Impact of True Armyworm (Lepidoptera: Noctuidae) Feeding on Wheat Yields in Arkansas[1]

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Abstract Wheat leaf consumption by the true armyworm, *Pseudaletia unipuncta* Haworth, was determined in the laboratory in 1993, 1994, and 1995. Total mean wheat leaf area consumed per larva from eclosion to pupation varied significantly from year to year (77.4-135.4 cm^2) with an overall mean leaf area consumed of 103.2 cm^2. Wheat field plots were infested with third-instar armyworms and allowed to consume wheat foliage at boot and anthesis stages until preset defoliation levels were met (0, 10, 25, and 50% defoliation in 1993, and 0, 35, 50, 65, and 75% defoliation in 1994, 1995, and 1996). Overall, no significant differences were seen between treatments in number of heads or mean weight of seeds per head in any year suggesting that at boot and anthesis stages Arkansas wheat can sustain up to 75% defoliation by armyworms with little loss in yield. Even at population levels that resulted in 75% defoliation head cutting was negligible.

Key Words Armyworm, *Pseudaletia unipuncta,* wheat, thresholds, larval feeding

The armyworm, *Pseudaletia unipuncta* Haworth (Lepidoptera: Noctuidae), is sporadically a serious pest of wheat, fescue, rice, and other crops in many states (Breeland 1958, Clark et al. 1994). Widespread outbreaks have occurred in the United States and Canada at irregular intervals of 5 to 20 yrs (Guppy 1967). During 1992, 1994, and 2001, armyworm outbreaks occurred in Arkansas causing millions of dollars in damage to wheat, seed fescue and other crops (Steinkraus et al. 1993, Thompson 1994). The reasons for these outbreaks are not entirely clear but are most likely related to environmental factors favoring *P. unipuncta* overwintering and early-spring survival.

Young larvae feed on the surface of leaf blades leaving an epidermal layer, whereas, older larvae consume the entire leaf blade (Coggin and Dively 1982). It is difficult to obtain accurate estimates of first and second-instar armyworm densities in scouting programs due to their small size, cryptic habits, and negligible feeding. Under crowded conditions, late-stage larvae may move from leaf feeding to feeding on the awns and developing seeds and may cut the wheat heads from the stems.

Economic thresholds for armyworms on wheat are poorly defined, in part because of the sporadic nature of major armyworm outbreaks. The effects of leaf feeding on crop yield are neither easily determined nor well understood. Consequently, damage or treatment threshold recommendations vary from state to state. In Arkansas, the

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recommended treatment threshold has been 5 to 6 larvae (size not specified) per 0.093 m^2 or when head cutting is occurring (Johnson 2000). In contrast, the threshold in Maryland is one sixth-instar larva per 30.5 cm of row (Coggin and Dively 1982). Because of a lack of published information, clearly defined thresholds based on replicated field data for leaf feeding armyworms are not available. Ideally, thresholds should consider factors such as number and size of larvae, plant developmental stages, distribution of field infestations, and impact of biological control agents.

The objectives of this study were to determine the area of wheat leaves consumed by armyworm larvae and to determine if various levels of defoliation by *P. unipuncta* larvae resulted in a reduction in wheat yields. A long-range objective is to use this information to improve our understanding or armyworm damage to wheat yield in order to determine economic thresholds.

Materials and Methods

All armyworms used were reared from eggs collected from wild, gravid, female armyworm moths collected between January and April of each year in a walk-in black light trap located at the University of Arkansas Experiment Station Farm in Fayetteville, Washington Co., AR. Moths were captured by hand then placed in groups of 25 in 19-L terrariums. Each terrarium contained a 2 cm layer of moist vermiculite covered with paper towels to provide humidity. Moths were fed a beer/honey/water (7:9:14) solution and provided with folded wax paper fans as oviposition sites. Eggs were collected daily and stored in plastic bags at 7°C. When sufficient numbers of eggs were obtained, eggs were removed from the incubator, washed in 3% formalin solution and held at 25°C for eclosion. Fresh field-grown wheat leaves were provided to the larvae, and old leaves and frass were removed regularly. Larvae were used directly as neonates in laboratory studies, or mass reared at 25°C to third instar in 3.8 L glass jars with cheesecloth tops for field studies.

Laboratory studies. Twenty-five neonate larvae (first generation progeny of field-collected moths) were placed singly in individual 100 × 15 mm Petri dishes containing wheat leaves from field-grown wheat plants (var. Coker 9835 in 1993, var. Cardinal in 1994-1996) then held in a temperature cabinet at 25°C. Prior to being fed to larvae, leaf areas were measured (cm^2) with a foliage area meter (LI-COR Model 3100 Area Meter, Lincoln, NE). Each day, partially-consumed leaves were removed from each Petri dish and measured with the area meter. The reduction in leaf area was considered the area of leaf tissue consumed by the larva. This procedure was repeated each day with fresh wheat leaves until pupation. In 1993, it was determined that first and second instars consumed negligible leaf tissue usually eating only a small area of the epidermal layer. Therefore, in 1994 and 1995, feeding studies started with third instars. Mean leaf area eaten per larva and overall means for each year were determined. When significant differences were found after ANOVA, means were compared using the Tukey-Kramer HSD test (JMP 2000). Data from this laboratory study were used to help determine the number of larvae needed to cause selected defoliation levels in the field.

Field studies. In the fall of each year, wheat (var. Coker 9835 in 1992, and var. Cardinal in 1993-1995) was planted according to standard agronomical practices at the University of Arkansas Experiment Station Farm in Fayetteville, AR. Within the wheat field each following spring, plots 5 rows wide and 150 cm long were covered with 3 × 3 × 3 m saran field cages stretched over aluminum electrical conduit frames.

A 5 to 10 cm thick layer of wheat straw was placed between the rows in each plot to provide resting sites for the larvae during the day. A randomized complete block design was used with 3 replicates per defoliation level. Armyworms were reared in the laboratory to the third stadium, then several hundred larvae were distributed by hand within the plots. In most years the experiment was conducted first at boot stage, then repeated at anthesis. At maturity, 100 cm of wheat from rows 2 and 4 were hand harvested for a total of 200 cm harvested. Parameters measured at plant maturity were number of heads, head seed weights (g per head), and in 1995 and 1996, the proportion of head cutting was determined by dividing the number of wheat heads by the number of wheat plants in the 200 cm sample. Data were analyzed by ANOVA (JMP 2000), and treatment means were separated by Tukey-Kramer HSD tests, when significant differences were found.

Preliminary observations showed that third through sixth-instar larvae fed on the lower leaves first and usually did not feed on the next leaf until the first was consumed. This feeding behavior made it relatively easy to visually determine percentage defoliation because wheat plants usually have 3 to 4 leaves. For example, the foliage for a 3-leaf plant could be quickly divided into thirds and a 4-leaf plant into fourths. To determine percentage defoliation, 25 plants were randomly selected per plot every 2 to 3 d. The defoliation level for each individual plant was determined, and the average defoliation level per plot was calculated. If a defoliation level was below the desired level, additional larvae were added. When the pre-set defoliation level for a treatment plot was reached, the larvae and straw mulch were removed by hand. During daylight hours, the great majority of larvae were found under the straw and easily removed.

Defoliation levels in 1993 were 0, 10, 25, and 50%. In 1994, 1995, and 1996, defoliation levels were increased to 0, 35, 50, 65, and 75% because no significant differences in yield were seen in 1993.

Results

Laboratory studies. The mean wheat leaf area consumed by *P. unipuncta* larvae in different years varied significantly from 79.1 to 135.4 cm^2, with an overall mean of 103.7 cm^2 consumed per larva ($F = 39.9$; $df = 3$; $P = 0.0001$) (Table 1). Larvae that hatched from the eggs collected from moths collected in January consumed signifi-

Table 1. Wheat leaf area consumed by *P. unipuncta* larvae in the laboratory

Year	Eclosion date	n*	Mean (SE) leaf area consumed (cm^2)
1993	5 Apr	22	109.0 (2.9) b
1994	24 Jan	22	77.4 (3.7) c
1994	17 Mar	25	91.2 (2.6) b
1995	10 Apr	25	135.4 (5.6) a
Overall mean		—	103.2 (12.5)

* Measurements were based on larvae that survived to pupation from an initial group of 25 neonates. Means within a column followed by different lower case letters are significantly different ($F = 39.9$; $df = 3$; $P = 0.0001$, Tukey-Kramer HSD test, JMP 2000).

cantly less wheat from eclosion to pupation than larvae resulting from moths collected in April (Table 1).

Field studies. No significant differences were found between the mean number of heads or the mean weight of seeds per head (yield) of wheat at up to 50% defoliation at boot, panicle emergence, or anthesis stages in 1993 (Table 2). At the panicle emergence stage, there was a numerical, but not significant, difference ($P = 0.0686$) between weight of seeds per head in control plots compared to plots in which armyworm larvae had consumed wheat leaves. Because no significant differences were observed in number of heads or yield at 50% defoliation in 1993, defoliation levels were increased in 1994, 1995, and 1996 to 35, 50, 65, and 75%.

In 1994, due to difficulties in obtaining sufficient moths and eggs the experiment was conducted only at anthesis stage. There were no significant differences in number of heads up to 75% defoliation (Table 2). Numerically, seed weight was highest in the control plots and progressively lower as the percentage defoliation increased, but not significantly.

At boot stage in 1995 there was a numerical trend for fewer heads in the defoliated plots than control, however, it was not significant ($P = 0.0631$). Otherwise, no significant differences were seen in head number or wheat yield at boot or anthesis stage in either 1995 or 1996 (Table 2).

Head cutting by armyworms in wheat is a serious concern. In our studies, insignificant head cutting was caused by armyworm feeding even under armyworm populations resulting in 75% defoliation (Table 3). Based on our data, it appears that head cutting will not occur until nearly all the wheat leaves have been consumed.

Discussion

The reasons for the variations in total wheat leaf area consumed by *P. unipuncta* larvae between eclosion and pupation from different years are unclear (Table 1). There may be several possible explanations for this result. First, wheat varieties fed to the larvae were changed, with var. Coker grown in 1993 and var. Cardinal being used in subsequent years. Second, field-collected wheat leaves may have varied in tenderness, nutritional content, digestibility, or thickness between January and April and between different years resulting in more or less leaf tissue required for development. Leaf area was measured in cm^2 and would not have detected differences in leaf thickness or quality.

This study found that first and second-instar armyworms consumed negligible areas of wheat foliage. Similarly, Rice et al. (1982a) found that 96% of the total rice foliage consumed by *P. unipuncta* took place during the fifth and sixth instars, and Davis and Satterthwait (1916) found that sixth-instar *P. unipuncta* consumed more than 80% of all the corn foliage consumed during the larval period. This information is critical in determining economic thresholds. Large numbers of first through fourth instars may be tolerated by the crop, especially if natural enemies such as parasitoids (Breeland 1958, Steinkraus and Young 1994), predators, and pathogens (Steinkraus et al. 1993) are present and reducing larval populations, if the plants are in late developmental stages, or if environmental conditions are adverse to armyworm survival. However, large numbers of healthy fifth and sixth instars can rapidly consume large leaf areas. Therefore, thresholds should take into account the size of larvae as well as the number.

Davis and Satterthwait (1916) found that *P. unipuncta* larvae consumed an aver-

Table 2. Effects of *P. unipuncta* larval feeding and resulting selected wheat defoliation levels on the mean numbers of wheat heads per 200 cm row and seed weight per head

		Mean (SE)	
% Defoliation	Year/stage	No. heads	Weight (g) seeds/head
	1993 boot stage		
0		130.7 (6.8)	0.71 (0.06)
10		129.7 (3.8)	0.66 (0.03)
25		138.3 (20.5)	0.66 (0.04)
50		136.0 (16.5)	0.62 (0.01)
		$F = 0.09$, $P = 0.9621$	$F = 0.85$, $P = 0.5062$
	1993 panicle emergence		
0		163.3 (14.8)	0.67 (0.02)
10		165.7 (2.0)	0.58 (0.03)
25		136.7 (11.0)	0.52 (0.06)
50		134.7 (6.6)	0.54 (0.01)
		$F = 2.87$, $P = 0.1036$	$F = 3.52$, $P = 0.0686$
	1993 anthesis		
0		149.0 (5.5)	0.52 (0.01)
10		123.7 (8.9)	0.54 (0.04)
25		135.0 (12.7)	0.58 (0.02)
50		148.3 (14.3)	0.55 (0.03)
		$F = 1.23$, $P = 0.3607$	$F = 0.76$, $P = 0.5469$
	1994 anthesis		
0		152.4 (8.2)	0.99 (0.07)
35		143.5 (22.5)	0.95 (0.08)
50		167.1 (10.5)	0.93 (0.07)
65		162.7 (4.0)	0.82 (0.17)
75		143.1 (13.1)	0.78 (0.01)
		$F = 0.78$, $P = 0.5607$	$F = 1.78$, $P = 0.2088$
	1995 boot stage		
0		215.7 (9.7)	0.87 (0.04)
35		171.0 (17.3)	0.81 (0.02)
50		173.7 (18.4)	0.70 (0.06)
65		138.3 (20.6)	0.90 (0.15)
75		166.7 (7.1)	0.77 (0.01)
		$F = 3.17$, $P = 0.0631$	$F = 1.15$, $P = 0.3884$
	1995 anthesis		
0		210.7 (11.7)	0.69 (0.01)
35		200.7 (22.9)	0.78 (0.02)
50		176.7 (21.5)	0.74 (0.10)
65		179.7 (6.5)	0.64 (0.05)
75		178.3 (8.9)	0.76 (0.05)
		$F = 0.96$, $P = 0.4694$	$F = 0.96$, $P = 0.4683$

Table 2. Continued.

% Defoliation	Year/stage	Mean (SE) No. heads	Mean (SE) Weight (g) seeds/head
	1996 boot stage		
0		174.7 (5.7)	1.09 (0.03)
35		159.3 (3.5)	0.98 (0.09)
50		157.3 (3.3)	0.97 (0.00)
65		157.3 (3.2)	1.01 (0.07)
75		172.7 (7.5)	1.00 (0.05)
		$F = 3.06$, $P = 0.0690$	$F = 0.64$, $P = 0.6450$
	1996 anthesis		
0		183.3 (1.8)	1.08 (0.09)
35		176.7 (9.9)	1.11 (0.05)
50		166.0 (3.5)	0.98 (0.06)
65		177.7 (1.8)	1.16 (0.09)
75		168.0 (5.0)	1.00 (0.02)
		$F = 1.82$, $P = 0.2018$	$F = 1.19$, $P = 0.3745$

Table 3. Mean percentage wheat heads cut at selected wheat defoliation levels by *P. unipuncta* larvae

% Defoliation	Mean* (SE) % heads cut Boot stage	Mean* (SE) % heads cut Anthesis
1995		
0	0	0
35	0	0
50	0.3 (0.3)	0.7 (0.7)
65	0	0.4 (0.4)
75	0	0
1996		
0	0	0
35	0.6 (0.6)	0
50	1.2 (0.6)	0.2 (0.2)
65	0.4 (0.2)	0.2 (0.2)
75	0.2 (0.2)	0.8 (0.5)

* Statistics: 1995, boot stage ($F = 1.00$, $P = 0.45$) and anthesis stage ($F = 0.79$, $P = 0.56$); 1996, boot stage ($F = 1.34$, $P = 0.32$) and anthesis stage ($F = 1.59$, $P = 0.25$).

age of 267 cm^2 corn foliage which is a considerably larger area than we found they consumed on wheat. Rice et al. (1982a) found that *P. unipuncta* larvae consumed an average of 267.7 cm^2 of rice foliage. It is probable that wheat leaves differ from rice and corn leaves in nutritional quality. Further research is needed on these points.

Larvae appeared to consume lower leaves first. Many of the bottom leaves senesce, even if armyworms do not consume them, and may play a lesser role in producing nutrients for head development. Therefore, armyworm feeding on lower leaves may not be a serious problem during boot and anthesis wheat stages. Gooding et al. (2000) stated that the flag leaf of wheat is of particular importance in the development of wheat seed development because it is the last leaf to senesce, it is at the top of the canopy and so intercepts more light than lower leaves, and it is in closer vascular proximity to the ear than lower leaves. Lupton (1972) estimated that at least 45% of the grain carbohydrate in wheat was derived from the flag leaves. Therefore, if the armyworms present in wheat fields are not predicted (based on their numbers, sizes, and activity of natural enemies) to feed significantly on the flag leaves, it may be possible to tolerate their presence in the fields.

It may be important for studies on the effect of armyworm defoliation on wheat yield to use live insects to cause the defoliation. Rice et al. (1982b) conducted an artificial defoliation study on rice to mimic armyworm feeding but acknowledged that artificial defoliation does not exactly simulate armyworm damage. Similarly, Capinera and Roltsch (1980) found that feeding on wheat by actual insects, in this case the migratory grasshopper, *Melanoplus sanguinipes* (F.) (Orthoptera: Acrididae), resulted in greater damage to wheat than simulated feeding. They concluded that defoliation by chewing insects may be more difficult to simulate than generally acknowledged. Recent studies on the effect of caterpillar saliva indicate that caterpillar feeding induces plant responses that are qualitatively different from mechanical wounding (Musser et al. 2002, Felton and Korth 2000).

Recent armyworm thresholds on wheat in Arkansas have been based on the number of larvae per area, i.e., 5 to 6 larvae per 0.093 m^2 (Johnson 2000). The cryptic habits of armyworm larvae make sampling methods difficult and inaccurate, especially when larvae are small. During daylight hours, armyworm larvae are usually found on the ground hiding under debris, in cracks in the soil or on the lower wheat leaves (Breeland 1958). Therefore, it may be useful for pest scouts to utilize plant injury, in the form of defoliation levels, in conjunction with number of larvae, their size, and natural enemies, as an indicator for determining treatment thresholds. We believe that one component of a treatment threshold should be when the top or flag leaf shows feeding damage and all other leaves have been consumed. The presence of the top or flag leaf 90% intact will result in little or no yield reduction.

The results of this study suggest that wheat at the boot and anthesis stages can tolerate up to 75% foliar feeding with no appreciable loss in yield. Because 90% of armyworm feeding occurs during the last larval instar, the number of larvae surviving to fifth and sixth instar is crucial. Current thresholds are probably set lower than justified, especially when larvae are small (first through fourth instars).

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