenbug-resistant cultivar, TAM-110, which was included in the study only in the 1996–1997 growing season, neither yield nor any yield component was correlated with greenbug-days, nor was there a correlation between yield and greenbug-days. In fall 1996, we were unable to achieve high enough greenbug infestations to expect to observe an effect on yield, but the lack of a significant correlation with yield of 'TAM-110' for spring infestations in 1997, when a broad range of infestations was achieved, is consistent with the contention that this cultivar can sustain higher greenbug infestations with less loss of yield than greenbug-susceptible cultivars such as Karl-92 for which yield was significantly negatively correlated with greenbug-days during spring 1997 (Table 2).

**Yield Loss Model.** Yield appeared to decrease linearly as greenbug-days increased for trials in which 400 or more greenbug-days accumulated even though it was quite variable in many cases (Figs. 1 and 2). We constructed a heterogeneity of slopes linear regression model based on equation 1 to relate yield to greenbug-days. We did not include data for TAM-110 in developing the model because its yield response to greenbug infestation appeared different from that of susceptible cultivars, and we did not feel that data were sufficient to develop a useful model for TAM-110 individually (Table 2). In constructing the heteroge-

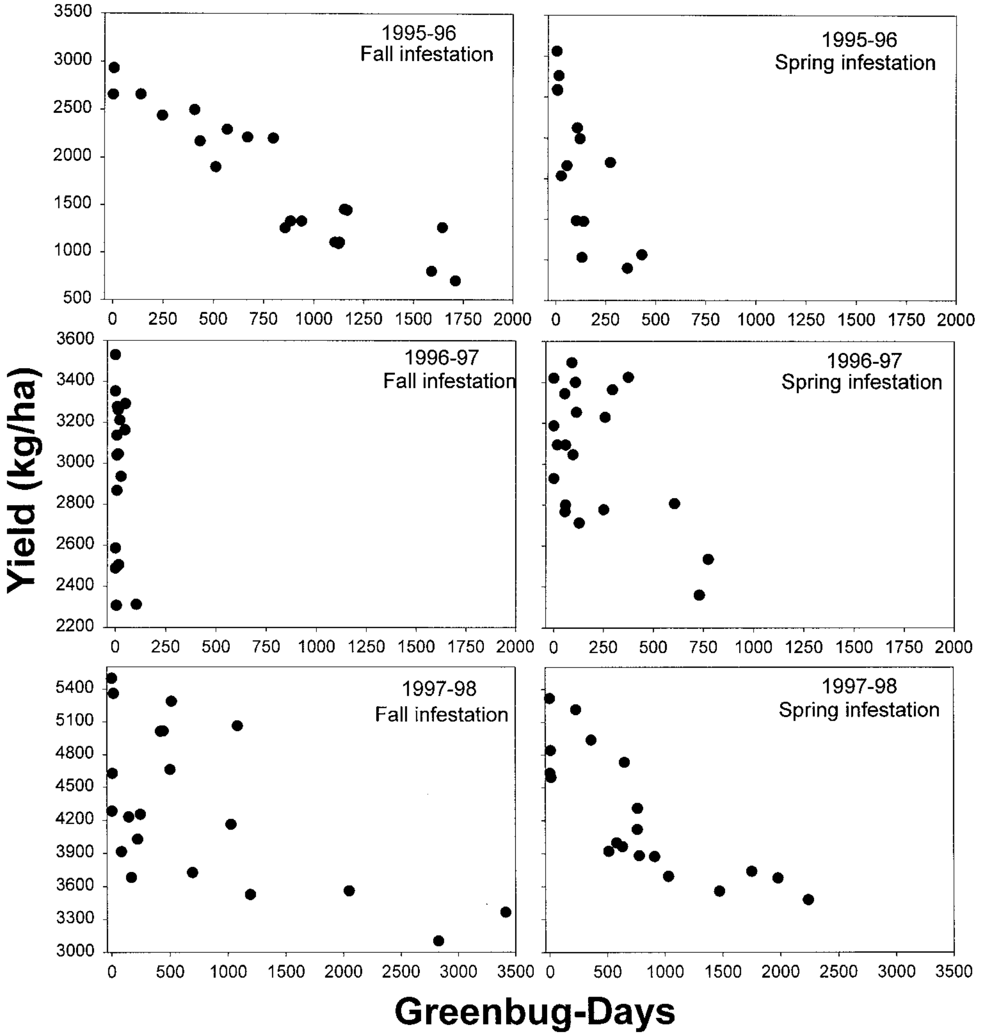


**Fig. 2.** Relationship between yield and greenbug-days for Karl-92 winter wheat.

neity of slopes regression model, our initial hypothesis was that there was a unique relationship between yield and greenbug-days for a each winter wheat cultivar infested during a particular growing season in a particular year. Thus, the heterogeneity of slopes model had 10 unique slope and 10 unique intercept parameters. This model was significant ($F$ = 82.6; df = 19, 170; $P < 0.0001$) and explained 90% of the variance in yield. After fitting the heterogeneity of slopes model, $F$-tests that particular regression coefficients equaled zero were constructed in an attempt to find a more parsimonious model. Based on logical considerations and trial and error, an acceptable model with a reduced number of parameters was discovered. The

**Table 2. Correlation coefficients between greenbug-days and three yield components and total yield of winter wheat cultivars infested in fall or spring of four years**

| Growing season | Cultivar | Fall infestation | | | | Spring infestation | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Heads | Seeds/head | Seed wt | Yield | Heads | Seeds/head | Seed wt | Yield |
| 1993–94 | Karl | −0.39 | −0.25 | 0.07 | −0.51* | 0.28 | −0.20 | 0.17 | 0.27 |
| 1995–96 | Karl-92 | −0.75* | −0.81* | −0.80* | −0.92* | −0.42* | −0.38 | −0.31 | −0.68* |
| 1996–97 | Karl-92 | −0.11 | −0.10 | −0.28 | −0.23 | −0.14 | −0.18 | −0.19 | −0.54* |
| | TAM-110 | 0.18 | −0.29 | 0.07 | −0.12 | −0.40* | 0.22 | −0.19 | −0.34 |
| 1997–98 | Karl-92 | −0.66* | −0.16 | 0.10 | −0.60* | −0.43* | −0.41* | −0.10 | −0.80* |
| | 2163 | −0.21 | −0.22 | 0.03 | −0.49* | 0.04 | −0.64* | −0.05 | −0.53* |

*, Significant correlation ($P < 0.05$).

reduced model had a single intercept parameter for each greenbug-susceptible cultivar grown in a particular year (five intercept parameters), and two slope parameters, one slope parameter for all growing seasons except fall of 1995 and spring of 1996 and a second slope parameter for those two growing seasons. The reduced model was significant ($F = 256.7$; df = 6, 183; $P < 0.0001$) and accounted for nearly as much of the variation in yield (89%) as the full model. The slopes were estimated by regression as −0.51 (SE = 0.06) for all growing seasons except fall of 1995 and spring of 1996, and −1.17 (*SE* = 0.19) for fall of 1995 and spring of 1996. The hypothesis that the slope parameters that were removed in constructing the reduced model were equal to zero was accepted ($F = 1.1$; df = 13, 170; $P < 0.70$). The hypothesis that the model in equation [1] could be reduced further by removing the slope parameter for 1995–1996 was rejected ($F = 20.9$; df = 1, 183; $P < 0.001$).

The most parsimonious model we found for relating yield of greenbug susceptible winter wheat cultivars to greenbug infestation was

$$\text{yield (kg/ha)} = a_i - 0.51 \cdot \text{greenbug-days/tiller}, \quad \text{for nondrought conditions}$$

$$\text{yield (kg/ha)} = a_i - 1.17 \cdot \text{greenbug-days/tiller}, \quad \text{for drought conditions} \quad [2]$$

Equation 2 contains unique values of $a_i$ for particular cultivars grown in particular years. The unique intercepts reflect the fact that yield in the absence of greenbugs varies among years and cultivars. It is obvious from equation 2 that yield in the absence of greenbugs, a variable that is difficult to determine before harvest, is not required to estimate the quantity of yield lost to greenbug infestation. Yield loss (kg/ha) for greenbug-susceptible winter wheat cultivars can be estimated by multiplying the inverse of the slope of equation 2 by accumulated greenbug-days per tiller.

The slope in equation 2 is over two times greater in magnitude for winter wheat grown during severe drought (the 1995–1996 growing season) indicating a strong interaction between drought and greenbug infestation in determining winter wheat yield. Previous studies have also shown that greenbugs cause more damage to cereal crops under drought conditions than when precipitation levels are near normal or above normal (Kindler and Staples 1981, Cuperus et al. 1985). In our study, precipitation levels varied from 66% of the 30-yr average for Stillwater, OK, to 131% of the 30-yr average during all winter wheat-growing seasons except 1995–1996, for which precipitation was less than one-third of the 30-yr average (Table 3). Thus, the two slopes included in equation 2 can be interpreted as representing the yield of winter wheat in relation to the intensity of greenbug infestation when moisture is adequate for normal growth ($b = -0.51$) and during severe drought ($b = -1.17$).

Yield loss from greenbug feeding was previously shown to depend on the growth stage of wheat at the time of infestation by greenbugs (Burton et al. 1985, Pike and Schaffner 1985, Kieckhefer and Kantack 1988). We did not observe this phenomenon in our study, in which yield loss was dependent primarily on the intensity of the greenbug infestation irrespective of wheat plant developmental stage. Our fall infestations were initiated when wheat was in the 3–4 leaf stage. Pike and Schaffner (1985) observed less difference in yield of winter wheat plants infested with greenbugs during the 4-leaf stage compared with plants infested during the tillering growth stage than they did for plants infested during the 2-leaf stage. The discrepancy between our results and those of others is perhaps partly due to the fact that we never infested plants during the very early growth stages. Although greenbugs can colonize wheat fields in Oklahoma as soon as plants emerge from the soil, such infestations are usually initiated by relatively few colonists, and large infestations are uncommon before the 4-leaf stage (S.D.K., N.C.E., K.L.G., and T.A.R., unpublished data). Even though our results may underestimate yield loss for wheat infested with large numbers of greenbugs during very early growth stages, we believe they are generally valid for infestations that typically occur in central Oklahoma during fall and during late-winter and spring.

**Table 3. Monthly precipitation (cm) recorded at Stillwater, OK during four winter wheat growing seasons, and 30-yr average precipitation during growing season**

| Month | Growing season | | | | |
|---|---|---|---|---|---|
| | 1993–94 | 1995–96 | 1996–97 | 1997–98 | 30-yr average |
| October | 1.68 | 1.57 | 6.58 | 8.03 | 7.67 |
| November | 4.27 | 0.15 | 7.37 | 2.21 | 5.77 |
| December | 2.67 | 5.08 | 0.00 | 9.88 | 3.66 |
| January | 0.00 | 0.08 | 0.56 | 10.16 | 3.50 |
| February | 1.42 | 0.53 | 8.86 | 0.18 | 4.27 |
| March | 6.32 | 2.41 | 2.34 | 18.97 | 7.37 |
| April | 12.14 | 1.04 | 13.69 | 13.36 | 8.05 |
| May | 7.29 | 4.82 | 6.22 | 8.36 | 13.84 |
| Total | 35.79 | 15.68 | 45.62 | 71.15 | 54.13 |

Three greenbug-susceptible winter wheat cultivars were used in this study and all exhibited similar yield loss in relation to the intensity of greenbug infestation, suggesting that the model is robust for predicting yield loss for susceptible cultivars. Our data for the greenbug resistant cultivar TAM-110 are limited but suggest that a different relationship between yield loss and greenbug infestation would be needed for that cultivar. The model developed in this study will assist growers and crop consultants in making more informed greenbug management decisions in greenbug-susceptible winter wheat cultivars grown in central Oklahoma.

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